Study on the Chemical Modification Process of Jute Fiber

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ABSTRACT

Degumming of pre-chlorite treated jute fiber was studied in this paper. The effects of sodium hydroxide concentration, treatment time, temperature, sodium silicate concentration, fiber-to-liquor ratio, penetrating agent TF-107B concentration and degumming agent TF-125A concentration were the process conditions examined. With respect to gum decomposition, fineness and mechanical properties, sodium hydroxide concentration, sodium silicate concentration and treatment time were found to be the most important parameters. An orthogonal $L_9(3^4)$ experiment designed to optimize the conditions for degumming resulted in the selection of the following procedure: sodium hydroxide of 12g/L, sodium silicate of 3g/L, TF-107B of 2g/L, TF-125A of 2g/L, treatment time of 105 min, temperature of 100℃ and fiber to liquor ratio of 1:20. The effect of the above degumming process on the removal of impurities was also examined and the results showed that degumming was an effective method for removing impurities, especially hemicellulose.

INTRODUCTION

Jute is a natural biodegradable fiber with advantages such as high tensile strength, excellent thermal conductivity, coolness, ventilation function et al.[1-2]. Recently, due to the improvement of people's living standards and need for environmental protection, the demand of natural biodegradable and eco-friendly fibers is rising worldwide day by day. Ramie, flax, hemp and some other vegetable fibers have been used as textile materials, but jute fiber is basically used for traditional purposes such as manufacture of sackings, hessian, carpet backing and the like. Taking account of the costliness of ramie and the shortage in sources of flax, and the challenges from the synthetic fibers in the traditional jute products market, if jute could be used to replace ramie and flax partially as textile material, not only the cost could be reduced but also a new market would be provided for jute products[2-9].

Jute fiber is a bast fiber obtained from the bark of jute plant containing three main categories of chemical compounds namely cellulose (58~63%), hemicellulose (20~24%) and lignin (12~15%), and some other small quantities of constituents like fats, pectin, aqueous extract, et al. Jute fiber is composed of small units of cellulose surrounded and cemented together by lignin and hemi-cellulose[10-11]. The low cellulose content, coarseness, stiffness, low extensibility, low grip performance and some other disadvantages seriously restrict the raw jute fiber

from spinning. So a series of wet chemical processing sequences are needed to improve the spinnability of jute. The qualities of the fiber and yarn mostly depend on the degumming effect. So degumming is one of the most important sequences in the chemical processing of jute[12-13].

Generally, there are three methods for degumming, i.e., mechanical, chemical and biological methods. The mechanical methods such as steam explosion[2,14], microwave and ultrasonic [15] have very limited effect on improving the spinnability of jute fiber. Biodegumming is an eco-friendly method has some advantages viz. mild conditions and high efficiency. However, the application of enzymes for degumming is hindered by some factors such as high substrate specificity, low activity stability, high cost, and low total gum decomposition[16-18]. The chemical method is the most commonly used method for degumming, but this traditional method has some major disadvantages like serious environmental pollution, lengthy time required and high cost [19]. Taking account of these problems, it is urgent to improve the degumming method for natural fibers.

In our previous study, the pre-chlorite treatment of jute fiber before degumming has been reported to lighten the burden of degumming and enhance delignification[20]. In this paper, we report the chemical degumming of the pre-chlorite treated jute fiber. Both the gum decomposition and the spinnabilities viz. fineness, breaking strength and breaking extension were tested to optimize the conditions for degumming. Changes in the constituent content of the treated jute fiber were also analyzed.

MATERIALS AND METHODS

Materials

Jute

Lightly combed and dewaxed raw jute fiber (Bengal).

Chemicals

Sodium chlorite and sodium silicate were supplied by the Shanghai Nuotai Chemical Co., Ltd., China. Acetic acid, sodium acetate, sodium hydroxide and sulphuric acid were purchased from the Shanghai Ruiteliang Chemical Industry Co., Ltd., China. Penetrating agent TF-107B and degumming agent TF-125A were provided by the Zhejiang Transfar Co., Ltd., China.

Methods

Pre-chlorite treatment

The samples were treated in a bath with sodium chlorite 1.5g/L, pH 3, liquor ratio 1:10, and kept at 30℃ for 30 min. and then thoroughly washed.

