Investigation on Characteristics of Bleached Bagasse Pulp Using Neutral Sulfite and Soda Solutions

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The aim of this paper was to evaluate the properties of three bleached pulps made of bagasse. Pulping was carried out with NaOH (15% o.d. bagasse) and Na_2SO_3:Na_2CO_3 with two different ratios (20:10% and 26.25:8.75% on oven-dried weight (o.d.) bagasse), with a time of 15 minutes time and a temperature of 170°C. Bleaching was done with sodium hypochlorite (8% o.d. pulp) at 120 minutes, 50°C temperature and 10% stock concentration at one stage. Some handsheets at 70 g/m^2 basis weight were made. The characteristics such as, total yield, screen yield, shives content, kappa number, bulk, tear index, burst index, breaking length, brightness, and opacity were measured according to TAPPI and ISO standards and then compared to each other. The results indicated that bagasse soda pulp had the highest screen yield (57.77%), and the least yield (42.07%) was obtained with 30% neutral sulfite solution. The strength properties showed that pulp obtained with neutral sulfite solution had better tear index (2.23 mN.m2/g), whereas that from soda solution had better breaking length (1.3 km) and burst index (0.73 kpa.m^2/g). The pulps cooked with neutral sulfite solution had better bleachability, whereas the bagasse soda pulp had better opacity.

Keywords: Bagasse; Soda pulping; Neutral sulfite; Sodium hypochlorite bleaching; Mechanical testing; Optical testing

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INTRODUCTION

Chemical pulp is frequently made from nonwood materials in countries that do not have sufficient wood resources (Atchison 1995). Research in Iran has focused especially on sugar cane bagasse, which is notably suitable to the Khuzestan Province climate. Among available agricultural residue, bagasse fibers are classified as short fibers (Hurter 1998). On the other hand, bleached short-fiber pulps alone are not utilized so much in papermaking and they are usually mixed with long-fiber pulps, which improve the strength and runability of the pulp. Also, short-fiber pulp is very important in papermaking, because it makes the paper smooth and opaque and is an excellent printing base (Rousu *et al.* 2002).

There is no doubt the nonwood lignocellulosic sources can have an important role in paper industry. Recently there has been an increasing tendency to use agricultural by-products in pulp and paper industry. In this regard, bagasse is the best starting material for pulp and paper production.

Some research about use of nonwood fibers in papermaking industry has been published. Hurter (2002) has reported that the physical properties (basis weight: 71, fold Number: 39, tear factor: 61.8, burst factor: 24.6) of bleached papers produced using 100% bagasse pulp have indicated good potential for use in papermaking. Nowadays, most nonwood fiber is pulped in continuous digesters at temperatures at around 130 to 160°C for 10 to 30 minutes. A method suitable for using hardwoods and nonwood fibers such as straw is the soda process, which uses sodium hydroxide as an active chemical in pulping (Biermann 1996).

One of the important processes for production of pulp and paper is the neutral sulfite process. This process is commonly used for high yield pulping of hardwoods, and it was developed in the early 1940s by the U.S. forest products laboratory in Madison, Wisconsin, USA using hardwoods in the paper industry. Its cooking liquor contains Na_2SO_3 plus Na_2CO_3 (10 to 15%); liquor pH is 7 to 10; cooking time is 0.5 to 2 h at 160 to 180°C. The residual lignin (15 to 20%) makes paper very stiff, which is an important property for corrugated medium (Biermann 1996). On the other hand, the soda pulping process is commonly used for most pulping processes of hardwoods and softwoods. Stephenson (1951) evaluated the production of pulp from straw with sodium sulfite (10%) and NaOH (5%) in a 6 h cook at 160°C. The pulp yield was about 55%. After bleaching with hypochlorite (5% on pulp), the yield was reduced to 42%. Aronovsky (1948) suggested an NSSC process for pulping wheat straw using 8% sodium sulfite and 2 to 3% sodium carbonate (on o.d. straw), with a liquor to straw ratio of 7:1, and a cooking time of two hours at 170°C. The pulp yield was 52 to 55%. The pulp could be brightened to 70% with 5 to 7% total chlorine in a three-stage process. Samariha and Khakifirooz (2011) investigated the production of fluting paper (127 g/m^2) from bagasse and hardwoods NSSC pulps which were cooked with 20% chemicals, cooking temperature 170°C, and 30 minutes cooking time. The pulps were refined to freeness values of 345 and 433 mL CSF. Their research shows that the quality of bagasse pulps is better than hardwoods pulps. Kermanian *et al*. (2013) studied the influence of refining on waste NSSC paper. The results indicated that NSSC pulp acts as a chemical pulp, namely increasing the recycling cycles decreases the strength properties. Kiaei *et al*. (2014) studied the potential of making NSSC pulp from canola plant, and results showed that optimum pulping conditions were selected applying a cooking temperature of 170°C and cooking time of 30 min in addition to the introduction of a 20% sodium sulfite (based on Na_2O). The handsheets made from Canola NSSC pulp had better properties in comparison with mixed hardwood NSSC pulp.

