Journal of Applied Science and Engineering Innovation Vol.2 No.3 2015 pp. 61-66
ISSN (Print): 2331-9062
ISSN (Online): 2331-9070

Non-thermal Effect of Microwave-assisted Abelmoschus Manihot Fiber Degumming

Sun Kaikai[1,a], Qu Wenguang[2,b],Tian Mingwei[3,c] and Qu Lijun[*4,d]

[1]*College of Textiles, Qingdao University, Qingdao, Shandong 266071, China*

[2] *Wendeng district industry management office, , Weihai, Shandong 264400, China*

[3]*College of Textiles, Qingdao University, Qingdao, Shandong 266071, China*

[4]*Laboratory of New Fiber Materials and Modern Textile, The Growing Base for State Key Laboratory, Qingdao University, Qingdao, Shandong 266071, China*

Abstract: In this paper, the experiment of microwave-assisted abelmoschus manihot fiber degumming was carried out as an example to investigated the non-thermal effect during microwave-assisted heating. And a fitting function of residual gum content involved in temperature and time based on the analysis of the experiment data was established with the moving average model. The result of experiment and analysis showed that the best degumming and the most obvious non-thermal effect of microwave-assisted degumming can be achieved within a fifteen-minutes microwave-assisted heating process. In addition, the non-thermal effect continues to vibrate within a certain level range when heated to a specified temperature, and eventually tends to be relatively stable. Especially, the non-thermal effect performs the most obvious within the period of time when heated to the specified temperature.

Keywords Microwave-assisted; Moving average model; Abelmoschus manihot fiber; Non-thermal effect

INTRODUCTION

Microwave radiations are part of the electromagnetic spectrum and considered to be the radiation ranging from 300MHz to 300GHz in frequency, which corresponding to a wavelength between 1m and 1mm [1,2]. The microwave heating of a dielectric material, which occurs through the conversion of electromagnetic energy into heat within the irradiated material, offers a number of advantages over conventional heating such as: (i) non-contact heating; (ii) energy transfer instead of heat transfer; (iii) rapid heating; (iv) selective material heating; (v) volumetric heating; (vi) quick start-up and stopping; (vii) heating from the interior of the material body; and, (viii) higher level of safety and automation [3,4].

Due to these advantages, microwaves are widely used in various technological and scientific fields in order to heat different kinds of materials, such as carbon materials [4], drug discovery [5], mineral treatment [3], environmental engineering [6]. And the utilization of microwave has been reported in hemp extraction [7], also, microwaves are observed to be used in fiber preparation [8,9].

A relevant issue lies in the fact that, according to the literatures, two types of effects can be ascribed to microwaves, i.e. thermal and non-thermal [10,11]. Especially, microwave non-thermal effects is unrelated to temperature change in the process of microwave-assisted heating, as suggested in many experiments [12-14]. However, very little is known about the mechanisms involved in the putative non-thermal effects which might involve in direct energy transfer from electromagnetic field to vibrational modes of macromolecules altering their conformation [15]. In recent years, Mahmoodi et al [16] has researched silk degumming with microwave -assisted heating, and Wang et al [17] has explored the microwave degumming mechanism of sisal fiber, insufficiently, they just study the thermal and non-thermal effect of microwave-assisted degumming process through experiment.

Generally, for the textile processibility of short natural cellulose fibers, such as flax and hemp, certain residual pectin and other binding materials after degumming are necessary to bind individual short fibers together into bundle [18]. Hence, in this paper, we took the residual gum content as a key parameter to evaluate the fiber quality, and we analyzed the microwave-assisted degumming of abelmoschus manihot fiber from a theoretical depth with the moving average model which has been widely used in various fields [19-21], furthermore, to validate the model.

Corresponding Author: Qu Lijun, Qingdao University, Qingdao, China. email address: lijunqu@126.com

MATERIALS AND METHODS

Materials

The abelmoschus manihot used in our study were planted in Zibo, Shandong Province, China. The abelmoschus manihot bast was cut and ripped into the desirable state before the fiber extraction procedure, as shown in Figure 1.

