Pulping of jute

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ABSTRACT: The search for a suitable jute pulping process shows that the neutral sulfite anthraquinone (NS-AQ) process is very promising. It eliminates the problems encountered in the alkaline processes. In addition, this economically feasible process produces pulp with higher yield and conifer-like kraft pulp, with regard to physical strength properties. This paper describes the in-depth studies on the NS-AQ pulping of jute.

KEYWORDS: Anthraquinone, jute, kinetics, neutral sulfite pulping, paper properties, physical properties, process variables.

Jute has a long historical role in the socioeconomic development of Bangladesh. The export of jute and related products accounts for a significant portion of total exports. In addition, it provides considerable employment opportunities to the country's work force. In recent years, jute has faced stiff competition from synthetics. As a result, its demand in local and overseas markets has shrunk. This has caused jute prices to drop, and the growers are the ultimate victims. The situation is further aggravated by a comparatively higher growth of low-quality jute (i.e., 46-54%) from 1977 to 1986 *(1).* About 200,000 metric tons of jute, with an additional 45,000 metric tons of jute cuttings, remain as surplus every year in Bangladesh *(1).* The government, well aware of the situation, is keenly interested in diversifying uses for jute.

Jute is characterized by a high cellulose content *(2);* its fibers are also quite long *(3).* The chemical and morphological properties, therefore, favor its use in making pulp.

Pulping of jute has been the subject of numerous studies for the last decade, both domestically and abroad, by conventional processes [i.e., soda and kraft either alone or with anthraquinone (AQ)]. Laboratory studies *(1, 4–11)* mention few problems in pulping jute by conventional processes. But problems were encountered in a mill trial when pulping jute by the soda process *(1)* and by the kraft process *(12).* These problems include lumping of the cooked materials, causing difficulties in digester blowing, washing, disintegration, and screening. The problems were confirmed in a later study *(3).* Yee *(13)* also found disintegration difficulties. In some cases, the pulp severely degraded on bleaching *(1, 3, 12).* Pulping of jute using soda-AQ is not expected to be substantially better, because the carbohydrate reactions with soda-AQ and kraft are similar. The only difference is that the AQ in soda pulping can replace the sulfide in kraft pulping to produce pulp similar to kraft in quantity and quality *(13).* Thus it is imperative to search for other processes that can eliminate the shortcomings of conventional processes while producing pulp with high yield and strength.

Recent studies *(14-17)* show that the neutral sulfite-anthraquinone (NS-AQ) process produces kraft-like pulp from wood with a 6–12% higher yield on ovendry (o.d.) wood compared to the kraft process. The NS-AQ process produces chemically defiberized pulp because of the accelerating effect of AQ. This prompted a team of scientists in the Bangladesh Forest Research Institute (BFRI) to make an in-depth study of NS-AQ jute pulping.

NS-AQ pulping of jute

It was first reported in 1988 *(3)* that NS-AQ is a promising process for pulping jute. Fully chemically defiberized pulp can be obtained by this process with a total alkali dose as low as 14% and an AQ dose of 0.1% (**Table I**). A slightly higher alkali level is needed with NS + 0.1% AQ compared to the reference kraft to delignify to kappa no. 20 (**Fig. 1**). The alkali requirement with the NS + 0.2% AQ is similar to that of the kraft. The alkali requirement is

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I. Cooking conditions and pulp analyses for NS, NS-AQ, and kraft pulping of jute.[a]

Cook no.	*AQ dose, %*	*Total or active alkali as NaOH, %*	*pH of cooking liquor*	*pH of waste liquor*	*Refining*	*Total yield, %*	*Reject, %*	*Kappa no.*	*Elrepho brightness, %*
NS									
1	0	24	11.5	7.7	Yes	65.7	0	39.5	45.6
2	0	28	11.3	7.6	Yes	64.6	0	34.6	48.1
3	0	32	11.3	7.8	Yes	64.3	0	34.0	47.6
NS-AQ									
4	0.1	14	11.2	7.7	No	63.2	0	24.0	49.7
5	0.1	18	11.4	7.7	No	61.8	0	22.3	51.5
6	0.1	20	11.4	8.6	No	61.8	0	21.4	50.2
7	0.1	22	11.4	7.9	No	61.4	0	19.1	53.9
8	0.1	24	11.5	7.8	No	61.7	0	19.1	51.5
9	0.2	14	11.4	7.5	No	64.2	0	25.2	49.5
10	0.2	16	11.2	7.4	No	61.8	0	20.6	51.8
11	0.2	18	11.4	8.0	No	62.5	0	20.3	52.7
12	0.2	20	11.4	7.5	No	61.3	0	17.3	55.5
16[b]	0.1	18	-	-	No	62.7	0	23.1	-
Kraft									
13	0	15.5	-	-	Yes	59.0	0	35.4	18.3
14[c]	0	17.0	-	-	No	55.6	0	22.2	24.3
15	0	18.5	-	-	No	54.1	0	13.8	27.6

