LABORATORY ASSESSMENT OF THE POTENTIAL OF NIGERIAN-GROWN *GMELINA ARBOREA* ROXB. FOR NEWSPRINT MANUFACTURE

by

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ABSTRACT

Extension of pulp and paper raw material base by increased utilization of hardwood species is one reasonable approach to the solution of the world fiber shortage problem. This is particularly so if mechanical pulp with adequate mechanical and optical properties can be produced from fast-growing hardwoods which have not been used to any great extent in the past as a raw material.

Laboratory studies reported in this thesis were carried out to assess the response of *Gmelina arborea* Roxb., a hardwood grown extensively in Nigeria, to mechanical pulping. In this work, both open discharge and simulated thermo-mechanical refiner groundwood pulps were produced. In the latter case, the effect of chemical pretreatment with both sodium sulfite and sodium hydroxide was also evaluated. It was found that while open discharge and standard thermo-mechanical treatments resulted in mechanical pulp with inferior properties, the treatment of chips of *Gmelina* arborea Roxb. with a 1% sodium hydroxide solution at 250^{O}F (121^{O}C) for 10 minutes prior to open discharge refining resulted in a mechanical pulp having mechanical and optical properties comparable to and, in certain aspects, better than those of stone groundwood used in North American newsprint.

The behaviour of this chemically pretreated refiner pulp from Gmelina in admixture with softwood kraft was also investigated. It was found that the properties of newsprint furnish handsheets containing mixtures of Gmelina mechanical pulp and West Coast semi-bleached kraft (SBK) compared favourably with those of handsheets produced from typical West Coast newsprint furnishes, thus indicating the possibility of using chemically pretreated Gmelina thermomechanical pulp (TMP) with reduced amounts of softwood SBK.

To cover the situation for a fully integrated mill, a brief study was included to assess the response of Gmelina to kraft cooking, and to evaluate the behaviour of this pulp in admixture with Gmelina mechanical pulp. As expected, the kraft pulp from Gmelina was significantly weaker, mechanically, than North American kraft pulps and its deficiencies were clearly evident in the properties of mixed furnish handsheets. It was concluded, from this part of the study, that newsprint containing both its chemical and its mechanical pulp components from Gmelina would require excessively large proportions of Gmelina chemical pulp and still exert a limiting influence on paper machine speed and subsequent printing operations because of its strength deficiencies.

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CHAPTER I

INTRODUCTION

Hardwood pulps have generally, in the past, been used in the manufacture of tissue and fine papers, or as filler pulps. In recent times, however, the decreasing availability of the preferred softwood species, the increasing concern regarding the world future demand for fibers, and the foreign exchange conservation policies of some pulp-producing countries not endowed with the favored softwood species, have led to an ever-increasing incentive to make use of hardwood pulps for paper products. The pulp and paper industry can no longer afford the luxury of regarding hardwood pulps just as secondary material.

As reported by Alade (3), the consumption of paper and paperboard in Nigeria was about 111,583,723 kg (123,000 short tons) in 1975 and is expected to reach 199,580,643 kg (220,000 tons) by the year 1980. The government's spending on these items, reported by FAO (8), for the years 1963, 1964 and 1965 is shown in Table I. Although more recent supporting figures are not available to the writer, it is essential to point out that the consumption of paper and paperboard in Nigeria has risen remarkably during the past decade. This trend continues, largely as a result of the recently introduced universal free primary education in the country, and the general advancement in literacy and standard of living.

Work by various researchers (4, 17, 18, 20, 26, 30, 27, 38, 51, 58, 59, 63, 65, 66, 68, 69, 70, 72, 74, 78) has identified the potential of hardwood pulps for use in fiber products. Consequently, at the present time, hardwood pulps are being used more and more to supplement the softwood raw material resource. Even in North America, small percentages of hardwoods are being contemplated for use in newsprint manufacture (46).

The present study was carried out with the limited objective of investigating the properties of *Gmelina arborea* Roxb., a hardwood species grown extensively in Nigeria, and considering future potential of this material for use in the manufacture of newsprint. Since the main component of newsprint is some form of mechanical pulp, the major part of the study was concerned with assessing the potential of Gmelina for this type of pulp. Laboratory work has been carried out to determine the properties of open discharge refiner pulp from Gmelina and these have been compared to those of mechanical pulps used for the manufacture of newsprint in North America. In view of the poor mechanical properties of this type of pulp, three possible approaches to upgrading the strength properties have been evaluated. These have included presteaming of the chips prior to refining without chemical treatment as well as presteaming with two different types of chemical pretreatments. In order to complete the picture, a brief evaluation was also carried out to assess the potential of the species as a raw material for kraft pulp.

CHAPTER II

LITERATURE SURVEY

General Introduction

Gmelina, a member of the Angiospermous family, Verbenaceae, is indigenous to Tropical Asia and Australia (48). It is known by the following vernacular names - Gumhar, Sewan, Gomari, Shivan, Shivani, Gumadi, Yemani, and in exotic plantations as Yemane or Gmelina (57).

Gmelina has been introduced to Africa and Central and South America (6) and, in these places, has been put to a wide range of uses: in construction work, general carpentry, packaging and in the cheaper grades of furniture. It peels well and has been found to be suitable for use as core stock in plywood manufacture (6, 16), for match boxes and splints (6), and for construction plywood (16). Chittenden et al. (26) considered Gmelina to be an extremely promising species for pulp production in Nigeria and other tropical countries where suitable growing conditions for the species exist.

