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# Optical Property of Chemimechanical Pulp Sheet from Fast-Growing Kenaf*1

Guo-Min Tan*2 and Nam-Seok Cho*3

# Kenaf 반화학펄프로부터 제조한 종이의 광학적 특성*1

譚 國 民*2. 趙 南 爽*3

## 요 약

오늘날 열대림 면적의 급격한 감소, 지구온난화등 지구환경 보전의 관점에서 이들 목재이외의 자원의 활용 및 양마와 같은 새로운 비목재자원 개발의 중요성이 재인식되기에 이르렀으며, 이 가운데서 양마는 생장이 빠르고 수확량이 크며, 목질부의 단섬유는 물론 긴 섬유장을 가진 인피부섬유로 구성되어 있고, 실리카함량도 매우 적어, 특히 산림자원이 부족한 개발도상국에서 펄프.제지용 자원으로서 주목되고 있다.

양마가 펄프.제지용 자원으로서 오늘날과 같은 세계적 주목을 받게 된 것은 미국 농무성 북부지역연구센타에서 이루어진 "새로운 섬유작물"에 관한 기초연구에서 양마가 제지용 섬유작물로서 높이 평가되고 있다. 양마의 경우 인피부는 비교적 리그닌함량이 적고, 목질부는 활엽수재에 가까운 리그닌을 함유하고 있는데다, 섬유형태에 있어서도 인피부와 목질부간에 큰 차이가 발견된다.

본 연구에서는 양마를 중성아황산법으로 전처리하여 제조한 반화학펄프로 부터 제조한 종이의 광학적 성질을 검토하였다. 펄프의 광학적 성질은 원료의 화학적 조성, 섬유의 형태, 부위. 화학적 처리정도, 원료의 저장기간 및 충전제의 첨가에 따라 크게 영향을 받았다. 장섬유와 낮은 리그닌함량을 가진 전간부 펄프시트는 불투명도가 낮았으며, 목질부 펄프로부터 상대적으로 밀도가 다소 높고, 불투명도도 높은 종이를 만들 수 있었다. 펄프원료의 저장기간이 백색도를 낮추었으며, 불투명도에는 그다지 영향하지 않았다. 약품전처리 및 표백이 백색도 및 불투명도에 크게 영향하였고, 특히 충전제 첨가로 광산란을 증가시켜 불투명도가 높은 종이를 제조할 수 있었다.

Keywords: Kenaf, chemimechanical pulp, optical property, brightness, scattering coefficient, adsorption coefficient

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*1 Received on

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*2 Tianjin University of Light Industry, Tianjin 300222, Republic of China
*3 College of Agriculture, Chungbuk National University, Cheongju 361-763, Korea

## 1. Introduction

Kenaf is an annual herbaceous plant, Malvaceae family, Hibiscus genus. This plant has strong adaptation to climate and soil, with growth circle of approximately 120 - 130 days and high yields. In the past Kenaf was used primarily as a source of coarse textile fibers for the manufacture of twine, carpet backing, burlap, and other related products. In the early 1960s, researchers began to study kenaf as a source of pulp fiber for paper in the United States[1]. Since then, it was internationally acknowledged[2-9] that kenaf is the best raw-material suited for papermaking among the non-woody fiber resources.

Kenaf stalks are made up of two different parts, bast and woody core, which differ from greatly in fiber morphology and chemical constituents. Those different characteristics make different pulp sheets. From viewpoint of future paper needs, intensive investigations were performed of pulping of potential annual crops for papermaking[10]. Besides its chemical pulping, thermomechanical pulping (TMP process)[11,8,9] and chemithermomechanical pulping (CTMP process)[12] have been reported. Nevertheless little is known of precise chemicals treatment effects in chemimechanical pulping. This study was carried out to understand the factors influencing to the optical properties of paper sheets made from kenaf chemimechanical pulp (CMP).