Figure 1. Abelmoschus manihot bast

Process

Abelmoschus manihot bast→ microwave pretreatment→ washing→ one bath of alkali-oxygen [22] with microwave-assisted heating→ washing→ drying→ weighing

Option of the process parameter

Microwave-assisted degumming pre-acid treatment:

H_2SO_4 solution (1 ml/L), temperature 50℃, liquor ratio 1:20, microwave power 600W, water bath heating for 16 min.

One bath of alkali-oxygen with microwave-assisted degumming:

NaOH solution (10 g/L), H_2O_2 solution (10 g/L), $MgSO_4 \cdot 7H_2O$ solution (0.1 g/L), H_2O_2 stabilizer (30% of H_2O_2), liquor ratio 1:20, temperature 90℃/ 95℃/ 100℃, water bath heating for 48min/ 50min/ 52min.

Methods

According to Degumming of Decorticated Ramie for Textile Purposes, we measured the residual gum content of abelmoschus manihot fiber prepared in strict accordance with the above mentioned process. Five replications of abelmoschus manihot fiber were simultaneously measured and their average values were defined as the standard results.

RESULTS AND DISCUSSION

The residual gum rate of microwave-assisted degumming

After the microwave-assisted degumming process of abelmoschus manihot fiber, the measured residual gum content as shown in Table 1. As we can see from the above table, with the increasing of microwave-assisted degumming time, the residual gum content gradually decreasing when the temperature of 90℃and 95℃; additionally, it's the opposite trend when the temperature of 100℃. In this paper, we established the corresponding residual gum content model of the above table based on the moving average model, and explained the mechanism of microwave non-thermal effect on the degumming of abelmoschus manihot fiber.

Table 1 Residual gum content of abelmoschus manihot fiber

Time /h and temperature /℃	48	50	52
90	1.86	1.32	1.27
95	1.5	1.46	1.32
100	1.62	1.63	1.69

To establish the moving average model

We established the mathematical model of the residual gum content in the microwave-assisted degumming process of abelmoschus manihot fiber based on the moving average method of statistical principle, as follows:

Y=TQCI

Among them, T is time factor, C is cycle factor, Q is trend factor, I is non-thermal effects factor, these four factors collectively determine the residual gum content of abelmoschus manihot fiber heated by microwave, and independent of each other.

The ultimate aim of the above mathematical model is to build a direct relationship between residual gum content (Y) and non-thermal effects (I), so time factor T, cycle factor C, trend factor Q of the residual gum content was eliminated in turn. Especially, time factor refers to the time span of microwave-assisted degumming which is an important factor affecting residual gum content as we can see in Table 1. Trend factor Q has the character of certain tendency after residual gum content excluding time factor T, and cycle factor C reflects the periodic law that microwave-assisted degumming time varying with different temperature.

Analysis of the microwave irradiation model

We obtained the center moving average(CMA) corresponding to the residual gum content (Y) in table 3.1 based on moving average method, and the time ratio(Y/CMA) is the basal data for subsequent analysis, the result is shown in the following Table 2.

Table 2 Center of the moving average value (CMA) and time ratio(Y/CMA)

Temperature/℃	Time/min	Residual gum content/Y%	CMA	Y/CMA
	48	1.86		
90	50	1.32	1.48	0.89
	52	1.27	1.15	1.1
	48	1.5	1.39	0.616
95	50	1.46	1.69	0.863
	52	1.32	1.39	0.885
	48	1.62	1.44	1.02
100	50	1.63	1.6	1.018
	52	1.69		

Time factor plays an important role in affecting the residual gum content, so we ruled out its impact on residual gum content firstly, the corresponding formula is:

$$\frac{Y}{T}=\frac{TQCI}{T}=QCI$$

To eliminate time factor and calculate time index. Firstly, implementing three times moving weighted average on residual gum content in Table 3.1, and then calculating time index according to center moving average (CMA) and residual gum content average, the results is shown in Table 3.