As different pulping processes have various applications and produce products with different properties, the object of this research was to investigate the chemical charge and pulping solution type on bagasse pulping, as a fundamental parameter of chemical pulping process. Thus, the purpose of this study was to evaluate two potential chemical treatments (neutral sulfite and soda) for their effectiveness in increasing the strength properties of bagasse fibers. It is also noted that in this research a high ratio liquor/bagasse was used because according to Lam *et al*. (2004) a relatively high liquor/matter ratio value (15/1) can be used on a laboratory scale to produce pulp from bagasse with a high yield and a fairly low kappa number.

EXPERIMENTAL

The raw material was obtained from Pars Paper Co. in Haft Tapeh, located in Khuzestan, Iran. The bleached bagasse pulps were produced at the laboratory of the Pars Paper Company according to Table 1.

Table 1. The Cooking Conditions and Freeness of Bagasse Pulps

Pulp ID	Cooking conditions						Total yield (%)	Freeness (mlcsf)
	Cooking Chemical	Chemical charge (%)	Liquor-to-bagasse Ratio	Max. temp. (°C)	Time to maximum temp. (min.)	Time cooking (min.)		
A	Na_2SO_3:Na_2CO_3 (2:1)	30	15:1	170	60	15	64.5	800
B	Na_2SO_3: Na_2CO_3 (3:1)	35	15:1	170	60	15	62.63	800
C	NaOH	15	15:1	170	60	15	65.7	685

After cooking, the residual liquor was extracted from the pulp. Total yield was measured by weighing the washed material on top of the screen without separation. Then, the pulps were disintegrated using 3000 revolutions per minute. The pulp was screened using a set of 2 screens, a 12 mesh screen on top of a 200 mesh screen. The material remaining on the 12 mesh screen was considered as shives and the fibers that passed the 12 mesh screen but remained on the 200 mesh screen were considered as accepts or screen yield. After that, the pulp was bleached with sodium hypochlorite (8% on O.D. pulp) at 120 minutes, under 50°C temperature and stock concentration 10%, followed by filtration under vacuum, finally washing with plant's water to remove any residual chemicals. Hypochlorite was selected at one stage to simulate similar conditions with Pars Paper Company. After bleaching, the yield loss (%) of the pulps was measured as well as the freeness of pulps based on TAPPI T227. In this research, the ability of different chemical materials to separate bagasse fibers was considered. For this reason, refining was not carried out. The process was then followed by converting the pulp suspension into handsheets using a handsheet machine (L & W, Messmer 155 Company) based on the TAPPI standards from accept pulp. Bleaching was done with sodium hypochlorite (NaClO) solution (Cl_2,8%) at one stage. This stage was carried out at 10% stock concentration, 50°C, 120 min and pH 8.5.

Testing Methods

Handsheets were made in an L & W handsheet former according to TAPPI T 205 sp-02 standard to evaluate the characteristics of the pulps. Some handsheets, each with a 200 cm^2 area and basis weight of 70 g/m^2, were made for each treatment. The samples were conditioned at 50±2% relative humidity and 23±1°C according to TAPPI T 402 sp-03 for at least 24 hours before performing strength tests.

Handsheets were cut according to TAPPI Standard T 220 sp-01 for physical properties measurement. Various test methods, consisting of tensile index (ISO-1924-2), tear index (ISO -1974), burst index (ISO - 2758), and double fold (TAPPI method T 511 om-02) were used for the analysis of the sheets. The brightness and opacity were measured according to ISO 2469.

RESULTS AND DISCUSSION

As can be seen in Table 1, the least freeness was belonged to pulp C (685 mL CSF), and the highest belonged to pulp A and B (800 mL CSF). This likely is attributable to the nature of different pulping condition of neutral sulfite and alkaline. In general, pulps produced from bagasse are known to be inferior to wood pulps in terms of properties such as freeness (Lavarack *et al*. 2005). Lower freeness is expected to result in greater fiber-to-fiber connection.

Figure 1 illustrates the properties of different pulps used in this research. According to the figure, the highest total yield was obtained with 15% NaOH (pulp C) (65.7%) and the least with 35% neutral sulfite (pulp B) (62.63%). One of important factors in pulping processes is chemical charge. The results exhibited that higher chemical charge reduced total yield. This is because of increasing delignification, which can be noted in the case of pulp B with use of 35% chemical charge.