## 2. Materials and Methods

Raw material of kenaf (*Hibiscus cannabinus*), which was from Huinan, China, was cultivated and harvested at the university farm of Chungbuk National University. This samples were separated to bast and woody core parts. Whole stems and woody cores are cooked with 3% of NaOH and 4 to 10 % of $Na_2SO_3$ at 130℃ or 140℃ for 30 min. to 60 min. and refined with laboratory disk refiner at room temperature. It had single disc with diameter of 12", rotating at 3,000rpm by a 45KW motor driving. The pulps were bleached with bleaching reagents, such as hydrogen peroxide, sodium borohydride, sodium thiosulfate and peracetic acid, using one stage or two stage bleaching. Paper sheets were made from 100% CMP, and mixed pulps from stem and core wood pulps. The sheets were evaluated for the optical properties, such as brightness, opacity and scattering coefficient according to KS and Tappi Methods.

## 3. Results and Discussion

### 3.1 General characteristics

Kenaf has strong adaptation to climate and soil, with a growing circle of approximately 120 - 130 days. This plant grows 1.5 to 3.2 m of the height and 2 - 4.8 cm in diameter. Kenaf stem is made up of two kinds of different fibrous part, bark part and woody core, which are greatly different in fiber morphology and their chemical constituents as in Table 1. The bast fiber is long with high ratio of length to width, whereas the fiber of woody core is short and wide. The weight ratio of bark part to woody core is about 36 to 64. The lignin content of bark is low, cellulose content high, hemicellulose low, whereas lignin content of core wood is high, holocellulose and ash contents lower.

### 3.2 Optical properties of CMP sheet

Different paper has different ability of reflecting, transmitting and absorbing, thus exihibiting different optical characteristics. The optical properties of paper include gloss, brightness, color, opacity and scattering coefficient. Scattering coefficient of paper is indirect proportion to weight specific sheet surface areas, inside and outside, inverse proportion to the density of paper. Increasing fiber to fiber bonding area, for example, beating, addition of starch, polyacrylamide strength aids, or increasing apparent density, for example, calendering, have scattering coefficient decreased. Addition of additives can enhance scattering coefficient. According to different usage and printing purpose, there is different specification of optical properties. High opacity is essential to the printing quality of papers.

Table 2 illustrates changes of absorption (K) and scattering (S) coefficients after bleaching kenaf pulps. When brightness and scattering coefficient of the sheet are constant, opacity increases with the increasing of sheet density. If density varies a little, they have a linear relationship.

When sheet density and scattering coefficient are constant, opacity

**Table 1. Fiber morphology and chemical constituents**

| | Bast part | Woody core | Pine wood |
|---|---|---|---|
| Fiber length, mm | 0.65 - 6.05 (2.86) | 0.40 - 1.40 (0.83) | 2.25 - 5.06 (3.61) |
| Fiber width, μm | 8 - 34 (16) | 12.5 - 57.5 (32) | 36.3 - 56.7 (50) |
| Wall thickness, μm | 5 - 8 (6.5) | 3.6 - 3.8 (3.7) | early wood 3.8<br>late wood 8.7 |
| Chemical composition,% | | | |
| Holocellulose | 80 - 84 | 77 - 78 | 71 - 74 |
| Lignin | 12 - 14 | 22 - 23 | 26 - 29 |
| Pentosan | 14 - 15 | 17 - 19 | 8 - 10 |
| Ash | 3 - 4 | 1 - 2 | 0.3 |

* ( ) is average value.

**Table 2. Changes in optical properties after bleaching**

| | 1 | | 2* | |
|---|---|---|---|---|
| | Before bleach | After bleach | Before bleach | After bleach |
| Brightness, % | 45.6 | 53.3 | 31.8 | 33.9 |
| Scattering Coefficient, m²/kg | 39.6 | 40.5 | 47.9 | 40.8 |
| Absorption Coefficient, m²/kg | 4.7 | 2.6 | 19.8 | 13.3 |

* a little decayed

increase, while brightness decreases. If there were slight change in brightness, these two also could be linearly related. Therefore, inadequate brightness increase will lead to decline of opacity resulting in unsatisfactory products. For example if unbleached pulp would be met the specification for some uses of paper sheet, we should adopt bleached pulp, because of lower opacity.

