# Anthraquinone pulping of kudzu (*Pueraria lobata*)

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*ABSTRACT: Kudzu was pulped under pulping conditions for kraft, kraft–AQ, soda, and soda–AQ processes. Anthraquinone addition increased the carbohydrate content of the brownstock pulp for all cooks. Anthraquinone addition lowered the brownstock kappa number while reducing the chemical demand. Brownstock from selected pulping sequences was tested to determine tear strength, tensile strength, burst strength, and freeness. The brownstock was also subjected to a CED bleaching sequence. For the bleached pulps, viscosity and average fiber length were determined.*

*KEYWORDS: Annual plants, anthraquinone, bleaching, kappa number, kraft pulping, nonwood fibers, physical properties, pulping, sequences, soda pulping, unbleached pulps, yield*

In recent years, the use of nonwood fibers as an alternative to wood pulp has been increasing (*1*). Many nonwood fibers derived from such sources as bamboo, jute, straw, rice, abaca, and bagasse are used in small commercial pulping operations (*1–4*). While the bulk of nonwood fibers (from straw, bagasse, and bamboo) are used in printing and writing papers, paperboard, and newsprint, many species are used in the production of specialty fiber materials (*2*).

Nonwood species present special problems, however, particularly in regard to storage and pulping (*5*). These materials are derived from annual crops that may be harvested only during one season of the year. Generally, nonwood species have a high moisture content, low bulk density, and a low pulped fiber yield (*5*). For these raw materials to be stored, the chips must be dried to prevent fiber degradation. As a result, it is expensive to procure and transport the raw materials. Also, nonwood fibers tend to be high in ash or silica, which can be dissolved in alkaline pulping liquors, thus increasing the viscosity and making pulping more difficult. The dissolved silica may also form hard smelt deposits in the recovery boiler or may plate out in the lime kiln and form a glassy coating that has to be removed during kiln downtime (*6*).

One method of improving the potential for using nonwood species would be to increase the carbohydrate yield. The addition of anthraquinone to hardwood soda cooks has been well documented as a method of increasing pulp yields (*7, 8*). Also well documented has been the effect of anthraquinone addition on carbohydrate stabilization and, hence, on cellulose and hemicellulose retention (*9*).

For these reasons, we studied the use of 9,10-anthraquinone (AQ) as a means of increasing the carbohydrate yield and reducing the kappa number of kudzu pulps while reducing the total amount of sulfur used in the pulping process. The brownstock pulps obtained from kraft, kraft–AQ soda, and soda–AQ cooks were evaluated for yield, kappa number, freeness, and strength properties. The bleaching response of selected kudzu brownstocks was also evaluated.

## Brief background on kudzu

Kudzu was imported from Japan into the United States during the late 1800s. It was originally used as a decorative vine and as a food source for livestock. Kudzu became prevalent in the southeastern United States during the 1930s when it was predominantly used as a food source for livestock and as a ground cover to prevent erosion.

As a ground cover, however, kudzu has been too successful. Today, kudzu is a nuisance plant in the Southeast. It is capable of smothering any vegetation in its way. The kudzu vine can grow up to 60 feet in one season. To date, the only commercial use of kudzu is in the production of a starchy noodle from the root of the plant.

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I. Yield and kappa number results of various kudzu pulping experiments