Table 3 Time index

Time/min and time index	48	50	52
90℃	0	0.89	0.93
95℃	1.06	1.02	0.9
100℃	1.07	0.99	0
Time index average	1.07	0.97	0.92
Correction time index	1.1	1	0.95

The above table shows that it is essential to correct time index because the average of time index is 0.97 which is not equal to 1, subsequently, excluding time factor according to the index of correction time. It takes 2.5min/ 3min/ 3.4min when heating from the starting temperature respectively to 90 ℃ / 95 ℃ / 100 ℃ in the experiment, consequently, we can obtain the actual time of heating process. Then, excluding time factor, as shown in Table 4.

Table 4 Residual gum content excluding time factor and the original residual gum content

Time/min	Original residual gum content/%	Residual gum content excluding time factor/%
50.5	1.86	1.68
51	1.5	1.36
51.4	1.62	1.47
52.5	1.32	1.32
53	1.46	1.46
53.4	1.63	1.63
54.5	1.27	1.34
55	1.32	1.39
55.4	1.69	1.78

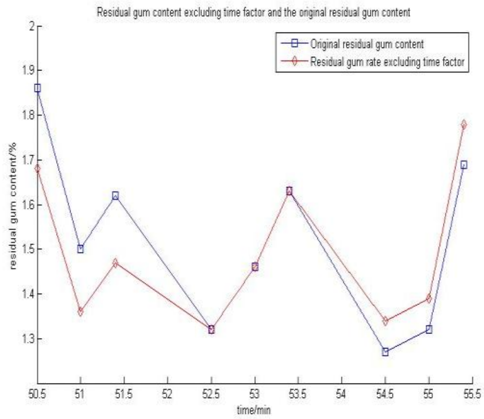

Figure 2. The residual gum content excluding time factor and the original residual gum content

We have made the appropriate data curve according to table 4, as shown in Figure 2. Considering that these data points are concentrated and the trend is obvious after excluding time factor, so single function

$$y=ax+b$$

was introduced to fit, to obtain the best linear regression equation, and then to obtain the value of trend factor. Obviously, the curve of residual gum content excluding time factor is more smooth with a certain trend, therefore, we can get a single function

$$y=0.00911x+1.00988$$

via the fitting of Origin. Further, the trend value can be obtained by considering time factor into the fitting function, as shown in Table 5.

Table 5 Time factor and trend value

Time/min	Trend value/Q
50.5	1.47
51	1.47
51.4	1.48
52.5	1.49
53	1.49
53.4	1.5
54.5	1.51
55	1.51
55.4	1.51

Similarly with excluding time factor, trend factor can be excluded by the following formula

$$\frac{Y}{TQ} = \frac{TQCI}{TQ} = CI$$

The results is shown in the following Table 6.

Cycle factor can be calculated by using the weighted moving average, similarly, we can obtain the cycle factor via three moving weighted average calculation. Then, according to formula

$$\frac{Y}{TQC} = \frac{TQCI}{TQC} = I$$

The non-thermal effect can be obtained as following Table 7.

Table 6 Excluding the trend factor

Tempera ture/℃	Time/mi n	Residual gum content/Y%	Time index	Excluding T	Trend Q	Cycle C and I
#1	#2	#3	#6	#3/#6=#7	#8	#7/#8=#9
	48	1.86	1.1	1.68	1.47	1.143
90	50	1.32	1	1.32	1.49	0.886
	52	1.27	0.95	1.34	1.51	0.887
	48	1.5	1.1	1.36	1.47	0.925
95	50	1.46	1	1.46	1.49	0.98
	52	1.32	0.95	1.39	1.51	0.921
	48	1.62	1.1	1.47	1.48	0.993
100	50	1.63	1	1.63	1.5	1.087
	52	1.69	0.95	1.78	1.51	1.789