When grammage and brightness are constant, opacity increases as scattering coefficient increases. If scattering coefficient changes little, they also have linear relationship. Pulp beating increases apparent density, thus lowering scattering coefficient and opacity. The relationship between opacity and scattering coefficient of woody core CMP is illustrated in Table 3.

There is no doubt that opacity is a function of absorption coefficient and scattering coefficient of paper. Not like R , opacity is only function of adsorption coefficient(K)/scattering coefficient (S), as well W(grammage), and K+2S. K and S have same effect on opacity. When grammage of paper is constant, increasing K or S will improve opacity of paper when absorption coefficient is less than 4 m²/kg, opacity declines dramatically as K value decreases as in Fig. 1.

The smaller K value is, the more opacity declines. Under average conditions

**Table 3. Relationship between opacity and scattering coefficients of woody core pulp**

| | | | |
|---|---|---|---|
| Scattering Coefficient, m²/kg | 56.2 | 48.4 | 48.2 |
| Opacity, % | 89.1 | 87.5 | 87.3 |
| Freeness, °SR | 35 | 45 | 55 |
| Apparent density, g/cm³ | 0.38 | 0.45 | 0.48 |

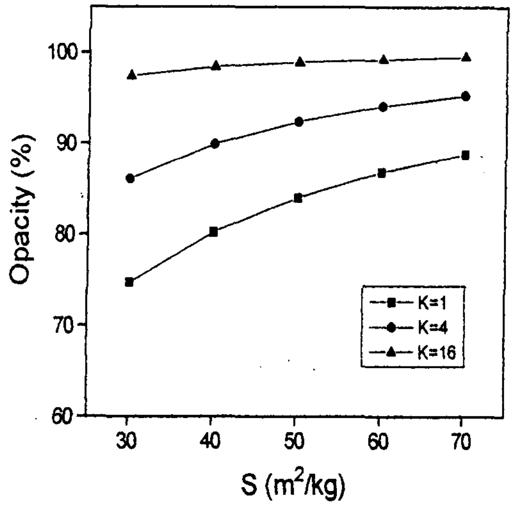


Fig. 1. The effect of scattering coefficient on paper opacity

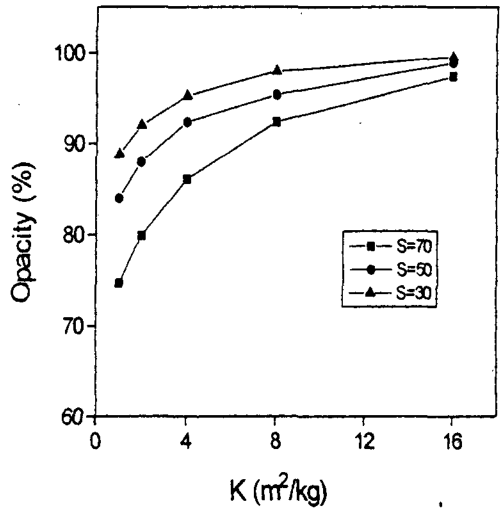


Fig. 2. The effect of absorption coefficient on paper opacity

scattering coefficient influences opacity gently. This explains why paper from groundwood pulp has very high opacity. It also explains why paper of small absorption coefficient having high brightness is difficult to get high opacity. Fig. 2 gives the relationship between opacity, absorption and scattering coefficients of the core pulps.

The relationship between opacity, absorption coefficient and scattering coefficient from core pulp was shown in Table 4. Table 5 shows printing opacity (C) of whole stem pulp and Tappi opacity($C_{0.89}$). Compared to wood pulps, kenaf contains higher hemicellulose and lower lignin contents, as well as more fibrous fines fractions and non-fibrous components. Therefore, optical properties could be decreased further by those features of kenaf pulps. Factors which significantly affect optical properties of kenaf pulps are sources, storage periods, raw material status, and different parts of kenaf (whole stem, bast fiber, and woody core).