Silviculture, Plantation Establishment and Growth

The silviculture of Gmelina has been discussed in a number of different publications (10, 12, 57). Gmelina is easily established in plantations because of its adaptability to a wide range of soil and climatic conditions. It fruits regularly and plentifully and the seeds have a high germinative power, which has been shown by Lamb (57) to decrease with the length of storage period. The cost of establishment in plantations is relatively low and, as estimated by FAO (8), amounted to \$82 to \$99 US dollars per acre in Nigeria, in 1968.

The rate of growth is initially fast, but decreases after the first 7 years (57, 69). Palmer (69) estimated that, given good growing conditions and a rotation of 7 to 8 years, the plantation area required to sustain a 300 t/day (100,000 t/a) kraft pulp mill would be 15,000 ha. Although a species rate of growth is a function of a multiplicity of factors, Gmelina is generally able to produce pulpwood in 6 to 10 years (8, 69). According to Obiaga and Wayman (65), under favourable conditions, Gmelina could produce a crop of timber size suitable for pulpwood in 3 to 4 years after planting. They based this deduction on the Nigerian experience with the species.

As reported by Palmer (69), the growth of Gmelina in Nigeria is 84 m^3/ha (1,200 ft^3/ac) on poor sandy soils after 12 years growth, 210 m^3/ha (3,000 ft^3/ac) on good clay or laterite soils after 12 years growth, and 252 m^3/ha (3,600 ft^3/ac) on the most favorable savanna sites after 10 years growth. A maximum value of 252 m^3/ha has been recorded for the Rain Forest Zone after 8 years growth. Chittenden et al. (26) pointed out that these values correspond to a mean annual increment of 7 to 31.5 m^3/ha/a, for high forest areas. Yeom and Sandrasegaran (92) summarized the Malayan experience with Gmelina by indicating that the mean yield from a plot planted at a spacing of 10 x 10 ft (approx. 3 x 3 meters) is of the order of 259 m^3/ha (3,700 ft^3/ac) between the ages of 7 to 9 years. These figures, however, represent ideal growth conditions, and it has been pointed out (12) that unless careful attention is paid to clean cultivation of young stands, the growth and yield of the species are bound to be poor.

The principal enemies of Gmelina include parasites, insect pests, fungal diseases and frost, fire and hurricane damage. Under any one or more of these conditions, both the growth and yield of the species will suffer.

Gmelina coppices well and its growth after the first clear-felling and subsequent second, third and even fourth rotation on the original stump has shown no reduction in yield. As indicated by FAO (8), a Gmelina plantation may require replanting only once every 50 years.

Wood and Fiber Properties

Gmelina wood is yellowish-gray or pinkish-white, changing to brownish-yellow with age. As shown clearly in Figure 1, it is diffuse-pored, firm and of uniform density despite the species fast growth rate. As reported (7, 93) it has a density of 497 kg/m^3 (31 lb/ft^3) at 12% moisture content, and 625 kg/m^3 (39 lb/ft^3) at 50% moisture content.

Palmer (69) reported a density range of 380 to 420 kg/m^3 (24 to 26 lb/ft^3). As pointed out by Lamb (57), and others (6), the density of Gmelina wood is comparable to that of Baltic redwood (*Pinus silvestris*).

The gross wood and fiber morphological characteristics of Gmelina have been discussed by various researchers (2, 7, 10, 30, 44, 67, 69, 70, 84). In Table II, data on Gmelina fiber characteristics are given. Chittenden et al. (26), pointed out that the fiber characteristics of Gmelina are comparable to those of other hardwoods, particularly with aspen (*Populus tremuloides*), birch (*Betula alba*) and various species of Eucalyptus.

As is common with hardwoods, Gmelina has only one kind of fiber in the growth zone. Softwoods generally contain two types - the flexible earlywood (EW) tracheids, with thin cell walls, and the stiffer latewood (LW) tracheids, with thicker fiber walls. The relative amounts of these two types of fiber components strongly affect the yield and quality of pulps. Thus a higher proportion of LW tracheids relative to the EW tracheids portion results in a higher yield of pulp per unit volume of wood. Furthermore, the proportions of LW and EW affect pulp quality through the difference in their cell-wall thickness. A high proportion of EW tracheids results in a better fiber conformability during sheet formation. Fiber conformability results in larger fiber to fiber contact areas, thus enhancing interfiber bonding. Consequently, it has a positive effect on the characteristics of a pulp. On the other hand, pulps with higher LW tracheid proportions are usually hard and yield bulky papers because LW fibers do not conform readily. Nevertheless, the fiber characteristics of Gmelina, as given in Table II, enhance fiber conformability and thus also lead to the formation of sheets of good density.

Previous Pulping Studies

A limited number of pulping studies have been carried out on Gmelina and almost all have been concerned with the potential of the species for use in the manufacture of chemical or semichemical pulps. A detailed review of these studies will, therefore, not be attempted, but rather their main findings will be summarized.

In 1961, Guha and Saxena (37) carried out sulfate pulping studies of Gmelina. Their studies showed Gmelina sulfate pulp to be suitable for the manufacture of writing and wrapping papers. They also carried out a chemical analysis of Gmelina wood and showed it to have a high cellulose content, comparing favorably with other materials generally used for papermaking.

Chittenden et al. (26) reported the results of sulfate and neutral sulfite semichemical (NSSC) pulping trials of Gmelina and showed that the unbleached sulfate pulp could be used in the production of lower grades of wrapping papers.