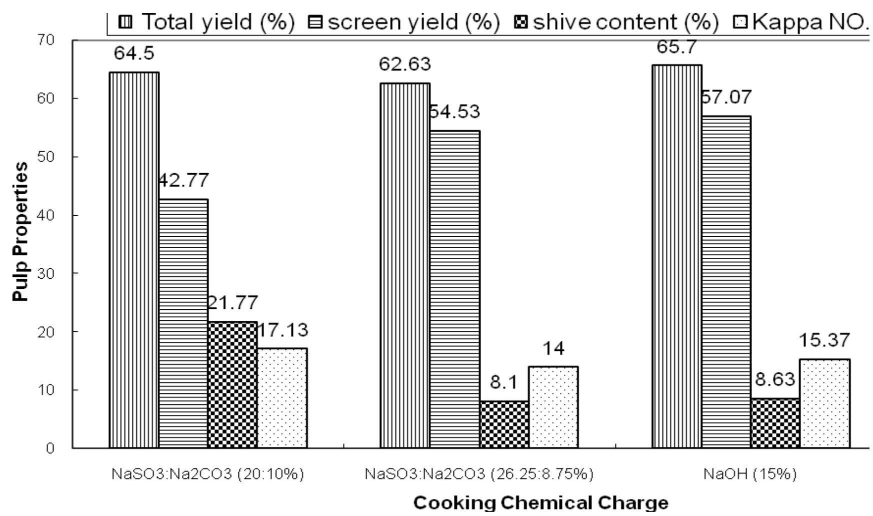

Fig. 1. Pulp properties resulted from different cooking conditions

Khakifirooze *et al*. (2011) gained higher yield (75 to 85%) by using less chemical charge (10 and 20%). By increasing chemical charge, the concentration of chemical increases, and then the reaction rate or delignification rate increases. Hence more delignification and more degradation of polysaccharides take place, reducing the total yield. On the other hand, the screen yield and shives content of the pulp A and B were very different. So, by increasing neutral sulfite to more than 10%, the screen yield was increased, the shive content decreased, and its kappa number was lower. As can be seen from Fig. 1, the mentioned properties for pulp C were similar to pulp B approximately. In these conditions, the effect of type of chemical was more than chemical charge. Pulp A, with the least screen yield and the highest shive content, showed the penetration of pulping chemicals into fiber was not sufficient. So, it will not produce paper with adequate strength properties.

In pulp B the delignification was high but fiber bonding can be poor because of chemical solution type (neutral sulfite solution). Also the results indicated that the delignification in pulp A was not sufficient to impart strong fiber-to-fiber bonding. Thus it is expected that strength properties of pulp C and bleachability of pulp B will be improved.

The effect of cooking solutions on the bulk of the resulting handsheets is shown in Fig. 2. There was no difference between two levels of neutral sulfite solutions. The handsheets which were made with pulp A had the highest bulk (2.24 cm^3/g), and pulp C had the least bulk (1.96 cm^3/g). According to Samariha and Khakifirooz's results (2011) bulkier sheets usually are less strong than sheets with less bulk, since fiber to fiber bonding is poorer in bulkier sheets. Such trends are in full compliance with results for breaking length and burst index.

As can be seen in Fig. 2, the alkaline solution (pulp C) increased the breaking length (1.3 km) since it had the least bulk or the most fiber-to-fiber bonding. This means there was strong fiber bonding in pulp C. By contrast, poor fiber bonding in pulp A gave rise to a lower breaking length (1.06 km). But, with increasing the concentration of neutral sulfite solution (pulp B) this property increased a little (1.1 km) in comparison with pulp A. Tensile strength (*i.e.* breaking length) is determined by both single fiber strength and inter-fiber bonding strength (Page 1969; Wistara 2010). The decrease of breaking length in our work is thought to be due to reduction of bonding ability. The same results were observed for burst index. Burst index is given as a function of freeness (Springer *et al.* 1993), and results showed that both of pulps (A and B) with similar freeness had similar burst index. It should be mentioned that Hemmasi and Samariha (2005) obtained 5.75 km of breaking length (after refining) for neutral sulfite pulping by using 20% chemical charge. Also, Biermann (1996) said that the relative surface area of fibers could be increased by reducing the freeness.

The work done in tearing is made up of two main contributions: (1) the work needed to sever individual fibers and (2) the work needed to pull out unbroken fibers from their surrounding networks (Caulfield and Gunderson 1988). The handsheets that were made with 35% neutral sulfite solution (pulp B) had the highest tear index (2.23 $mN.m^2/g$), which indicated the fibers were not damaged due to increasing the chemical charge and sufficient effect of chemical materials on fibers. There was no difference between 30% neutral sulfite (pulp A) and alkaline solution (pulp C) (fig. 2). Short fibers such as bagasse fibers are obviously easier to pull out than long fibers; papers made of long fibers showed much better tearing resistance than those made with short fibers (Van den Akker *et al.* 1958). However, It should be mentioned that Samariha and Khakifirooze (2011) obtained higher tear index (6.9 $mN.m^2/g$) with neutral sulfite pulping by using bagasse fibers.