Table 4. Relationship between opacity, absorption coefficient and scattering coefficient of woody core pulp

| | | | | |
|---|---|---|---|---|
| Scattering coefficient, m²/kg | 48.8 | 55.0 | 41.7 | 45.5 |
| Absorption coefficient, m²/kg | 2.8 | 4.0 | 13.2 | 19.7 |
| Opacity, % | 90.1 | 92.8 | 97.7 | 99.3 |
| Brightness, % | 54.1 | 51.7 | 36.3 | 32.9 |

**Table 5. Printing opacity and Tappi opacity of whole stem pulp**

| | | | | | | |
|---|---|---|---|---|---|---|
| Brightness($R_{457}$), % | 31.8 | 33.9 | 40.5 | 45.6 | 48.7 | 53.3 |
| $R_\infty$ (550nm) | 41.5 | 45.5 | 57.4 | 61.7 | 65.9 | 70.5 |
| Printing opacity(C),% | 99.2 | 97.7 | 92.3 | 91.4 | 87.3 | 86.4 |
| Tappi opacity($C_{0.89}$),% | 97.8 | 94.3 | 85.4 | 84.9 | 80.0 | 80.1 |

**Table 6. The effect of storage periods on optical properties of unbleached whole stem pulp**

| Storage | | 〈 half year | 〈 one year | 〈 half year | 〉 one year |
|---|---|---|---|---|---|
| Brightness,% | Whole stem | 54.9 | - | 57.0 | 45.6 |
| | Core | - | 56.8 | - | 51.7 |
| Opacity, % | Whole stem | 91.3 | - | 91.4 | 91.4 |
| | Core | - | 92.0 | 92.8 | 92.8 |

**Table 7. Comparison of optical properties between whole stem and woody core pulps**

| | Unbleached | | Bleached | |
|---|---|---|---|---|
| | Whole stem | Core | Whole stem | Core |
| Freeness, °SR | 45 | 41 | 43 | 40 |
| Grammage, g/m² | 50.9 | 48.4 | 49.3 | 50.6 |
| Brightness,% | 45.6 | 51.7 | 53.3 | 54.1 |
| Opacity, % | 91.4 | 92.8 | 86.4 | 90.1 |
| Scattering coefficient,m²/kg | 39.6 | 55.0 | 40.5 | 48.8 |
| Absorption coefficient,m²/kg | 4.7 | 4.0 | 2.6 | 2.8 |

Table 6 represents the effect of storage time on optical properties of unbleached whole stem pulp. Brightness of whole stem pulp stored less than half year is about 9 - 11% higher than that of the pulp from over one-year stored. Core pulp also shows 5% higher than that of latters stored over one year, and resulted in just same tendency as formers. Therefore, using kenaf stored for about half year (bark remains as light green, and core part shows opalescence) may obtain satisfactory optical properties from the pulp.

Kenaf is composed of bark portion and woody core. As mentioned before, bark

Table 8. Effect of sulfite pulping conditions on optical properties of kenaf pulps

| | Pretreatment | | | Optical properties | | | |
|---|---|---|---|---|---|---|---|
| | NaOH % | $Na_2SO_3$ % | Max.temp. ℃ | Brightness % | Opacity % | Scatt.Co. m²/kg | Abs. Co. m²/kg |
| Woody Core | 3.0 | 4.0 | 140 | 50 | 95 | 49.3 | 5.7 |
| Woody Core | 3.0 | 6.0 | 140 | 51 | 96 | 59.3 | 6.5 |
| Woody Core | 3.0 | 8.0 | 130 | 53 | 95 | 53.7 | 5.0 |
| Woody Core | 3.0 | 10.0 | 130 | 56 | 95 | 50.7 | 5.6 |

portion weighs 35 - 40% of whole weight. Its fiber is slim and long, having a high ratio of the cell wall thickness to lumen diameter. Whereas core fiber is short and wide, having lower ratio of the cell wall thickness to lumen diameter. Lignin content in bark is lower than that of core part, and holocellulose content in bark portion is much higher than in core wood. Therefore pulps of whole stem and woody core notably exhibit different optical properties as shown in Table 7. Brightness, opacity and scattering coefficient of whole kenaf bleached and unbleached CMP are lower than those of woody core.