Scouring

The pre-chlorite treated jute fiber was treated with sodium hydroxide 5-30g/L, sodium silicate 1.0-5.0g/L, TF-107B 0.5-6.0g/L, TF-125A 1.0-8.0g/L, and kept at 60-100℃ for 60-240 min. with fiber to liquor ratio 1:10-1:40. At the end of the desired treatment, the fibers were neutralized with sulphuric acid, and then thoroughly washed with distilled water.

Testing

Breaking strength and breaking extension were tested using a XQ-1 fiber breaking strength machine in a constant 20℃ temperature and 65% relative humidity room (in accordance with ASTM Method D-5035). The fineness was tested according to

GB/T12411.3. The constituent contents were tested according to GB/5889–86, and gum decomposition was calculated using Eq. 1:

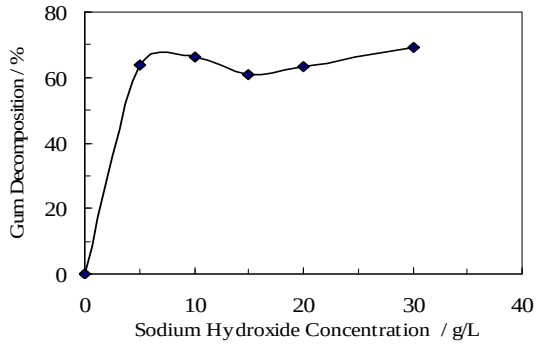
$$Gum\ Decomposition(\%)=\frac{M_0-M_1}{M_0}\times 100\% \quad (1)$$

Where M_0 is the gum content of the raw jute fiber, M_1 is the residual gum content of the degummed jute fiber.

RESULTS AND DISCUSSION

Effect of Sodium Hydroxide Concentration

In order to obtain the optimum sodium hydroxide concentration for degumming, the pretreated jute fiber was treated with different sodium hydroxide concentration viz. 5g/L, 10g/L, 20g/L, 30g/L, and the solution was made with sodium silicate 3.0g/L, TF-107B 2.0g/L, TF-125A 2.0g/L, fiber to liquor ratio 1:20, and treated at 98℃ for 120 min, followed by washing and finally dried in an oven. After the treatment, the gum decomposition, fineness and mechanical properties were tested to estimate the effect of sodium hydroxide concentration. The results are represented in *Figure 1* and *Table I*.



* 0g/L indicates the untreated jute fiber in all Figures

FIGURE 1. Effect of sodium hydroxide concentration on gum decomposition

TABLE I. Effect of sodium hydroxide concentration on jute mechanical properties

Sodium hydroxide concentration/gL^{-1}	Breaking strength/cN	Breaking extension/%	Fineness/Tex
5	64.67	5.59	3.42
10	68.08	4.00	2.56
15	59.94	3.44	2.68
20	67.49	4.64	2.55
30	44.15	4.26	1.85

Figure 1 shows that the gum decomposition value increased up to 66.5 % with the sodium hydroxide concentration increased up to 10 g/L, but slightly decreased when the concentration of sodium hydroxide was between 10g/L and 15g/L, and increased again with further increase of sodium hydroxide concentration. And it is observed from *Table I* that the values of the breaking strength and the fineness decreased as the sodium hydroxide concentration increased. Taking account of the spinnability of jute fiber, which largely depends on its two important properties namely fineness and breaking strength[21], our conclusion is that the optimum sodium hydroxide concentration should be strictly controlled at 10g/L.

Effect of Time

In order to obtain the optimum time for degumming, the pretreated jute fiber was treated for different time viz. 60 min., 90 min., 120 min., 180 min., 240 min., and the solution was made with sodium hydroxide 10g/L, sodium silicate 3.0g/L, TF107-B 2.0g/L, TF-125A 2.0g/L, fiber to liquor ratio 1:20, and treated at 98℃, followed by washing and finally dried in an oven. After the treatment, the gum decomposition, fineness and mechanical properties were tested to evaluate the effect of time. The results are showed in *Figure 2* and *Table II*.