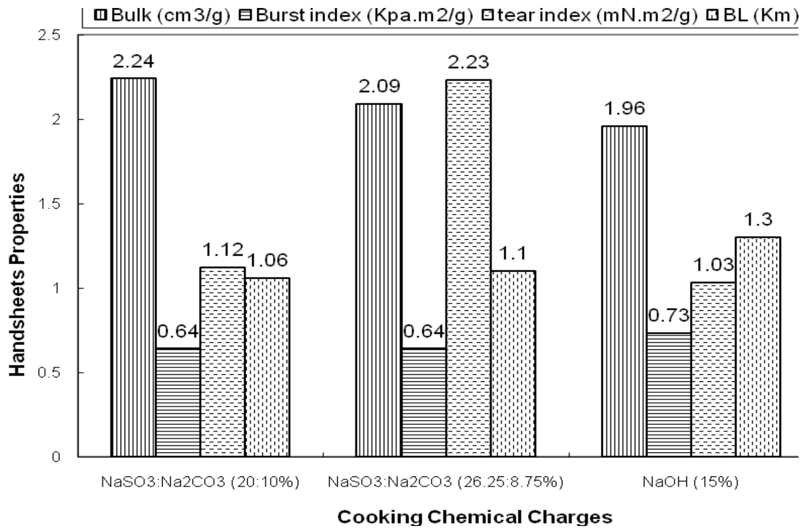

Fig. 2. Handsheet properties made of soda pulping and neutral sulfite pulping of bagasse

The effects of bleaching conditions on the brightness and opacity of the resulting handsheets are shown in Table 2. The results indicated that the lowest brightness (71.67%) and the highest opacity (96.83%) were related to the soda bagasse pulp (pulp C), and both levels of neutral sulfite solution were not different in mentioned properties. The highest brightness (73.67) was related to pulp B. This result corresponded with its lower yield (54.5%) and lower kappa number (14) (Fig. 1), which indicated more delignification. Thus, pulp B had better bleachability. Soda pulp (pulp C) had approximately 97% opacity so that it had better printability, which is important in printing papers. Chandra (1998) said that bagasse is best at contributing excellent formation to papers and can replace hardwood chemical pulps for printing and writing paper. The yield loss of soda pulp (pulp C) during bleaching was much lower than the other pulps, resulting in lower brightness.

Nonwood pulps are bleached more easily than wood pulps, and also shorter bleaching sequences and lower chemical charges are used to bleach nonwoods (Hurter 1998). The brightness increased to 71-73% with one hypochlorite (H) stage. This result completely agreed with Biermann (1996), who wrote that brightness can be increased to 72% with one hypochlorite (H) stage for nonwood fibers.

Table 2. Optical Properties of Soda Pulp and Neutral Sulfite Pulp of Bagasse

Pulp ID	Chemical charge (%)	Yield loss (%)	Brightness ISO (%)	Opacity (%)
Pulp A	30	5.4	73	87.33
Pulp B	35	5.9	73.67	88
Pulp C	15	1.6	71.67	96.83

CONCLUSIONS

In this research three chemical treatments for bagasse (neutral sulfite solution 30% and 35%, alkaline solution 15%) were used. The results indicated that:

1- It could be concluded that bagasse paper from neutral sulfite pulp is a paper with poor strength properties, high bleachability, and low opacity. Factors such as pulp strength and bleachability must ultimately be determined to make a final judgment regarding the efficacy of a particular pulping process (Biermann 1996). The paper from neutral sulfite pulping is more suitable for papers for which their appearance quality is important.

2- It could be concluded that alkaline solution produced lower freeness, therefore fiber bonding was improved to a greater extent. Thus this pulp showed better paper strength properties such as breaking length and burst index. However tear factor was poor. This must be attributed to fiber bundles due to insufficient effect of chemical materials on fibers, because the chemical charge in this pulp was less. Also results from bleaching showed that this pulp had high printability because of its high opacity.

3- According to this study, applying more chemical charge in soda pulping of bagasse or more cooking time in order to decrease the kappa number of pulp, can produce a pulp with better quality. So it is recommended that the use of same chemical charge and different cooking time for both soda pulping and neutral sulfite pulping of bagasse be studied for comparing the effect of two types of cooking solutions on bagasse fibers.

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