They also showed the bleached products to be suitable for a wide range of writing and printing papers, while the NSSC pulp would be suitable, in the unbleached condition, for the manufacture of paperboard for cartons and board manufacture. They considered that a rather higher quality semichemical pulp should find application for the manufacture of lower and intermediate grades of book and magazine papers.

Peh (72) obtained good yields of unbleached and bleached sulfate pulps of Gmelina. His study showed that the physical strength properties of bleached and unbleached sulfate pulps from Gmelina were better than those of the Australian commercial Eucalypt sulfate pulp. He carried out his study on Gmelina grown in Malaya.

Obiaga and Wayman (65), studied the kinetics of delignification of Gmelina from Nigeria in kraft and poly-sulfide pulping. They demonstrated that over a Kappa number range of 25 to 34, polysulfide digestions of Gmelina resulted in pulp yields of 55 to 64%. They found these values to be about 10% higher than the yields of kraft pulps in the same Kappa number range.

Ballon et al. (17) indicated that unbleached yields of the order of 57 to 58% could be achieved from Gmelina by the sulfate pulping process. Their results differ markedly from those reported in most literature and that obtained in the present study, about 50%, but is similar to that reported by Palmer (69), for Philippine trials digested for a short time at maximum temperature. Ballon et al. did not mention details of the cooking condition, but it does appear that the chips were not fully cooked. If, indeed, the chips were undercooked, then the low bleaching chemical requirement they reported appears to be inconsistent. Nevertheless, their work showed that the bleached kraft pulp of Gmelina may serve in the production of good quality bond and writing papers. They cited an unpublished work by Estudillo and associates, on Philippine-grown material, which showed that in the sulfate pulping of Gmelina, pulp yield increased from 52.7 to 60.4% with an increase in sulfidity up to 45%. This seems consistent with the work of Obiaga and Wayman (65), although the conditions of the cook were not indicated. The pulps also showed approximately the same degree of bleachability with almost identical permanganate numbers at 11 ± 0.5.

Estudillo et al. (30) studied the effects of sulfidity and length of cooking time on pulp yield, bleachability and mechanical properties of Gmelina grown in the Phillipines. They established the optimum pulping conditions to be at 25.5% sulfidity and an active alkali of 15.6%, using a liquor to wood ratio of 4:1 and a 30 to 90 minute cooking schedule at a maximum temperature of 338^{O}F (170^{O}C).

Palmer (69) reported pulping trials of Gmelina obtained from seven different countries. The following were the major findings described in his report:

1. Pulping trials by the sulfate process showed that digestion with about 15% active alkali at 338°F (170°C) resulted in an unbleached pulp of 50% yield. The pulp had good strength characteristics and could be bleached to a high degree of brightness adopting four different bleaching sequences: CEHH, HEH, CEH and CEHD. The pulp was found to be comparable or superior to hardwood pulps such as those of Eucalyptus, birch and poplar, and to be useful for writing, printing, bond, onionskin and wrapping papers.

2. In trials by the NSSC process, between 66 and 76% of unbleached pulp was obtained with satisfactory strengths for this type of pulp. The pulp could be fully bleached only by using a high application of chlorine, and the strength and brightness characteristics of the fully bleached NSSC pulp were comparable to those of bleached sulfate pulp. With lower application levels of chlorine, a useful semi-bleached pulp was obtained.

3. In general, over a wide range of drainage characteristics (600 to 200 Canadian standard freeness (Csf)), all properties that depend mainly on the bonding of fibers (tensile, bursting and folding strengths) increase with beating, but the tearing strength remains fairly constant. The Malayan trial differed and showed a marked increase in tearing strength with increased beating. This increase in tearing strength with increased beating reported for the Malayan trial, however, appears unrealistic.

4. In sulfite digestions, rather severe conditions were required for pulping and the pulp was inferior to sulfate pulps in strength characteristics and, in the case of bleached pulp, in brightness.

5. Cold soda semichemical pulps were obtained in yields of about 80%. The pulps were bulkier and weaker than sulfate pulps and also more difficult to bleach to a lower brightness.

Palmer and Gibbs (70), in 1974, found that Gmelina sulfate pulps could be bleached to a good brightness following a simple four-stage bleaching sequence and demonstrated that the bleached sulfate pulp gave denser sheets than those of hardwoods from Southern United States of America and Eucalypts from Australia. They also showed the yield of Gmelina sulfate pulps to be comparable to those of hardwoods from the Southern United States of America, pulped under similar conditions.

A recent FAO study (10) showed that in the sulfate pulping of Gmelina, the consumption of active alkali depended to some extent on species provenances, whereas NSSC pulping was not affected by species provenance or place of origin.

Sosanwo (83) carried out kraft and sulfate-oxygen (two-stage) digestions of Gmelina chips. He found that unbleached Gmelina kraft pulp compared favorably in physical properties to unbleached birch kraft pulp and that the bleaching of the sulfate pulp was not associated with a loss of pulp physical strength, thus confirming an earlier observation by Chittenden et al. (26). He also showed Gmelina kraft and sulfate-oxygen pulps to have comparable properties.