Table 7 Excluding cycle factor

℃	time	Y	Time index	Excluding T	Trend Q	Cycle C and I	Cycle C	Non-thermal effect I
#1	#2	#3	#6	#3/#6=#7	#8	#7/#8=#9	CMA/#9=#10	#9/#10
90	48	1.86	1.1	1.68	1.47	1.143		
	50	1.32	1	1.32	1.49	0.886	0.972	0.912
	52	1.27	0.95	1.34	1.51	0.887	0.899	0.998
95	48	1.5	1.1	1.36	1.47	0.925	0.93	0.995
	50	1.46	1	1.46	1.49	0.98	0.942	1.04
	52	1.32	0.95	1.39	1.51	0.921	0.965	0.95
100	48	1.62	1.1	1.47	1.48	0.993	1	0.99
	50	1.63	1	1.63	1.5	1.087	1.29	0.84
	52	1.69	0.95	1.78	1.51	1.789		

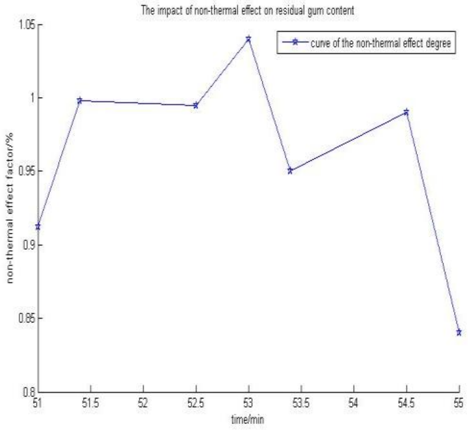

Figure 3. The impact of non-thermal effects on residual gum content

We made a curve of the non-thermal effects degree according to the corresponding data in the table, as shown in Figure 3.In this way, we can know the impact of non-thermal effect on residual gum content. Analytically, the non-thermal effect of abelmoschus manihot fiber by microwave-assisted degumming varied with different temperature and time condition, even different time period.

In order to validate the model, we predicted and confirmed the residual gum content of a 48min heating at 80℃ according to the model. Further, as what we analyzed by the fitting function of trend factor, it takes 2min when heating to 80℃, so totally in 50 min. Then, considering time factor into fitting function

$$y = 0.00911x + 1.00988$$

The result is 1.465. Especially, the residual gum content is 1.611% when we considering the time index which is 1.1 as we can see from the above analysis. In summary, the residual gum rate of a 50min heating at 80℃ is 1.611%, which is consistent with the experimental result.

CONCLUSION

In this model, we obtained the relationship between non-thermal effects (I) and residual gum content (Y) by eliminating time factor, temperature factor and trend factor. Furthermore, we explored and got the non-thermal effects mechanism of abelmoschus manihot fiber with microwave -assisted degumming. It is that the role in promoting of microwave non-thermal effects for degumming is mainly in the period of time when the temperature is just heated to a specified temperature. Additionally, non-thermal effects is relatively faint when the temperature is stable and fluctuating continuously within a certain level range, and eventually stabilize.

REFERENCES

[1] S. Banik, S. Bandyopadhyay, S. Ganguly, Bioeffects of microwave - a brief review, Bioresource Technology 87 (2003) 155-159.

[2] N.Esmaeilian, M. Arami, F.M. Mazaheri, S.M. Bidoki, A comparison between microwave-assisted and thermally synthesized esterquat softeners used as textile softening agents, Journal of the Textile Institute 105 (2014) 569-574.

[3] K.E. Haque, Microwave energy for mineral treatment processes - a brief review, International Journal of Mineral Processing 57 (1999) 1-24.

[4] J.A. Menendez, A. Arenillas, B. Fidalgo, Y. Fernandez, L. Zubizarreta, E.G. Calvo, J.M. Bermudez, Microwave heating processes involving carbon materials, Fuel Processing Technology 91 (2010) 1-8.

[5] M. de Rosa, J. Gising, L.R. Odell, M. Larhed, Syntheses of new tuberculosis inhibitors promoted by microwave irradiation, Upsala Journal of Medical Sciences 119 (2014) 181-191.