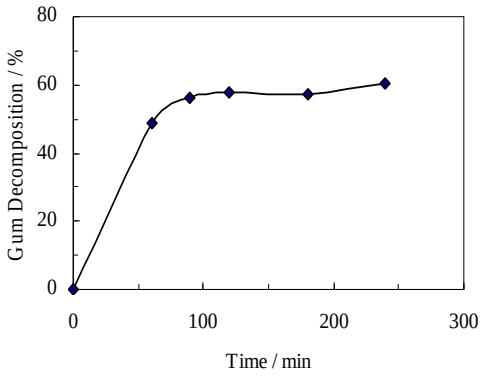


FIGURE 2. Effect of time on gum decomposition

TABLE II Effect of time on jute mechanical properties

Time /min	Breaking strength/cN	Breaking extension/%	Fineness/Tex
60	44.01	4.53	3.10
90	42.16	3.22	3.08
120	46.62	3.66	3.15
180	37.65	3.61	3.07
240	46.27	3.57	3.06

It can be seen from *Figure 2* that gum decomposition value initially increased with the increase of treatment time, but no obvious changes were observed after 120 min. It may be explained that the extent of jute fiber swelling increased with time and was fairly complete within 120 min. The gum loosened and opened up, allowing the auxiliary agents to easily penetrate into the fiber. As a result, the auxiliary agents react sufficiently with non-cellulose materials, and make them decompose and dissolve in the treatment solution. At the same time, it may be also explained that the decomposable and dissolvable materials have been completely removed in 120 min. So there is no need to continue treatment after 120 min.

Table II further indicates that the treatment time, for the most part, did not have major effect on the fineness and breaking strength. So the optimum treatment time for degumming should be controlled at 120 min.

Effect of Temperature

In order to obtain the optimum temperature for degumming, the pretreated jute fiber was treated at different temperature viz. 60℃, 70℃, 80℃, 90℃, 100℃, and the solution was made with sodium hydroxide 10 g/L, sodium silicate 3.0 g/L, TF-107B 2.0 g/L, TF-125A 2.0 g/L, fiber to liquor ratio 1:20, and treated for 120 min, followed by washing and finally drying in an oven. After the treatment, the gum decomposition, fineness and mechanical properties were tested to determine the effect of temperature. The results are represented in *Figure 3* and *Table III*.

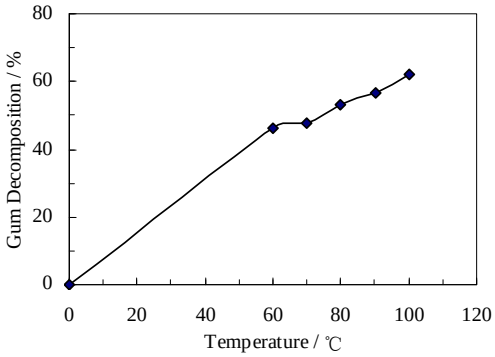


FIGURE 3. Effect of temperature on gum decomposition

TABLE III Effect of temperature on jute mechanical properties

Temperature/℃	Breaking strength/cN	Breaking extension/%	Fineness/Tex
60	62.88	5.26	3.96
70	65.18	4.63	3.74
80	68.63	4.48	3.12
90	53.91	3.82	3.00
100	43.16	3.97	2.18

Figure 3 shows that gum decomposition value was almost linearly increasing with the increase of temperature. It may be explained that penetrability of auxiliary agents and swelling degree of fiber increased with the increase in temperature. As a result, the non-cellulose compositions were sufficiently decomposed by chemicals or effectively dissolved.

Table III indicates that the breaking strength increased slightly when the temperature increased from 60℃ to 80℃, but distinctly decreased when the temperature further increased. It may be explained that when the non-cellulosic materials were partially removed, the inter-fibrillar region was likely less dense and less rigid, thereby making the fibrils more capable of rearranging themselves along the direction of tensile deformation. When jute fiber is stretched, such rearrangement amongst the fibrils should result in better load sharing by them and hence result in an increase in fiber breaking strength[22]. But the excessive removal of non-cellulosic materials could also be negatively accompanied by a formidable decrease in the breaking strength of the jute fiber. Thankfully the breaking strength was acceptable for spinning, so it was concluded that the optimum temperature should be controlled at 100℃.

Effect of Sodium Silicate Concentration

In order to obtain the optimum sodium silicate concentration for degumming, the pretreated jute fiber was treated with different sodium silicate concentration viz. 1.0g/L, 1.5g/L, 2.0g/L, 3.0g/L, 5.0g/L, and the solution was made with sodium hydroxide 10g/L, TF-107B 2.0g/L, TF-125A 2.0g/L, fiber to liquor ratio 1:20, and treated at 100℃ for 120 min., followed by washing and finally drying in an oven. After the treatment, the gum decomposition, fineness and mechanical properties were tested to evaluate the effect of sodium silicate concentration. The results are showed in *Figure 4* and *Table IV.*