The single mechanical pulping study on Gmelina reported in the literature was that carried out by Orgill (68). In this study it was shown that impregnating Gmelina chips with a mixture of sodium hydroxide (NaOH) and sodium sulfite (Na_2SO_3) prior to thermomechanical pulping (TMP) reduced power consumption, lowered shive content and improved the strength properties of the pulp. The study also suggested that Gmelina thermomechanical pulp would find use in the manufacture of diapers and other disposable products where the main requirement of the pulp is its ability to absorb liquid under pressure. Orgill did not consider the potential of the species for use in newsprint manufacture.

Mechanical Pulping

The term, mechanical pulp, is a generic one and refers to those pulps produced by the direct attrition of wood by mechanical means. Thus conventional stone groundwood (SGW) pulp, chemigroundwood pulp and chip refiner mechanical pulps all fall in this category. Mechanical pulping processes are characterized by extremely high yield (above 90%, based on wood) (89), since the lignin binder, which is removed in the case of chemical pulping, remains as an integral part of the fiber in mechanical pulps. Mechanical pulp is the main component of the newsprint furnish and until fairly recently, newsprint was produced from a mixture of 20 to 30 percent chemical pulp and 80 to 70 percent mechanical pulp. The advent of higher strength mechanical or pseudomechanical pulps in the last few years has offered some potential for reducing the chemical pulp content of newsprint furnish and in one or two cases, it has been possible to eliminate, completely, the chemical pulp component from newsprint furnish.

The basic principles involved in the manufacture of these mechanical pulps are simple and, essentially, involve the direct attrition of wood in a grinding process (SGW), or in a refining process (RMP or TMP), with or without the addition of relatively small amounts of chemicals. These various processes for the production of mechanical pulp are briefly outlined below.

1. Stone Groundwood (SGW) Process

The SGW process involves the attrition of logs of wood by pressing them against the abrasive surface of a rotating grindstone in the presence of water. By this means, the wood is reduced to pulp. The water cools and lubricates the grinding surface and also conveys the pulp into the pit. The SGW process is one of random attrition and, as a result, is difficult to bring under technical control. Consequently, groundwood pulps are subject to a wide range of variation in physical properties, one of the main contributing factors being the gradual wearing and consequent change in shape of the stone surface characteristics. Furthermore, a large number of grinders are required to supply the mechanical pulp requirements of modern newsprint machines. Thus the properties of the pulp fed to the machine depend on the properties of the pulp produced at each individual grindstone.

The SGW process causes extensive fiber damage and, as a consequence, the resulting pulps have relatively poor strengths. Nevertheless, its high yield of pulp of good bulk, high opacity and good printing properties, makes it highly desirable for newsprint.

The chemigroundwood process essentially involves a treatment of the wood raw material, in grinder lengths, with chemicals prior to grinding. To ensure adequate liquor penetration, the chemical treatment is usually carried out in large cooking vessels at elevated temperature and pressure. A complete liquor penetration, however, does not seem to be tenable with material in grinder lengths, but in general, the extent of penetration reflects species anatomical differences. Nevertheless, the process entails a sizeable capital investment and this is probably one of the main reasons for its limited acceptance.

2. Chip Refiner Mechanical Pulping

a) Chip Refiner Mechanical Pulp (RMP)

Compared to the SGW process, chip refiner mechanical pulping promotes the preservation of fiber length, one of the two factors considered to be essential for the development of a strong pulp. It has, however, been pointed out by Peterson and Nelson (74), and Jackson (46), that the RMP process does not do much to enhance the bonding characteristics of a pulp. Consequently, those physical properties of paper which depend solely on the bonding potential of the fibers and thus on the hydrodynamic surface area of the pulp as it emerges from the mechanical pulping process, are not likely to be significantly improved beyond the level obtained with SGW pulps.

A more detailed information on chip refiner mechanical pulp is beyond the scope of this thesis, but has been published elsewhere by Keays and Leask (50).

b) Thermomechanical Process (TMP)

Although TMP has been known for a long time, its application had been limited to the manufacture of board, flooring and roofing felts. It is only during the last five years that TMP has been employed extensively in the manufacture of newsprint grades (19). The last two International Mechanical Pulping Conferences (IMPC) (49) highlighted the importance of TMP to the pulp and paper industry. TMP has brought about a significant improvement in the properties of refiner mechanical pulps.

Although, in principle, the TMP process is similar to open discharge refining, it differs from it in two important aspects. In contrast to conventional chip refining, the chips for TMP are preheated in high temperature steam in the range 250 to 260^{o}F (121 to 130^{o}C) (19, 46, 47) for a period of 2 to 3 minutes. Furthermore, the first refining stage of the operation is also carried out at elevated pressure of about 30 psig thus ensuring high temperature in the refining zone, and the elimination of problems associated with steam generation in the refiner. Refining generally proceeds in two stages, the pressure in the primary stage being above atmospheric in order to maintain the pulp temperature in the range 240 to 250^{o}F (115 to 121^{o}C). The second stage of the process is carried out at atmospheric pressure as in the case of RMP. As reported (5), three-stage refining is carried out using one of the two C-E Bauer TMP systems at Blandin, and also at the Bowater Carolina mill in Catawba.

The TMP process preserves fiber length and also enhances the development of good bonding potential. Since most of the conventional physical properties of mechanical pulps can be ascribed to those parameters, the physical properties of thermomechanical pulps are generally better than those of open discharge refiner pulps and significantly superior to those exhibited by stone groundwood pulps.

c) Significance of Chip Refiner Mechanical Pulping

Both the RMP and TMP processes permit the manufacture of good quality pulp from chipped forest and sawmill residue materials and thereby bring about a considerable extension in forest resource utilization. This is particularly significant in areas where there is serious competition for pulpwood, or in the Pacific Northwest coast of North America, where logging and sawmill operations generate large volumes of residue materials. The use of residue materials for pulping has become phenomenal in recent times and the trend is steadily rising. Figure 2 shows the trend in the use of residue material for pulping in British Columbia and Canada in general (24).