[6] D.A. Jones, T.P. Lelyveld, S.D. Mavrofidis, S.W. Kingman, N.J. Miles, Microwave heating applications in enviromnental engineering - a review, Resources Conservation and Recycling 34 (2002) 75-90.

[7] H.M. Wang, X. Wang, Hemp processing with microwave and ultrasonic treatments, 2004.

[8] T. Ohe, Y. Yoshimura, Microwave Irradiation onto Nylon 6 Fibers in Organic Solvent, Sen-I Gakkaishi 65 (2009) 8-14.

[9] M. Svanberg, T. Suortti, M. Nyman, Intestinal degradation of dietary fibre in green beans - effects of microwave treatments, International Journal of Food Sciences and Nutrition 50 (1999) 245-253.

[10] E. Calabro, S. Magazu, Non-Thermal Effects of Microwave Oven Heating on Ground Beef Meat Studied in the Mid-Infrared Region by Fourier Transform Infrared Spectroscopy, Spectroscopy Letters 47 (2014) 649-656.

[11] M. Ballardin, I. Tusa, N. Fontana, A. Monorchio, C. Pelletti, A. Rogovich, R. Barale, R. Scarpato, Non-thermal effects of 2.45 GHz microwaves on spindle assembly, mitotic cells and viability of Chinese hamster V-79 cells, Mutation Research-Fundamental and Molecular Mechanisms of Mutagenesis 716 (2011) 1-9.

[12] A. de la Hoz, A. Diaz-Ortiz, A. Moreno, Microwaves in organic synthesis. Thermal and non-thermal microwave effects, Chemical Society Reviews 34 (2005) 164-178.

[13] P. Purnama, S.H. Kim, Stereocomplex formation of polylactide using microwave irradiation, Polymer International 63 (2014) 741-745.

[14] F.A. Bassyouni, S.M. Abu-Bakr, M.A. Rehim, Evolution of microwave irradiation and its application in green chemistry and biosciences, Research on Chemical Intermediates 38 (2012) 283-322.

[15] S. Horikoshi, S. Matsuzaki, S. Sakamoto, N. Serpone, Efficient degassing of dissolved oxygen in aqueous media by microwave irradiation and the effect of microwaves on a reaction catalyzed by Wilkinson's catalyst, Radiation Physics and Chemistry 97 (2014) 48-55.

[16] N.M. Mahmoodi, F. Moghimi, M. Arami, F. Mazaheri, Silk Degumming Using Microwave Irradiation as an Environmentally Friendly Surface Modification Method, Fibers and Polymers 11 (2010) 234-240.

[17] E. Wang, W. Chen, J. Wu, in: X.M. Qian, H.W. Liu (Eds.), Advanced Textile Materials, Pts 1-3, 2011, p. 213-216.

[18] M. Yuksek, Effect of Degumming Performed with Different Type Natural Soaps and Through Microwave Energy Method on The Properties of Silk Fiber, Asian Journal of Chemistry 24 (2012) 742-746.

[19] L. Yu, L. Zhou, L. Tan, H. Jiang, Y. Wang, S. Wei, S. Nie, Application of a New Hybrid Model with Seasonal Auto-Regressive Integrated Moving Average (ARIMA) and Nonlinear Auto-Regressive Neural Network (NARNN) in Forecasting Incidence Cases of HFMD in Shenzhen, China, Plos One 9 (2014).

[20] M. Kvarnstrom, K. Podgorski, I. Rychlik, Laplace moving average model for multi-axial responses in fatigue analysis of a cultivator, Probabilistic Engineering Mechanics 34 (2013) 12-25.

[21] L.H.C. Chua, T.S.W. Wong, Runoff forecasting for an asphalt plane by Artificial Neural Networks and comparisons with kinematic wave and autoregressive moving average models, Journal of Hydrology 397 (2011) 191-201.

[22] L.J. Qu, S.F. Zhu, M.J. Liu, S.Y. Wang, The mechanism and technology parameters optimization of alkali-H2O2 one-bath cooking and bleaching of hemp, Journal of Applied Polymer Science 97 (2005) 2279-2285.