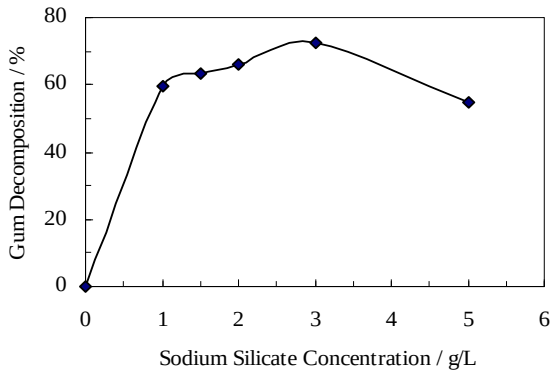


FIGURE 4. Effect of sodium silicate concentration on gum decomposition

TABLE IV Effect of sodium silicate concentration on jute mechanical properties

Sodium silicate concentration/gL^{-1}	Breaking strength/cN	Breaking extension/ %	Fineness/Tex
1.0	69.38	2.63	2.80
1.5	61.36	2.74	2.88
2.0	60.13	3.57	2.62
3.0	53.57	2.78	2.06
5.0	63.40	4.64	2.58

It can be seen from *Figure 4* that the gum decomposition value increased up to 72.6% at sodium silicate concentration 3.0g/L, but decreased with further increase in the sodium silicate concentration. *Table IV* also shows the lowest fineness (tex) was observed at 3.0g/L, but the breaking strength was more U-shaped for the sodium silicate concentrations evaluated. As expected, sodium silicate is an effective adsorbent, which is needed in the degumming process for the

adsorption of the decomposed and dissolved gum. When the sodium silicate concentration is lower than 3.0g/L, the decomposed gum could not sufficiently be adsorbed by the sodium silicate and might stick onto the surface of jute fiber. When the treated fibers were drying, the fibers would connect to each other again. But when the sodium silicate concentration was further increased, the sodium silicate with decomposed gum would be held by the jute fiber, preventing the decomposed gum from dissolving. So the control of sodium silicate concentration is very critical during the degumming process. Based on the above discussion, it was concluded that the optimum concentration should be controlled at 3.0g/L.

Effect of Fiber to Liquor Ratio

In order to obtain the optimum fiber to liquor ratio for degumming, the pretreated jute fiber was treated with different fiber to liquor ratio viz. 1:10, 1:15, 1:20, 1:30, 1:40, and the solution was made with sodium hydroxide 10 g/L, sodium silicate 3.0g/L, TF-107B 2.0g/L, TF-125A 2.0g/L, and treated at 100℃ for 120 min, followed by washing and finally drying in an oven. After the treatment, the gum decomposition, fineness and mechanical properties were tested to determine the effect of fiber to liquor ratio. The results are represented in *Figure 5* and *Table V*.

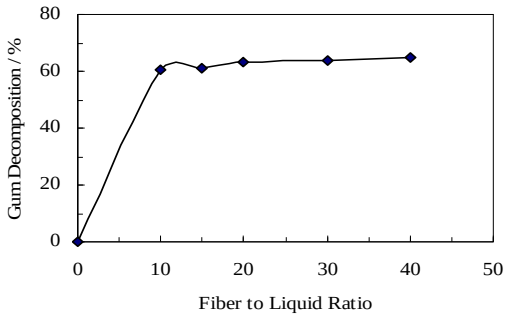


FIGURE 5. Effect of fiber to liquor ratio on gum decomposition

TABLE V Effect of fiber to liquor ratio on jute mechanical properties

Fiber to liquor ratio	Breaking strength/cN	Breaking extension/%	Fineness/Tex
1:10	48.32	4.18	3.34
1:15	62.62	2.74	3.00
1:20	44.77	3.45	2.36
1:30	44.29	3.63	2.62
1:40	53.38	3.65	2.98

Figure 5 shows that the gum decomposition value obviously increased up to 63.1% with the fiber to liquor ratio increased to 1:20, and then slightly increased with further increase in the fiber to liquor ratio. It may be explained that when the fiber to liquor ratio was lower than 1:20, the decomposed gum would stick to the fiber again, thereby contributing to an increase in breaking strength and a decrease in fineness, which is confirmed by *Table V*. When the residual gum content of treated jute fiber was tested, the undissolved decomposed gum dissolved in the treatment solution, increasing the content of the residual gum. But further raising the fiber to liquor ratio more than 1:20 was not only unnecessary, but a waste of energy and resources. Therefore, the optimum fiber to liquor ratio should be controlled at 1:20.