| *Type of cook* | *Effective alkali, %* | *AQ, %* | *Sulfidity, %* | *Yield, %* | *Kappa no.* |
|---|---|---|---|---|---|
| Raw material | ... | ... | ... | ... | 78.3 |
| Kraft | 20.0 | ... | 25.0 | 43.3 | 51.9 |
| | 20.0 | ... | 35.0 | 35.2 | 24.0 |
| Kraft–AQ | 20.0 | 0.1 | 5.0 | 38.9 | 25.6 |
| | 20.0 | 0.1 | 10.0 | 36.5 | 25.0 |
| | 20.0 | 0.1 | 15.0 | 30.4 | 23.5 |
| | 20.0 | 0.1 | 25.0 | 33.7 | 22.4 |
| | 20.0 | 0.1 | 35.0 | 36.2 | 22.0 |
| Soda | 20.0 | ... | ... | 40.0 | 49.6 |
| | 25.0 | ... | ... | 39.2 | 46.6 |
| | 30.0 | ... | ... | 34.7 | 35.1 |
| Soda–AQ | 20.0 | 0.1 | ... | 40.0 | 29.6 |
| | 25.0 | 0.1 | ... | 34.8 | 22.5 |
| | 30.0 | 0.01 | ... | 37.0 | 28.9 |
| | 30.0 | 0.05 | ... | 36.3 | 23.1 |
| | 30.0 | 0.1 | ... | 34.1 | 14.2 |

In our efforts to determine the papermaking potential of the vine, we found no literature on the pulping of kudzu fibers. However, one paper was discovered that dealt with the pulping of a vine-like noxious weed from India (*10*). The results of this work were inconclusive, but they were positive with respect to the production of a usable fiber material.

## Experimental procedures

Kudzu was harvested from a field in Atlanta, GA. The vine-like stems were obtained near the end of the kudzu winter dormancy period (late January through early February). Most of the leaves had fallen off the vine. The vines were cut into strips about 6.35–9 cm long. The diameters of the vines were about 0.5–0.9 cm. The raw material had a moisture content of about 22–30%. Harvested kudzu was stored in a cooler until it was used in this work. Upon storage in chip form, the moisture content dropped to about 10–15%.

After the raw material was obtained, we conducted kraft, kraft–AQ, soda, and soda–AQ pulping experiments. Multiple conditions were investigated because no literature on previous studies was available to limit the scope of the pulping study.

The effective alkali (EA) was varied from 20% to 30% on o.d. pulp. The sulfidity was altered from 0% to 35%. Anthraquinone addition to the soda cooks was altered from 0.01% to 0.1% AQ on o.d,. chips. Anthraquinone addition was maintained at 0.1% by wt. on o.d. chips for the kraft–AQ cooks. A liquor-to-wood ratio of 8:1 was used. Along with distilled water, reagent-grade NaOH, $Na_2S$, and anthraquinone were used to prepare the required pulping liquors. A 10-L M/K laboratory digester with an indirect liquor heating and cooling system was used for the pulping experiments.

After the digester was loaded, the reaction mixture was heated to 170°C and was held at temperature for 2 h and 5 min. An H-factor of about 2000 was maintained for each cook. After cooking, the brownstock was cooled to 60°C and was washed with cold water.

Initial trial cooks with H-factors from 1050 to 2000 were conducted. The lower level of H-factor was picked to be representative of hardwood cooking conducted in our digester. The H-factor of 2000 was set as the upper limit because it was representative of the H-factor that had been successfully used for softwood cooking. These screening cooks indicated that a 2000 H-factor would be required for kudzu. The reason the high H-factor was required is that kudzu has a tight pore structure and a high bark content, thus requiring more cooking to liberate the useful fiber.

Once the H-factor was set, the chemical charge was varied to obtain acceptable brownstock pulps. The amount of nonfibrous bark (25.9% by wt.) and pithy core (3.3% by wt.) pulped with the kudzu consumed a large amount of chemical. Kudzu stems have a small diameter, thus producing a large surface-to-volume ratio. Bark on the surface of the kudzu vine thus requires a large amount of the active chemical if it is to be efficiently dissolved into the pulping liquor. For this work, no attempt was made to remove the bark or pith.

## Results and discussion

### Yield and kappa number

Data for yield and kappa number were collected for each of the pulping conditions studied. The results of these cooks are listed in **Table I**. Hardwood studies have indicated that anthraquinone addition should improve the carbohydrate yield while decreasing the sulfidity of a kraft cook (*7–9*). Anthraquinone addition to the soda process was expected to increase the carbohydrate yield while decreasing the kappa number. Similar results were obtained with kudzu and other nonwood species pulped in our lab.