[a]Liquor/jute ratio: 7:1; time for temperature rise from 80°C: 90 min; cooking temperature: 170°C; cooking time for kraft: 90 min; cooking time for NS and NS-AQ: 180 min; kraft sulfidity: 25%; alkali ratio for NS and NS-AQ: 0.83 *(3)*

[b]Unchopped jute cutting with 10–60 cm length

[c]Pulp was disintegrated and screened with difficulty

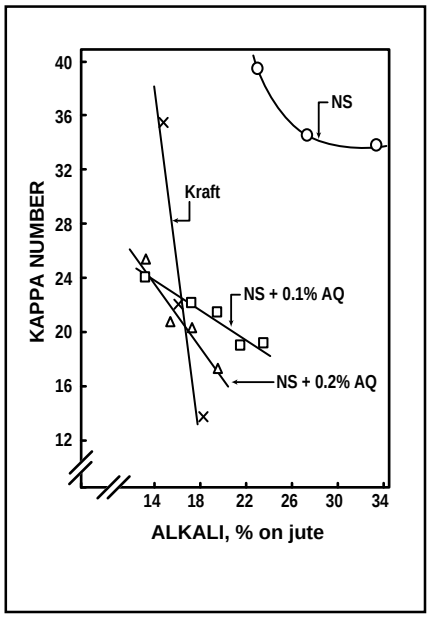
less in the NS-AQ process than that in the kraft process if the delignification is achieved at a kappa number higher than 22, but still giving fully defiberized pulp (Fig. 1 and Table I).

Disintegrating and screening pose no problems in the chemically defiberized pulp obtained with the NS-AQ process. The kraft pulp, even at kappa no. 22.2 with no screening rejects, was disintegrated and screened with considerable difficulty (Table I). The cooked material ropes heavily around the disintegrator (**Fig. 2**) and lumps on the screen. Consequently, defiberization and screening in commercial kraft, soda, and soda-AQ pulping of jute pose severe problems. This drawback has limited the soda pulping of jute in the Sylhet pulp mills. However, if kraft cooking is continued at a kappa number near 14, the disintegration and screening problems can be avoided. The yield will then further decline, producing pulp with inferior strength.

The remarkable advantage of NS-AQ pulping is clearly higher pulp yield compared to the kraft control (**Fig. 3**). The yield in NS + 0.1% AQ pulping is 6.3% higher on o.d. jute at kappa no. 20. An AQ dose of 0.1% is sufficient for the gain in yield.

The NS-AQ process produces brighter pulp than does the kraft process (Table I). The brightness of the unbleached NS-AQ pulp is high enough that it does not require bleaching to be used as reinforcement in newsprint. The strength properties of the unbleached NS-AQ jute pulp are equivalent to its kraft counterpart (**Fig. 4**). On bleaching, the NS-AQ pulp quality improves. On the other hand, the kraft pulp deteriorates on bleaching. The NS-

1. Effect of total alkali or active alkali (kraft) on delignification of jute *(3)*



2. Disintegration of kraft pulp from jute (kappa no. 22.2) *(3)*

AQ pulp is more easily beaten and drains faster than the comparable kraft pulp. The bleaching response of the NS-AQ pulp is also superior *(3)*.

The quality of the NS-AQ jute pulp exceeds that of the kraft pulp from some common coniferous species (**Table II**). This pulp has the potential to replace kraft pulp from coniferous wood species in the manufacture of paper requiring high strength properties. The pulp can also be mixed with pulps from hardwoods and agricultural residues, which have intrinsically low tearing strength.