Chemical pretreatment affects physical, mechanical and optical properties of the pulps. Also variables such as chemical charges, cooking temperatures, and cooking times have striking influence on optical properties of CMP as shown in Table 8.

In preliminary experiments (data are not shown), when NaOH concentrations are 2% and 3%, pulp brightness approaches or exceeds 50%, and opacity exceeds 90%. When NaOH is below 5%, whether whole stem pulp or woody core pulp, its brightness is below 40%. When $Na_2SO_3$ concentration is 4%, and NaOH increases from 3 to 5%, brightness of woody core pulp subsequently drops from 50% to 40%. Therefore NaOH concentration should not exceed to 3%.

Brightness of kenaf pulp increases with increasing of NaOH the $Na_2SO_3$ concentrations. The more concentration of $Na_2SO_3$, the greater extent brightness increases. Whereas opacity and scattering coefficient obtain their highest values at 6% $Na_2SO_3$ addition. High pretreatment temperature have brightness, scattering coefficient and opacity decrease. The experimental results show that appropriate NaOH and $Na_2SO_3$ addition, 130-140℃ for 0.5 - 1 hr have little influence on optical properties of kenaf pulps.

Bleaching of pulp affects mainly paper opacity. Bleaching increases pulp brightness which leads to decrease

**Table 9. Effect of bleaching agents on the optical properties**

| Source | Bleaching agents | Brightness % | Scatt. Coeff. m²/kg | Absorp. Coeff. m²/kg | Opacity % | Color | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | L | a | b |
| Whole stem | Unbleached | 58.6 | 49.0 | 3.46 | 91.3 | 85.4 | 2.40 | 7.60 |
| | 3% $H_2O_2$ | 74.1 | - | - | 81.5 | - | - | - |
| | 1% $NaBH_4$ | 66.3 | 47.2 | 2.90 | 88.6 | 88.8 | 1.55 | 4.30 |
| | 4% $CH_3COOOH$ | 64.5 | 54.1 | 2.14 | 90.0 | 89.7 | 2.60 | 9.92 |
| | 1% $Na_2S_2O_4$ | 65.2 | 66.2 | 2.45 | 92.7 | 90.0 | 1.90 | 7.94 |
| | 3% $H_2O_2$- 1% $H_2O_2$ | 76.1 | - | - | 80.9 | 93.6 | 0.10 | 5.22 |
| | 1% $NaBH_4$- 3% $H_2O_2$ | 74.9 | - | - | 75.7 | - | - | - |
| | 3% $H_2O_2$- 1% $NaBH_4$ | 74.1 | - | - | 74.3 | - | - | - |
| | 3% $H_2O_2$- 1% $Na_2S_2O_4$ | 75.9 | - | - | 81.1 | - | - | - |
| Woody core | Unbleached | 49.6 | 63.5 | 4.75 | 95.4 | 86.0 | -0.55 | 14.02 |
| | 3% $H_2O_2$ | 63.7 | - | - | 88.7 | - | - | - |
| | 1% $NaBH_4$ | 58.9 | 67.8 | 2.62 | 93.1 | 89.8 | -0.87 | 9.87 |
| | 4% $CH_3COOOH$ | 57.0 | - | - | 94.5 | - | - | - |
| | 1% $Na_2S_2O_4$ | 56.1 | 82.2 | 3.52 | 95.9 | 89.2 | -1.23 | 14.8 |
| | 3% $H_2O_2$- 1% $H_2O_2$ | 66.8 | - | - | 88.1 | - | - | - |
| | 1% $NaBH_4$- 3% $H_2O_2$ | 65.2 | - | - | 82.6 | - | - | - |
| | 3% $H_2O_2$- 1% $NaBH_4$ | 64.7 | - | - | 81.2 | - | - | - |
| | 3% $H_2O_2$- 1% $Na_2S_2O_4$ | 65.7 | - | - | 88.9 | - | - | - |