The addition of anthraquinone to the kraft process increased the kudzu pulp yield. The increase in yield resulted from the tendency of anthraquinone to stabilize the carbohydrates, which gives rise to the retention of more of the desirable portions of the pulp (*9*). The final kappa number of the brownstock remained relatively constant during the kraft cooking sequences.

The addition of anthraquinone to the soda process had a dramatic effect on the kappa number. In many cases, the addition of 0.1% AQ on pulp decreased the brownstock kappa number by as much as 50%. The yield increased even though more of the lignin was removed from the fibers. The combined effects of (a) the carbohydrate stabilization of the aldehyde end-group and (b) the delignification catalyzed by anthraquinone were responsible for these events.

### Effect of sulfidity on nonwood kraft–AQ pulping

Seven pulping experiments were conducted to determine the effect of sulfidity on kraft–AQ pulping of kudzu. The effective alkali and the anthraquinone additions were held constant at 20% and 0.1% by wt., respectively. The sulfidity was varied from 0% to 35% over the various cooks (Table I). With anthraquinone addition, the sulfidity required for a specific cook should decrease.

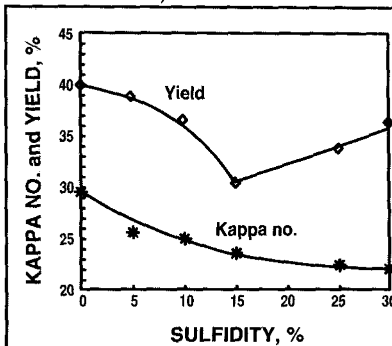
The yield associated with the increasing sulfidity went through a minimum at about the point at which the effect of sulfidity on the kappa number leveled off (Fig 1). These results indicate that anthraquinone addition plays two distinctive roles in the kraft–AQ pulping process. The first role is that of kappa number reduction. The second job of anthraquinone is the stabilization of carbohydrate. When the task of delignification is taken over by the sulfidity portion of the cooking chemicals, the major portion of anthraquinone may be used for carbohydrate stabilization, hence increasing the yield.

### Effect of anthraquinone addition on nonwood soda–AQ pulping

Anthraquinone has been reported to work in catalytic amounts (*7–9*). Most of the literature on anthraquinone pulping of woody materials reports anthraquinone additions of 0.05–0.1% by wt. on wood (*11*). In this work, we used anthraquinone at various levels of addition from 0.01% to 0.1% by wt. on o.d. wood.

The results indicate that even at very low levels, anthraquinone addition has a marked effect on the kappa number of the brownstock pulp. We obtained a value of 0.996 as the coefficient of variation ($r^2$) for the linear fit of kappa number as a function of anthraquinone addition. At the limit of 0% AQ, the linear fit predicts a final kappa number of about 30. Laboratory results obtained from the soda process have indicated a kappa number of 35.1. The catalytic effect of anthraquinone should result in a drop of at least five points in kappa number during the soda–AQ pulping process.

1. Kappa number and brownstock yield as a function of pulping liquor sulfidity. (kudzu fiber. kraft-AQ pulping: 20.0% EA, 0.1% by wt. AQ on o.d. fiber.)




### Physical properties

The addition of anthraquinone to the pulping process was expected to increase the tensile and bursting strengths. The basis for this expectation is the fact that carbohydrate retention increases with the addition of anthraquinone. A high retention of hemicellulose should increase the tensile and bursting strengths of a handsheet by improving the bonding area and bonding strength.

TAPPI handsheets (T 205) were prepared from selected brownstock samples. These handsheets were subjected to physical testing. Tear index (T 414), tensile index (T 494), and burst index (T 403) were determined. The freeness of unbeaten pulp was also determined. **Figure 2** presents the results of these physical tests.