Apart from the extension of the raw material base, refiner mechanical pulping processes offer the opportunity for incorporating a more effective chemical treatment than is possible with the chemigroundwood process. As discussed by Keays and Leask (50), a number of chemicals, including sodium hydroxide (NaOH), sodium bisulfite ($NaHSO_3$) and sodium sulfite (Na_2SO_3) have been used on hardwoods with beneficial effects. Sodium borohydride ($NaHB_4$) may also be used (36, 61, 75), but is extremely expensive.

Refiner mechanical pulps have generally improved strength properties over stone groundwood and their use permits a reduction in the expensive chemical pulp component in paper products. As quoted by Keays and Leask (50), successful trials have been made on the production of newsprint from 100% open discharge refiner groundwood. The newsprint produced was, however, bulky and consequently lacking in bonding potential and, therefore, not ideally adaptable to currently used printing methods. Keays (49) cited the production of TMP in the Hallsta mill in Sweden where it was found that when TMP replaced 75% of the stone groundwood in the manufacture of 48.8 g/m^2 (30 lb/3,000 ft^2) basis weight newsprint at 840 meters (2,756 ft) per minute machine speed, the chemical pulp component could be reduced from 22 to 12%. The use of 100% TMP has been speculated upon (20, 60) and several mills in North America and Scandinavia have run 100% TMP newsprint for short periods of time (46). This single furnish not only reduces production costs, but also decreases environmental problems associated with the manufacture of chemical pulp.

Other significant considerations in favor of refiner mechanical pulping processes include, among others, their relatively low labor content and ease of control. Better control results in the production of pulps with less variation, which, in turn, relates to more stable paper machine operation. Further consideration of the significance of the refiner mechanical pulping processes is beyond the scope of the present study.

Chipping

For greater operational efficiency during pulping, it is essential to reduce pulpwood to chips, prior to fiberizing. An overall summary of the effect of chip specifications in pulp processing is given in Table III, while in Figure 3, a diagramatic representation of a typical chip is shown.

Liquor penetration, in the case of chemical pulping, and water penetration, in the case of mechanical pulping, are related to the total surface area of the starting material, and is generally better the thinner the chip. The incidence of debris or reject materials increases with chip thickness, the situation being more critical in the case of hardwoods than for softwoods, because of penetration problems. Chip length is important from the packing density point of view during the charging of the digester, while corrugations and cracks relate to effective chip thickness and also enhance liquor and water penetration.

Although conventional chippersproduce chips of fairly uniform size, ranging from 1.6 to 1.9 cm (0.6 to 0.8 in) long and 0.3 cm (0.1 in) thick (61), chips may generally be classified, according to size, as over-large, over-thick, accepts, pin chips, and fines in a screening operation. Over-large chips are generally re-chipped and over-thick chips passed through compression rolls to cause them to crack, while pin chips and fines are used as fuel. In present times, however, most mills obtain part or all of their chip supply from outside sources and chip quality is not necessarily under their control.

Chip Pretreatments

The primary objective of pretreatment of chips prior to refining or mechanical fiberizing is to achieve a softening of the lignin or interfiber bonding material, thereby facilitating fiber separation and the subsequent development of pulp. This may generally be achieved through steam or chemical pretreatment, or a combination of both. It has been shown by Rydholm (79) that adequate chip pretreatment has beneficial effects on fiber length preservation, as well as on the energy requirement for fiberizing the material. Chemical pretreatments also affect the characteristics of the resulting pulps in the positive direction.

1. Pretreatment by Steaming

The temperature dependence of mechanical properties of wood has been discussed at length by Rydholm (79). In this book, it was pointed out that wetter wood shows a less marked temperature dependence while the reverse condition exists for the swelling and residual elasticity properties of wood. The explanation for the wood mechanical strength-temperature relation may be based on the softening range of lignin which, as quoted by Rydholm (79) and Atack (15), occurs in the range 329 to 347°F (165 to 175°C). It is necessary to point out at this juncture that the presence of water may necessarily also depress or broaden the softening interval of lignin.

The softening effect of water on wood at room temperature is well known and illustrated by the difference in mechanical strength test values on small clear specimens of wood. As indicated by Iloabachie (45) working on Terminalia ivorensis (Idigbo), with the exception of impact bending resistance, all other strength properties of wood decrease with an increase in moisture content in the zero to fiber saturation point (fsp) range. This is possibly due to the splitting of hydrogen bonds within the wood and the subsequent swelling of the carbohydrate portions of the wood.

Chemically, water does not seem to have a significant effect on wood at normal room temperature. At presteaming temperatures, however, there may occur splitting of acetyl groups of hemi-celluloses at the glycosidic bonds of carbohydrates; the much-debated lignin-carbohydrate bonds which are probably also glycosidic or ether bonds (61); and the intra-lignin bonds which are mainly benzyl-alkyl ether bonds (54, 79). The incidence of these results in a decrease in pH and consequently a rapid removal of some carbohydrate material and lignin by mild acid hydrolysis (42, 54, 61, 79).