NS-AQ pulping of whole-length jute

Jute chopping is tedious, time consuming, and expensive. It has been estimated *(1)* that jute chopping would cost about TK 1000/metric ton (US$ 25/metric ton). Therefore, eliminating jute chopping before pulping would significantly reduce pulp production costs.

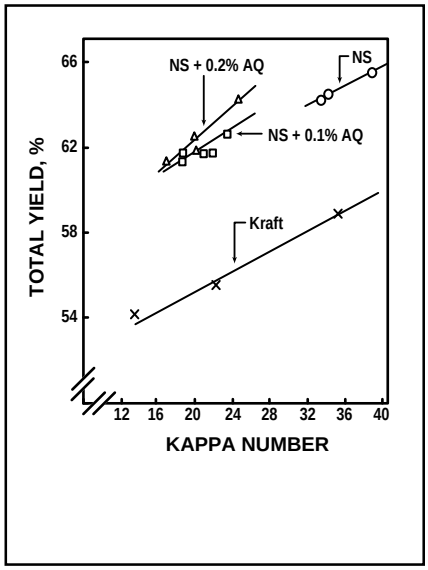
Table III shows that fully chemically defiberized pulp can be obtained from unchopped jute by the NS-AQ process *(18)*. There are no problems in disintegrating, washing, or screening the pulp. The degree of delignification is about the same in the unchopped and chopped jute. Furthermore, the pulp yield is slightly better with whole-length jute compared with the chopped control *(18)*. The strength properties of the pulp from both jute types are nearly equivalent. Chopping, therefore, appears to be unnecessary in pulping jute by the NS-AQ process. Conversely, chopping is an essential step in the kraft, soda, and soda-AQ processes.

Papermaking properties when blending NS-AQ with conventional pulps

There is no general pattern regarding how the blends of different pulps affect papermaking properties *(19)*. Paper strength properties are quite intricate. Thus, it is important to know how NS-AQ jute pulp, in a mixture with conventional pulp, affects the strength properties.

An evaluation of the properties of a mixture of jute-bagasse, jute-hardwood, and jute-bamboo pulps shows that no general relationship predicts the tensile index, burst index, and

3. Total yield vs. kappa number in NS, NS-AQ, and kraft pulping of jute *(3)*

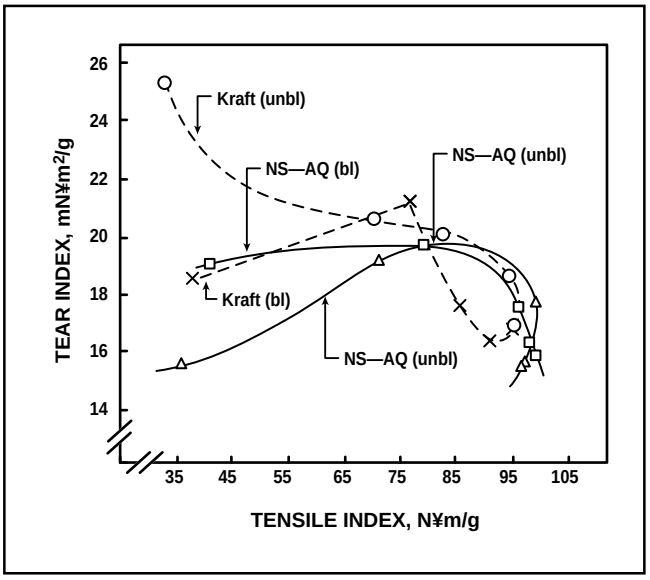


density of the blended pulp *(19)*. The results show either additive, synergistic, or abating properties in the mixture. In all the cases, the tear index is directly proportional to that of the components in the respective pulp furnish. The hardwood and bagasse pulp can be blended with NS-AQ pulp to improve the paper quality. A small advantage is seen in the bamboo-jute pulp blend.