The addition of anthraquinone increased the tensile index and burst index of the handsheets for every set of pulping conditions examined. The tear index also indicated improvement with the addition of anthraquinone. It is not possible to compare absolutely the anthraquinone and non-anthraquinone values for tear, tensile, and burst strengths because the freeness values of the brownstock pulps are not the same. However, general comparisons may be made.

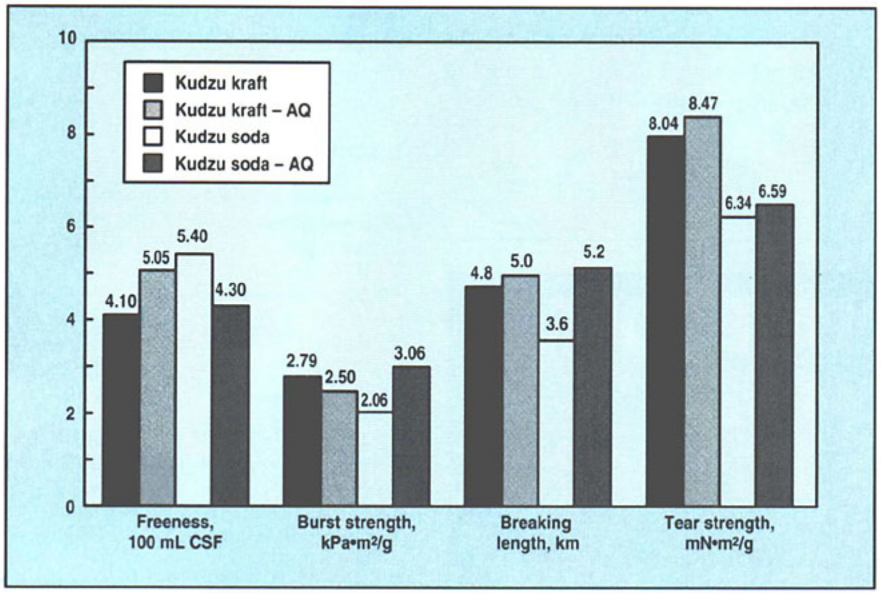
In addition to determining the physical properties of the kudzu pulps, we determined the average fiber length. A Kajaani FS-100 was used to determine the weighted average fiber length. Duplicate samples were run to determine that kudzu brownstock pulps have a weighted average fiber length of 0.685 mm.

### Bleaching response—three-stage CED sequence

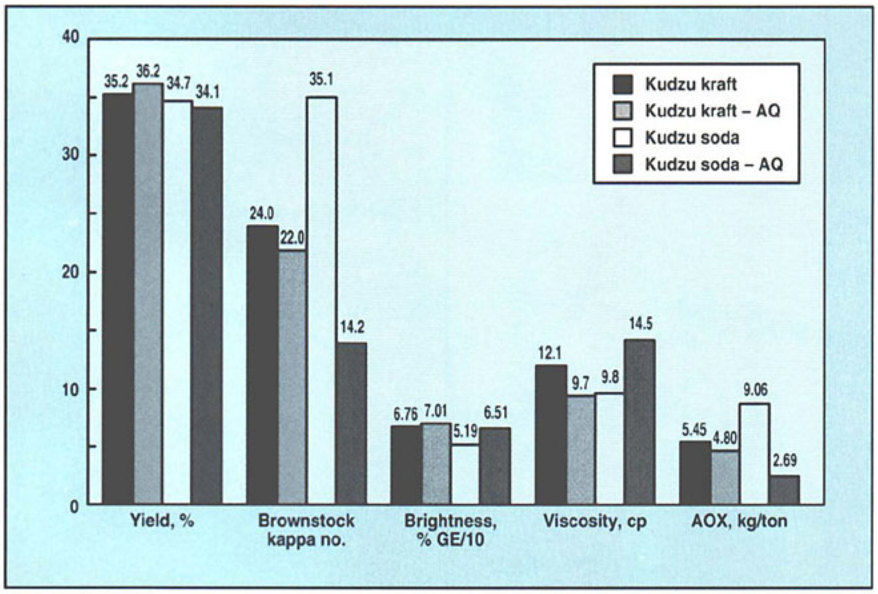
Selected brownstock fibers were subjected to a three-stage CED bleaching sequence. A chlorine multiple of 0.22 was used to establish the amount of chlorine added in the chlorination stage. A caustic multiple of 0.65 was employed to calculate the NaOH charge supplied to the caustic extraction stage. The final chlorine dioxide stage was set at a charge of 0.5% $ClO_2$ by wt.