As pointed out by Rydholm (79), acid hydrolysis is pH-dependent and its rate may be appreciable even at temperatures below $212^{o}F$ ($100^{o}C$), if pH is significantly low. This was confirmed by Kratzl and Paszner (54), who showed that a continuous degradation of the lignin macromolecule occurs at

212°F (100°C). They based their findings on the fact that monomeric building units such as coniferyl aldehyde, vanillin, guaiacol, the β-ether and other minor products were isolated from wood at a temperature of 212°F (100°C).

Cellulose tends to resist acid hydrolysis better than the hemicelluloses (61). This is due primarily to the super-molecular structure of cellulose because of which cellulose is not readily accessible even to polar solvents despite its polarity. However, the swelling of the carbohydrate fraction of wood following the formation of addition compounds of cellulose tend to "open up" the structure, thereby enhancing its availability to polar reagents. Acid hydrolysis, nevertheless, causes a degradadation of the wood substance and thus adversely affects the yield of pulp. The application of sodium borohydride ($NaHB_4$) for the purpose of controlling thermal degradation during the treatment of wood chips has been discussed by Pietro (75). The same result may also be achieved if chips are impregnated with a weak alkaline solution prior to presteaming. It has also been shown by Hoglund and Bodin (42) that application of sodium sulfite (Na_2SO_3) at concentrations up to 18% based on bone dry wood weight prevents dissolution of woody material. In the process, the Na_2SO_3 acts as a buffering agent against autocatalytic action of organic acids resulting from the splitting of acetyls and uronic acids from wood.

The ultimate effect of presteaming pretreatment is to reduce fiber cleavage and thus preserve fiber length, and to cause rupture, preferentially on the outer parts of the fiber wall. A compromise temperature is, however, necessary as too high a softening temperature may cause fiber separation to take place in the lignin-rich middle lamella (ML) thereby reducing the bonding potential of the fibers. On the other hand, lower softening temperatures may cause the fibers to separate at the S_1 layer (15, 34, 41, 60) thereby compromising the preservation of fiber length, while, as pointed out by Hoglund et al. (41), enhancing fiber bonding potential. A presteaming temperature of 250 to 260°F (121 to 127°C) is generally considered adequate for optimum strength development.

As demonstrated by Giertz (35), when softened at the high temperature prevailing in the refining process, the primary wall is rolled back along the fiber as a sleeve and simultaneously the helix of the S_1 layer cracks and fibrils and lamellae are peeled off. This occurrence results in increased fiber flexibility, which has been shown by Forgacs (31) to be an important feature for strong mechanical pulps. This is so because the resulting ribbons and fibrils have a high bonding potential.

Presteaming pretreatment generally also results in a darkening of the pulp. However, as indicated by Keays and Leask (50), and Bystedt and Vardheim (23), this brightening loss may be controlled by suitably balancing time and pressure during the presteaming operation, or, as quoted by Atack (15) and Leask (60), by quickly reducing the temperature of the pulp as it emerges from the refiner. Alternatively, incorporating a mild treatment with a brightening agent at some stage of the refining process will also achieve a similar result.

2. Chemical Pretreatment

Various chemicals are known to achieve the desired softening of the inter-fiber bonding material and thereby bring about a more efficient fiber separation with a minimum requirement of energy. Chemicals are able to achieve softening of inter-fiber material either by directly causing it to solubilize or by their differential swelling action on the wood substance. The pulps from chemically pretreated softwood chips have been shown by Hoglund and Bodin (42) to have comparable mechanical strength properties to those of chemical pulps.

The best results in terms of physical strength properties seem to be those obtained by treatments with alkaline hydroxides (41, 49, 86) and the improvement in strength has been shown by Beecher et al. (20) to increase with alkali concentration. This is mainly because alkali hydroxides act as swelling agents for most forms of cellulose, and as solvents for modified and degraded forms of cellulose, hemicelluloses and lignins.

Treatment with an aqueous solution of sodium hydroxide (NaOH) has been shown by Kruger et al. (55) and Rydholm (79) to have a cooking action on wood and thus results in a yield of between 85 to 94% on wood. Yield loss following caustic pretreatment may also be explained by the fact that alkaline hydrolysis of monoxidized cellulose may result in the splitting off of one glucose unit at a time in the form of saccharinic acid (peeling), or in a random hydrolytic cleavage of the acetyl linkage in cellulose (61). The former condition is favored at temperatures over 158^{O}F (70^{O}C), while the latter is favored at temperatures above 302^{O}F (150^{O}C), such as is encountered in the sulfate pulping process. Yield loss due to degradation of carbohydrate and lignin fractions by acid hydrolysis at elevated temperatures has been discussed earlier under the effect of presteaming pretreatment.

Caustic pretreatment is generally accompanied by a rapid swelling of the wood. The swelling is, however, limited to the carbohydrate fraction as lignin tends to restrict it. This swelling differential results in the build-up of considerable stresses within the fiber structure, and following the kneading action of the refining process, the more lignified outer portions of the fiber, already under tension, peel off. This amounts to increased fiber flexibility and also exposes the more hydrophylic carbohydrate parts which have been shown by Forgacs (31), Giertz (35) and Rydholm (79) to have good bonding potential.