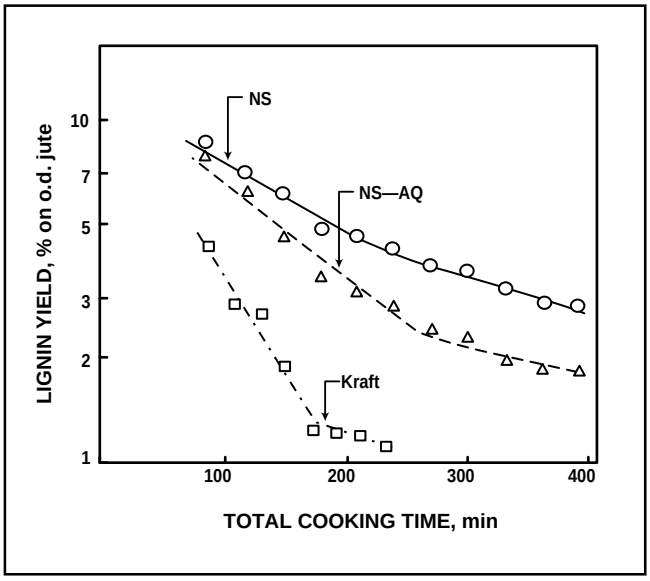
II. Comparison of coniferous kraft pulp with NS-AQ jute pulp. Unbleached yield and pulp quality at 300 mL CSF *(3).*

Species	Kappa no.	Total yield, %	Tear index, $mN \cdot m^2/g$	Burst index, $kPa \cdot m^2/g$	Tensile index, Nm/g	Apparent density, kg/m^3
Jute	23.1	62.7	19.9	10.6	108.0	618
Douglas-fir	32.1	42.1	17.0	6.85	94.5	650
Southern pine	37.1	45.5	14.3	5.90	94.0	680
Pinus silvestris	39.3	47.0	12.7	7.65	110.0	690
Pinus taeda	30.6	44.0	11.5	7.15	105.0	690
Pinus patula	35.0	44.1	12.6	7.15	108.0	680

4. Tear index vs. tensile index of unbleached and bleached NS-AQ and kraft pulp from jute with the same unbleached kappa number *(3)*



5. Logarithmic plot of lignin yield vs. cooking time in NS, NS-AQ, and kraft pulping of jute *(20)*



Kinetics of jute pulping

The ultimate objective of the kinetic study in pulping is to control the cook to produce pulp with better yield and quality. The kinetics of pulping, though very complicated, can in no way be ignored in determining to what extent the cook is continued.

A study of the kinetics shows that three phases of delignification, each following a first-order reaction, can be distinguished in NS, NS-AQ, and kraft pulping of jute *(20).* The rate of delignification is most rapid in kraft, followed by NS-AQ and NS pulping (**Fig. 5**). The first transition point between the initial and the bulk phases (**Table IV**) and the second transition point between the bulk and residual phases (Fig. 5) change to a lower lignin content with the addition of AQ in NS pulping. However, these points turn at the lowest lignin yield in kraft pulping.

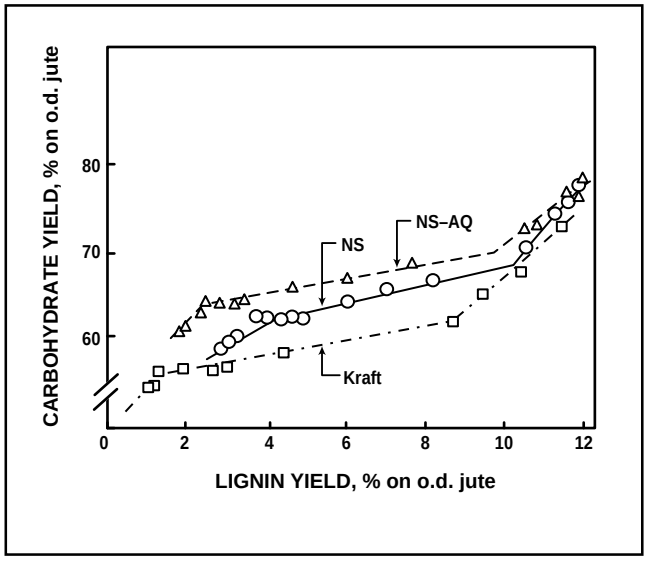
Although the second transition point in kraft pulping occurs at the lowest lignin yield, the carbohydrate yield is the poorest at this point (**Fig.**