The final viscosity of the bleached pulp was determined after the CED sequence. Anthraquinone slightly decreased the viscosity of bleached pulp prepared by the kraft sequence. Pulp prepared by the soda pulping method had a higher viscosity when anthraquinone was added to the pulping process.

2. Physical properties of kudzu brownstock prepared under various pulping conditions. (Kraft pulping: 20% EA, 35% sulfidity. Soda pulping: 30% EA. AQ addition: 0.1% by wt. for both kraft and soda.)




3. Bleaching response of kudzu pulps prepared under various pulping conditions and subjected to a CED bleaching sequence. (Kraft pulping: 20% EA, 35% sulfidity. Soda pulping: 30% EA. AQ addition: 0.1% by wt. 0.22 kappa factor, 0.65 caustic multiple, 0.5% $ClO_2$ by wt.)




TAPPI handsheets were made from the bleached pulp for determining GE brightness. **Figure 3** shows the bleaching response of the nonwood fibers. The addition of anthraquinone to the pulping sequence generally increased the unbleached brightness of the pulp and reduced the amount of active chlorine required for bleaching. In addition, the final bleached brightness was improved.

Effluent samples were collected for analysis of AOX (adsorbable organic halogens). The addition of less chlorine meant a decrease in the amount of AOX released into the bleaching effluent.

## Repeatability

From two sets of data representing both the kraft and soda processes, randomly chosen cooks were repeated to determine if the yield, kappa number, and freeness data were reasonably reproducible. In the data set for the kraft process (20.2% EA, 35.0% sulfidity), cooks had percentage differences of only 1.14%, 0.42%, and 1.22% for the yield, kappa number, and freeness, respectively. In the data set for the soda process (30.0% EA, 0.1% AQ), the cooks had percentage differences of 0.29%, 1.43%, and 4.65% for these properties, respectively. Consequently, the data indicate that the values obtained from the digestion process could be repeated with reasonable agreement.

## Conclusions

Kudzu responded well to anthraquinone pulping. Brownstock and bleached fibers of reasonable quality could be obtained through kraft and soda pulping with the addition of anthraquinone.

The sulfidity of the pulping process could either be substantially lowered or eliminated by the addition of anthraquinone. Yield improvements were also documented. However, the yields were still low when compared to wood pulp yields. The low yields and the costs associated with annual harvesting and storage are problems in the effort to make commercial use of kudzu.

Also, the bark and pith content of the kudzu represents a high chemical burden. Methods of removing some of the bark should be studied before more pulping work is conducted with this species.

The addition of 0.1% AQ by wt. on o.d. fiber to the nonwood fibers improved the quality of the resulting brownstock pulps. Brownstock fiber yield was increased over identical cooks without anthraquinone. Physical properties, especially tensile and burst strengths, were increased with anthraquinone addition. The brownstock pulps from anthraquinone cooks had a higher brightness and were easier to bleach than nonanthraquinone pulps. Bleached pulps from the soda process had a higher CED viscosity when anthraquinone was used. Also, lower AOX discharges were obtained from materials pulped with anthraquinone.

Brownstock pulp yields were increased by the addition of anthraquinone to the pulping process. Anthraquinone added to the soda pulping process increased the fiber yield while lowering the kappa number of the brownstock pulp. When anthraquin-one was added to the kudzu kraft pulping process, yields increased, sulfidity requirements fell, and the kappa number remained unaffected.

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