In a similar manner, as noted for the presteaming treatment, alkali pretreatment usually also results in pulp discoloration ranging from pale yellow to dark brown. The resulting pulps consequently need to be brightened. A satisfactory brightness may be achieved with a single stage application of sodium peroxide (Na_2O_2), calcium hypochlorite ($Ca(OCl)_2$), or sodium hypochlorite (NaOCl); or by incorporating a brightening agent at some stage in the refining process. This adds to the cost of production, but the gains in pulp quality and the expected savings in energy requirement tend to justify the added cost. The effect of chemical pretreatment on the characteristics of open discharge and pressure refiner pulps are shown in Table IV. From this table, it is evident that chemical treatment, in the case of open discharge refining, resulted in higher density, strength and brightness values, but decreased opacity. In the case of pressurized refining, the results are more difficult to interpret since the pulps are at different freeness levels. It seems, however, that although sodium sulfate would have a modest effect on strength characteristics, it has a negative effect on brightness.

Significance of Fiber Length and Fiber Fractions

The importance of fiber length as a fundamental factor controlling the physical properties of a pulp has long been recognized. More recent, the significance of some other fiber characteristics has been clarified. The ratio between cell lumen width and cell wall thickness, and particularly the ratio of fiber length to fiber width (aspect ratio) have been shown by Dinwoodie (28) to affect pulp and paper properties to a greater extent than fiber length alone. Investigations by the Regie Industrielle de la Cellulose Colonials (RICC), on West African Tropical Woods, cited by Peteri (73), showed that no relation existed between the lengths of fibers and the tensile and bursting strengths, but that relationships existed between these properties and the coefficients of flexibility of the fibers.

As pointed out by Panshin and de Zeeuw (71), and as quoted by Forgacs (31), fiber length is important insofar as a minimum fiber length is required to provide sufficient bonding surface for effective stress distribution over the entire area of the sheet. The same authors also pointed out that paper consisting of short fibers will offer less resistance to pull-out because short fibers have more free fiber ends per unit volume of pulp.

In a review of the effect of fiber length on strength properties, Forgacs (31) showed that the effect of fiber length on properties other than tear was secondary and further indicated that the wet web strength and the tearing strength, burst strength, breaking length, bulk and air resistance of laboratory handsheets made from a wide range of mechanical pulps are almost wholly dependent on structural composition, and could be predicted with considerable accuracy from the

L- and S-factor. This was illustrated by Jackson (46), in Table V. Although a number of techniques can be used to identify a length and shape factor, the Forgacs' Length or L-factor was defined (31) as that fraction of pulp retained on the 48 mesh screen during a Bauer McNett fractionation, while the Forgacs' Shape or S-factor was defined as the hydrodynamic specific surface of the 48/100 mesh fraction.

From Table V, referred to above, it is clear that S-factor plays a more significant role in determining the properties of SGW pulp than in the case of TMP where both L- and S-factor seem to have equal importance. The table also shows that those properties which depend on fiber bonding potential, for example, bulk, bursting strength, and breaking length, primarily depend on S-factor, whereas tear depends primarily on L-factor.

In general, however, a number of factors combine to determine the final characteristics of a pulp. These, as cited by Schutt (81) include fiber dimensions, fiber strength, fiber conformability, surface area, swollen specific volume, bonding area, bonding strength per unit of bonded area, distribution of bonds (sheet formation), and stress distribution.

Pulp Blending

Classical chemical pulping processes give a relatively low yield of pulp; consequently, the pulps are expensive and, therefore, high-grade for some categories of use.

Furthermore, the mechanical properties of chemical pulps may generally exceed those required in some paper products. Mechanical pulping processes have a very significant yield advantage over the chemical pulping processes, but the resulting pulps are relatively weak for most applications. This is particularly true in the case of stone groundwood pulp. Mechanical pulps, however, influence paper surface and printing properties in the positive direction (46, 91). The blending of pulps, therefore, is important, not only in making available a material of a suitable quality for a given paper product, but also from the cost-saving point of view. The blending of Gmelina sulfate pulp with long-fiber sulfate pulps to enhance the mechanical strength properties of the former had been contemplated by Chittenden et al. (26).

Printing papers are expected to exhibit a suitable combination of printability, physical and mechanical strength properties. The blending of chemical and mechanical pulps for the production of newsprint, therefore, demands careful consideration and compromise. This is because, as illustrated by Wahren (91), there is a close relationship between mechanical and optical properties.

Pulp blending may be achieved in a variety of ways, depending upon what conditions apply. Where the aim is to improve the mechanical strength of short-fiber pulps with those of long-fiber pulps, the wood raw material for the different types may be blended prior to pulping (32, 39, 76) or during the beating operation. In some cases, the pulps may be beaten separately and then blended (39). The major component of the newsprint furnish is mechanical pulp, which may be up to 75 to 80%, the remaining 25 to 20% being chemical pulp. The proportions may, however, be varied depending on the properties of the pulps to be blended, and/or anticipated product quality. For example, Paper Industries Corporation of the Philippines produces newsprint from 100% hardwood pulps using 60% refiner mechanical pulp and 40% semi-bleached kraft pulp (25). The application of linear programming methods for a greater efficiency of blending operations was discussed by Foster (32).

CHAPTER III

EXPERIMENTAL WORK

Introduction

The entire range of mechanical pulps obtainable by refining were produced from Gmelina arborea Roxb., by simulation of both open discharge and pressurized refining on laboratory equipment. In the case of simulated pressurized refining, three conditions were used. The first one simulated conventional TMP, and the other two simulated chemically pretreated TMP using NaOH in one case and Na_2SO_3 in the other.