III. Cooking conditions and pulp analyses for NS-AQ pulping of unchopped jute.[a]

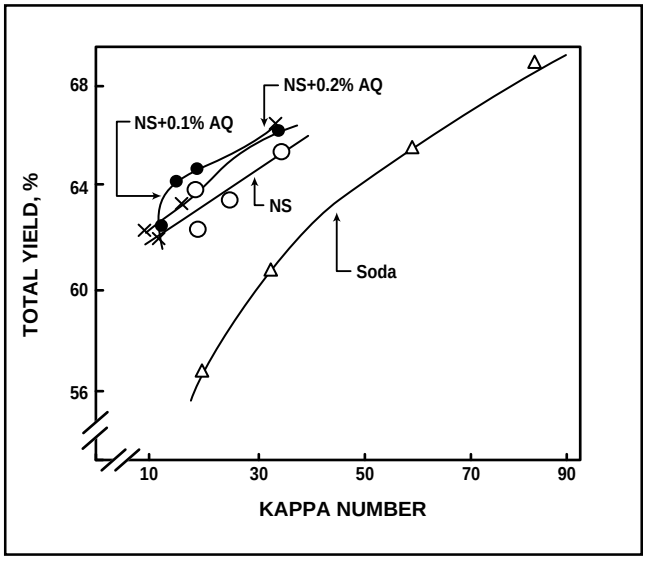
Jute type	AQ dose, %	Total alkali as NaOH, %	Refining	Rejects, %	Total yield, %	Kappa no.
Whole length	0.1	14	No	Nil	65.4	24.9
Whole length	0.1	16	No	Nil	64.6	20.4
Whole length	0.1	18	No	Nil	64.4	20.1
Whole length	0.1	20	No	Nil	63.9	19.5
Whole length	0.2	12	Yes	Nil	65.6	26.5
Whole length	0.2	14	No	Nil	64.8	19.1
Whole length	0.2	16	No	Nil	64.6	18.6
Whole length	0.2	18	No	Nil	63.7	16.9
Whole length	0.2	20	No	Nil	62.8	16.4
Chopped	0.1	14	No	Nil	64.8	22.8
Chopped	0.1	16	No	Nil	64.5	21.0
Chopped	0.1	18	No	Nil	64.6	19.8
Chopped	0.1	20	No	Nil	62.9	18.9

[a]Liquor/jute ratio: 7:1; time for temperature rise from 80°C: 90 min; cooking temperature: 170°C; cooking time: 3 h.; alkali ratio: 0.83 *(18)*

6. Dissolution of carbohydrates during NS, NS-AQ, and kraft pulping of jute *(20)*



7. Total yield vs. kappa number for NS, NS-AQ, and soda pulping of bagasse *(22)*



6). This does not favor the selectivity of the process.

Effect of cooking variables in NS-AQ pulping of jute

Pulping involves many variables, and each of these variables influences the chemical reactions differently. It is therefore important to study the effect of these variables on pulping. An investigation was conducted to study the effect of alkali ratio, total alkali, cooking time, cooking temperature, and liquor-to-fiber ratio on NS-AQ pulping of jute *(21)*. The following are our findings:

- The alkali ratio is an important variable that influences delignification. Maximum delignification occurs at an alkali ratio of 0.80 to 0.85.
- Fully chemically defiberized pulp can be obtained at a kappa number of about 27.
- Delignification is dependent on total alkali charge, cooking temperature, and liquor-to-fiber ratio. The delignification slows toward the end of the cook.
- The alkali charge has a minor effect on the pulp yield. An elevated temperature reduces the yield. A more concentrated liquor better

IV. Behavior of the first transition point with addition of AQ in NS pulping of jute compared to kraft pulping *(20)*

Pulping process	*Lignin yield, %*	*Carbohydrate yield, %*	*Na_2SO_3 or active alkali consumed, %*
NS	10.3	69.4	5.36
NS-AQ	9.88	70.9	4.30
Kraft	8.88	62.7	12.7

preserves the yield on extended delignification. The yield falls rapidly toward the end of the cook. Such a shift is dependent on the alkali charge, cooking temperature, and liquor-to-fiber ratio.