absorption coefficient. When scattering coefficient varies little, decreased absorption coefficient results in decreasing of opacity. Therefore it is wise to use the pale-colored kenaf raw material of short storage time to produce paper product with other pulp, thus meeting brightness specification of the paper what we need. If the specified brightness does not meet, the pulp must be bleached. Bleaching agents affect the optical properties of the pulp. There are two kinds of bleaching agents used for bleaching pulp. One is oxidizing agent, for example, hydrogen peroxide, oxygen, ozone, and peracetic acid, etc.. The other is reducing chemicals, such as sodium borohydride and sodium thiosulfate, etc.. The most widely used bleaching agent for mechanical pulp is hydrogen peroxide.

Table 9 shows the effect of various bleaching reagents on the optical property of the sheet, using one stage or two stages bleaching. Bleaching agents have different effects on optical properties of kenaf pulps. Hydrogen peroxide and sodium borohydride have better brightening effect than sodium thiosulfate and peracetic acid, but the former greatly reduces the opacity, and the latter affects opacity slightly, even having trend of increasing opacity which is related to their lower brightness increasement. At almost same brightness level, opacity of bleached pulp with sodium thiosulfate and peracetic acid is higher than that of bleached pulp with hydrogen peroxide and sodium borohydride. This is mainly because hydrogen peroxide and sodium borohydride have little effect on scattering coefficient of the pulp, and even have the tendency of increasing scattering coefficient.

Concerned to improvement of optical pulp properties by filler addition, as shown in Table 10, precipitated calcium carbonate

**Table 10. Effect of additives on the optical properties**

| No. | Additives | Addition % | Retention % | Brightness % | Scatt. Coeff. m²/kg | Absorp. Coeff. m²/kg | Opacity % | Remarks |
|---|---|---|---|---|---|---|---|---|
| 1 | Talc | 0 | | 64.0 | 44.9 | 1.47 | 84.5 | 1-10:wood pulp 20% added |
| 2 | | 5 | | 63.1 | 46.5 | 1.28 | 84.2 | |
| 3 | | 10 | | 62.9 | 47.2 | 1.34 | 85.0 | |
| 4 | | 15 | | 64.1 | 47.4 | 1.16 | 84.0 | |
| 5 | Precipitated $CaCO_3$ | 5 | | 66.0 | 53.9 | 1.45 | 87.1 | 2-10: ampho.-starch 1.5% |
| 6 | | 10 | | 66.7 | 63.4 | 1.48 | 89.4 | |
| 7 | | 15 | | 67.5 | 65.8 | 1.38 | 89.8 | |
| 8 | Organic synthetic additive | 5 | | 63.7 | 57.1 | 1.92 | 89.5 | |
| 9 | | 10 | | 64.7 | 60.3 | 1.72 | 89.5 | |
| 10 | | 15 | | 66.2 | 65.8 | 1.71 | 90.6 | 11-18: 100% stem pulp + 0.8% cat. starch |
| 11 | Talc | 5 | 74.2 | 57.9 | 41.2 | 5.21 | 92.2 | |
| 12 | | 10 | 71.6 | 59.2 | 45.2 | 5.12 | 93.0 | |
| 13 | | 15 | 69.8 | 60.4 | 50.2 | 4.80 | 93.6 | |
| 14 | Precipitated $CaCO_3$ | 5 | 73.5 | 60.2 | 46.5 | 4.81 | 92.9 | |
| 15 | | 10 | 70.9 | 61.9 | 50.6 | 4.91 | 93.8 | |
| 16 | | 15 | 68.7 | 63.7 | 54.0 | 4.97 | 94.4 | |
| 17 | Inorganic synthetic additive | 10 | 72.2 | 61.0 | 42.2 | 5.02 | 92.2 | |
| 18 | | 0 | | 57.0 | 39.2 | 4.11 | 89.9 | |

and organic synthetic additives give the best effect, talc second, while inorganic synthetic additives somehow poor. The particle sizes of precipitated calcium carbonate and organic synthetic additives are observed as below 1μm by optical microscope. Some particle sizes of inorganic synthetic additives are above 100 μm, and have much crystalline water, not easy to disperse in pulp slurry. Filler having small partile size and homogenous distribute on the surface of fiber provides more interface for light reflectance, and increased light scattering coefficient drastically. Increased number of interface makes less fiber-fiber hydrogen bonding area, thus sheet strength would be poor.