Effect of TF-125A Concentration

By keeping a constant concentration of sodium hydroxide 10g/L, sodium silicate 3.0g/L, TF-107B 2.0g/L, fiber to liquor ratio 1:20, the degumming of jute fiber was studied at 100℃ for 120 min. with different concentrations of TF-125A ranging from 1.0 to 8.0g/L. The gum decomposition, breaking strength, breaking extension and fineness were then tested to determine the effect of TF-125A concentration. The results are shown in *Figure 6* and *Table VI*.

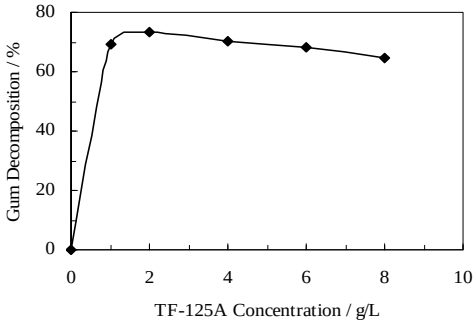


FIGURE 6. Effect of TF-125A (degumming agent) concentration on gum decomposition

TABLE VI Effect of TF-125A (degumming agent) concentration on jute mechanical properties

TF-125A concentration/g·L^{-1}	Breaking strength/cN	Breaking extension/%	Fineness/Tex
1.0	78.44	6.33	2.54
2 .0	66.21	5.73	2.02
4 .0	67.96	5.43	2.26
6 .0	58.68	5.05	2.24
8.0	51.39	4.79	2.47

It can be seen from *Figure 6* that at a low level of applied TF-125A, the gum decomposition value increased with the increasing of TF-125A concentration. When the applied TF-125A was more than 2.0g/L, the value of gum decomposition gradually decreased. And the results in *Table VI* show that both the breaking strength value and breaking extension value decreased almost linearly. And the minimum fineness value 2.02 tex was obtained at TF-125A concentration 2.0g/L. It may be explained that the application of TF-125A could observably enhance the degumming effect. With the increasing of TF-125A concentration, the decomposition of gum was accelerated and accompanied by degradation of cellulose. Thus it can be seen that using 2.0g/L TF-125A was sufficient to obtain a fiber with favorable spinnability and little reversion would be gained by using excess amounts of TF-125A.

Effect of TF-107B Concentration

To examine the effect of TF-107B concentration, the pretreated jute fiber was treated using sodium hydroxide 10g/L, sodium silicate 3.0g/L, TF-125A 2.0g/L, fiber to liquor ratio 1:20, and kept at 100℃ for 120 min with different concentrations of TF-107B ranging from 1.0 to 8.0g/L. The gum decomposition, breaking strength, breaking extension and fineness of the degummed jute fiber were tested to optimize the TF-107B concentration. The results are shown in *Figure 7* and *Table VII*.

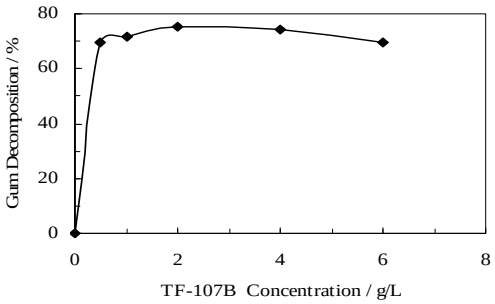


FIGURE 7. Effect of TF-107B (penetrating agent) concentration on gum decomposition

TABLE VII Effect of TF-107B (penetrating agent) concentration on jute mechanical properties

TF-107B concentration/g·L^{-1}	Breaking strength/cN	Breaking extension/%	Fineness/Tex
0.5	80.76	5.67	2.73
1.0	83.96	6.03	2.45
2.0	73.50	5.41	2.39
4.0	67.35	5.32	2.21
6.0	62.63	4.93	2.31

It can be seen from *Figure 7* that increasing the concentration of TF-107B from 0.5 to 2.0g/L was accompanied by an increase in gum decomposition. A further increase in TF-107B concentration gave little reversion in the gum decomposition. *Table VII* shows that both the breaking strength and the breaking extension obtained the maximum value 83.96cN and 6.03% at TF-107B 1.0g/L, respectively, and then gradually decreased with further increase in the concentration of TF-107B. *Table VII* also shows that the fineness value of the degummed fiber decreased almost linearly. Taking account of all the above four indexes, it is clear that the optimum concentration of TF-107B for degumming should be controlled at 2.0g/L.