- Pulp with exceptionally high physical strength properties can be obtained from jute by the NS-AQ process.
- The alkali charge and liquor-to-fiber ratio show relatively minor effects on the tearing strength of the pulp. But the cooking temperature contributes decisively to this property. An extended delignification improves this property.
- The tensile strength of the pulp is not dependent on the alkali charge. The property is improved when pulping is done at 173°C. A lower liquor-to-fiber ratio is better for tensile strength. An extended cook weakens the pulp property.

NS-AQ pulping of unretted jute, jute plant, and jute stick

The pulping study of unretted jute bark, jute plant, and jute stick is in progress at the BFRI. These materials do not cause problems in cooking, washing, disintegration, and screening. Furthermore, fully chemically defiberized pulp can be obtained from them. The pulp from unretted jute bark has good physical strength properties. The jute plant provides better pulp than do hardwoods. As expected, the pulp from jute stick is poor in quality; it also drains slowly.

Raw material alternative to jute in NS-AQ pulping

Jute is a seasonal agricultural crop. In areas of adverse climatic conditions, a chance of crop failure is always present. Therefore, a pulp mill based wholly on jute may face serious problems. As a result, an alternative raw material that also responds positively to the NS-AQ process should be explored. Bagasse may be that alternative raw material if a proposed jute pulp mill is built near the Jamuna river. The total production of bagasse was 374,000 o.d. metric tons in 1989 and 1990 *(22)*. Most of that is now unavailable because it is used as fuel in the sugar mill boilers. In the future, following the construction of the Jamuna bridge, bagasse may be available as a surplus for pulp production.

Bagasse shows good response to the NS-AQ process *(22)*. It is possible to make bleachable grades of pulp with high yield and low or no screening rejects by NS-AQ pulping of bagasse. The use 0.1% AQ in the process is sufficient for delignification and yield protection. The unbleached yield gain is 7.9% on o.d. bagasse compared to the soda control (**Fig. 7**). Bleaching response of the pulp is also good, and the pulp is superior to its soda counterpart. Thus, bagasse may be a viable alternative raw material in the proposed jute-based pulp mill in Bangladesh.

Economics of NS-AQ pulping of jute

An empirical economic analysis of NS-AQ pulping of jute has been carried out by Akhtaruzzaman *(23)*. It is claimed that NS-AQ pulping of jute yields a saving of TK 2500/a.d. ton (US$ 63/a.d. ton) of bleached pulp compared to kraft pulping of jute. The author also indicates that straight morrah reject white and tossa grades of jute and jute cuttings are cheaper raw materials for NS-AQ pulping compared to kraft pulping of bamboo.

General aspects

Because of the high cooking yield, the heating value of NS-AQ waste liquor is lower than that of the kraft black liquor. However, NS-AQ pulp is easier to wash, and therefore less water is needed; because of this, less energy is needed for evaporation. This is likely to counteract the lower heating value of the waste liquor.

The evaporation of waste liquor and the regeneration of Na_2SO_3 and Na_2CO_3 should pose no serious problems. The same equipment used in the kraft process can be used in the NS-AQ process. However, additional equipment is needed for SO_2 production from the Na_2S portion of the green liquor. The cooking liquor can be prepared with the Tampella, Rauma-Repola, or Stora conversion methods *(16)*.

Conclusions

Alkaline pulping of jute causes several process difficulties that result in low yield and inferior pulp quality. NS-AQ jute pulping offers many advantages compared to kraft pulping:

- Higher pulp yield (6.3% on o.d. jute for unbleached pulp at kappa no. 20)
- No pulp disintegration, washing, or screening problems that are part of the kraft process
- Full chemical defiberization of the fiber with no screening rejects
- No jute chopping needed

- Alkali requirements may be less
- Easier to wash. Less wash water is needed, and waste liquor from spills is nearly neutral.
- No foul odor
- Quick beating response of the pulp
- Pulp drains faster
- Pulp is easier to bleach
- The physical strength properties of unbleached pulp are nearly identical to those of the kraft pulp. Bleached pulp shows better strength properties.
- The strength properties of the unbleached pulp are superior to those of the kraft pulp from some common coniferous wood species.
- Economically more advantageous.

The main drawbacks of the NS-AQ process are:

- Pulping time at a given temperature is longer than the kraft process. However, proper selection of alkali dose, temperature, and chemicals concentration may reduce the cooking time.
- The heating value of the waste liquor is low because of high pulp yield.

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