## 4. Conclusions

The kenaf bast fiber is long with high ratio of fiber length to width, whereas the woody core fiber short and wide. The weight ratio of bast to woody core is about 36 to 64. Bast fiber has low lignin, high cellulose, and low hemicellulose contents, whereas core wood has higher lignin, and lower holocellulose and ash contents.

The optical properties of kenaf chemimechanical pulp (CMP) are influenced by raw materials, its chemical compositions, fiber morphology, storage time, parts of the kenaf stalk, chemical treatments and additives. The lower lignin and higher hemicellulose of kenaf fibers than woody core fibers have adverse influence on opacity and absorbency of the paper sheet. When sheet apparent density and scattering coefficient are constant, opacity increases, while brightness decreases. When grammage and brightness are constant, opacity increases as scattering coefficient increases. Beating increases sheet apparent density because of short fiber length and more fine fibers of woody part, thus lowering scattering coefficient and opacity. On the other hand, the sulfite pulping condition may reduce the opacity and light absorption of the kenaf pulp sheet.

Bleaching increases pulp brightness which leads to decrease absorption coefficient. When scattering coefficient varies little, decreased absorption coefficient results in decreasing of opacity. Bleached pulp with hydrogen peroxide and sodium borohydride have better brightening effect than sodium thiosulfate and peracetic acid, but the former greatly reduces the opacity, and the latter affects opacity slightly, even having trend of increasing opacity which is related to their lower brightness increasement. Addition of filler provides enhanced more interface for light reflectance, and enhanced drastically light scattering coefficient.

## Literatures cited


1. Clark, T. F., Nelson, G. H., Nieschlag, H. J., A search for new fiber crops. Part V. Pulping studies on Kenaf. Tappi 45(10):780 (1962).
2. Trotter, W. K., A search for new fiber crops. Part VII. An economic assessment. Tappi 45(12):915(1962).

3. Clark, T. F. and Wolff, I. A., A search for new fiber crops. Part VI. Kenaf and wood pulp blend. Tappi 45(10):786(1962).
4. Clark, T. F. and Wolff, I. A., A search for new fiber crops. Part IX. Tappi 48(6): 381(1965).
5. Clark, T. F., Uhr, S. C. and Wolff, I. A., A search for new fiber crops. Part X. Effect of plant maturity location of growth on Kenaf composition and pulping characteristics. Tappi 50(11):52A (1967).
6. Clark, T. F., Paper Trade J. 154(2):48(1970).
7. Cunningham, R. L., Touzinsky, G. F., and Bagby, M. O., Brightening of kenaf thermomechanical pulp. Tappi 62(4):69 (1979).
8. Touzinsky, G. F., Cunningham, R. L., and Bagby, M. O., Papermaking properties of Kenaf thermomechanical pulp. Tappi 63(1):53-55(1980).
9. Touzinsky, G. F., Cunningham, R . L., and Bagby, M. O., Laboratory paper machine runs with kenaf thermomechanical pulp. Tappi 63(3):109-110(1980).
10. Bagby, M. O., Kenaf, A practical fiber resources. Tappi Nonwood Plant Fiber Pulping. Progress Report No. 8, 75-80(1977).
11. Bagby, M. O., Cunningham, R. L., Touzinsky, G. F., Hamerstrand, G. E., Cutis, E. L., and Hofreiter, B. T., Kenaf thermomechanical pulp in newsprint. Tappi Nonwood Plant Fiber Pulping. Progress Report No.10, 111 (1979).
12. Hodgson, P. W., Lawford, W. H., Perrault, J., and Thompson, C. A., Commercial paper machine trial of CTMP kenaf in newsprint. Tappi 64(9):611-164 (1981).