$L_9(3^4)$ Orthogonal Experiment

According to the above discussions, a $L_9(3^4)$ orthogonal experiment was designed to optimize the condition for degumming process. The factors, levels and results are represented in *Table VIII* and *Table IX*.

TABLE VIII. Factors and Levels

Levels	Factors		
	A: Concentration of sodium hydroxide/g·L^{-1}	B: Concentration of sodium silicate/g·L^{-1}	C: time/min
1	8.5	2.7	105
2	10.0	3.0	120
3	12.0	3.2	130

TABLE IX. $L_9(3^3)$

S. No.	Factors			Gum decomposition/%	Breaking strength/cN	Fineness/Tex
	A	B	C			
1	1	1	1	59.1	31.32	3.26
2	1	2	2	56.5	36.61	2.84
3	1	3	3	57.5	54.48	2.88
4	2	1	2	52.1	48.55	2.56
5	2	2	3	56.7	43.41	3.20
6	2	3	1	55.5	49.72	2.75
7	3	1	3	61.9	51.70	3.48
8	3	2	1	61.9	46.93	2.02
9	3	3	2	54.6	49.08	2.48

	Gum decomposition/%			Breaking strength/cN			Fineness/Tex		
	A	B	C	A	B	C	A	B	C
Level1	57.70	57.70	58.83	40.80	43.86	42.66	2.99	3.10	2.68
Level2	54.77	58.37	54.40	47.23	42.32	44.75	2.79	2.69	2.76
Level3	59.47	55.87	58.70	49.24	51.09	49.86	2.66	2.70	3.17
Effect	4.70	2.50	4.43	8.44	8.77	7.20	0.33	0.41	0.49

Table IX shows that the concentration of sodium hydroxide and treatment time were the two most important factors for gum decomposition ratio, the effect of sodium silicate was inferior to them, thus the optimum condition for gum decomposition was $A_3B_2C_1$. And the optimum fineness index 2.02 tex was obtained with $A_3B_2C_1$. But the optimum condition for degumming was $A_3B_3C_2$ on the basis of the breaking strength. With the view that the primary purpose for degumming is to remove more and more non-cellulose materials and obtain spinnable fiber with appropriate fineness, so long as the breaking strength can satisfy the need of spinning. Therefore, the optimum condition for degumming was ascertained as $A_3B_2C_1$, i. e. sodium hydroxide 12 g/L, sodium silicate 3.0 g/L, time 105 min.

Effect of Degumming on the Constituent Contents of Jute Fiber

The major constituents of raw and treated jute fiber were assessed to analyze the effect of degumming on the removing of non-cellulose. The results were shown in *Table X*.

TABLE X. Constitutes content of the raw and degummed jute fiber

Samples	Cellulose/%	Hemicellulose/%	Lignin/%	Aqueous extract/%	Fats and wax/%	Pectin/%
Raw	65.44	17.61	14.35	1.86	0.61	0.13
Degummed	84.78	4.67	9.25	0.98	0.28	0.04

It can be seen from *Table X* that all the non-cellulose constituents namely hemicellulose, lignin, aqueous extract, pectin, fat and wax were obviously removed by degumming process, especially for the hemicellulose. *Table X* also shows that the cellulose content value increased from 65.44 % to 84.78 % after degumming.

CONCLUSIONS

The degumming process is necessary for improving the textile properties of jute fiber. The pre-chlorite treated jute fiber was degummed by varying sodium hydroxide concentration, treatment time, temperature, sodium silicate concentration, degumming agent TF-125A concentration, penetrating agent TF-107B concentration and fiber to liquor ratio. It was found that sodium hydroxide concentration, sodium silicate concentration and treatment time were the three most important parameters for degumming process, and the degumming process was an effective method to remove hemicellulose, lignin, pectin and some other non-cellulose materials. According to the results of the $L_9(3^4)$ orthogonal experiment, the gum decomposition ratio 61.9 % and fineness index 2.02 Tex were obtained with the optimum treating conditions such as sodium hydroxide of 12 g/L, sodium silicate of 3.0 g/L, TF-107B of 2.0 g/L, TF-125A of 2.0 g/L, treatment time of 105 min, temperature of 100℃ and fiber to liquor ratio of 1:20.

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