The physical properties of all pulps were evaluated and TAPPI standard handsheets were produced for the evaluation of mechanical and optical properties. Since the specific energy consumption in refining and the drainage characteristics of the pulps were known, this permitted interpolation of the physical property data to a given level of either energy input or drainage characteristic. For comparison, similar data were also obtained on SGW pulps produced on the West Coast of Canada for use in newsprint.

As newsprint in North America generally consists of 25% chemical pulp (kraft or sulfite) and 75% SGW, handsheets were also produced from mixtures of Gmelina mechanical pulp and kraft pulp in the ratios 75:25, 80:20 and 85:15. The properties of the simulated newsprint handsheets were then compared to those of handsheets produced from West Coast SBK and SGW. However, since this situation implies that a mill producing such newsprint would operate with market SBK (which is expensive and would, therefore, affect mill profitability adversely), the alternative would be to consider an integrated mill with its own source of chemical pulp. To cover this possibility, a third set of simulated newsprint sheets were made using Gmelina for both the chemical pulp and the mechanical pulp.

Source of Materials and Materials Storage

The Gmelina wood used for the present study was grown in the former Mid-Western part of Nigeria, currently known as Bendel State of Nigeria. It was the remaining portion of a sample used in an earlier study in Eastern Canada.

Logs of Gmelina measuring about 2.4 meters (8 feet) long and 15 to 25 cm (6 to 10 inches) diameter arrived unbarked in Vancouver in good condition, exhibiting an average moisture content of 95%. The logs were stored at the Western Forest Products Laboratory (WFPL) and their moisture content was maintained by sprinkler irrigation until they were required for chipping.

Chipping and Chip Handling

Prior to chipping, the logs were debarked manually and cut into 0.6 to 0.9 meter (2 to 3 foot) sections, as governed by such features as prominent knots or crookedness.

Each section was then split axially into four pieces with an axe and a club to provide material having suitable dimensions for the preparation of chips.

Chipping was carried out at the British Columbia Institute of Technology (BCIT), using an experimental, 30 in diameter, two-knife, CAE chipper, set to produce 5/8 in long chips. The chips were screened using a chip screen with a vertical gyratory motion. Fines and oversize chips were discarded and accepts stored in polythene bags at $42^{\circ}F$ ($6^{\circ}C$) and 76% relative humidity.

Mechanical Pulping

Hardwoods in general have shorter fiber lengths than softwoods and consequently have been used to a much lesser extent in SGW pulp manufacture. Open discharge refining may be a reasonable alternative for mechanical pulping of Gmelina, but the poor bonding potential of such pulps would limit the extent to which the pulp potential strength might be realized. The best approach, therefore, appears to be TMP, possibly in conjunction with chemical pretreatment.

Although a suitable pilot plant for TMP was not available for the present study, a reasonable approximation of TMP was attempted by presteaming the chips in an experimental digester and then rapidly transferring them to a 12-inch Sprout Waldron laboratory open discharge refiner, which had previously been heated to the boiling point of water.

The experimental work was carried out to cover the entire range of pulps capable of being produced by refining. Thus, both open discharge and pressurized refining were simulated. In the latter case, the effect of chemical pretreatment was also evaluated.

The various treatments carried out are outlined in Table VI. In each case, the equivalent wet weight of 908 g (2 lb) bone dry weight of chips was treated prior to fiberizing. As many refiner passes as were necessary to obtain pulps having similar drainage characteristics to those of SGW pulps used in the manufacture of newsprint, 100 ± 20 ml (Csf) (46) were made in each case. As refining proceeded, refiner passes to be studied in detail were identified and sufficient amounts of pulps representing them were withdrawn for study.

Pulp Evaluation

1. Latency Removal

Latency refers to the presence of latent strength in refiner pulps and arises as a result of a combination of highly kinked and curled fiber exiting from a hot refiner and experiencing temperature shock (46). The shock relates to the temperature difference between the refining zone and the refined stock chest. The kinked fibers tend to set in their curled condition and are unable to achieve the same degree of optical contact or bonding as they would if they were straightened out. Latency may also result if the pulp is dried to any degree, as shown by Skeet and Allan (82). Pulps exhibiting latency only exhibit part of their full potential strength and, therefore, require revival by a dispersion operation at high temperature. As demonstrated by Skeet and Allan (82), a 15 min (1,800 rev) disintegration at $85^{o}F$ ($29^{o}C$) in a standard disintegrator is sufficient to straighten the kinked fibers and thus permit a pulp to exhibit its full potential strength.

The latency removal operation described above was carried out on the Gmelina mechanical pulps at a temperature of $85^{o}F$ ($29^{o}C$) using a standard disintegrator. The operation lasted 15 min.

2. Debris Content

Following hot disintegration, the pulps were screened on a 150-mesh flat screen for measurement of debris or reject content. This property is generally expressed as a percentage and provides an indication of how well pretreatment and refining operations have separated the individual fibers in the wood. The debris contents of the different pulp samples are given in Table VI.

3. Freeness

Freeness, though difficult to define, is a standard pulp test that provides an indication of the drainage characteristics of a suspension of fibers. As pointed out (61), and as quoted by Kwei and Garceau (56), it is mainly a measure of the fines which passed through the 200-mesh screen. The value obtained from the freeness test is, to a first approximation, inversely proportional to the bonding potential of a pulp.

Freeness testing was carried out in accordance with T227os-58 of TAPPI Standards (88), using a freeness tester. The result of the test is termed Canadian standard freeness (Csf), and is generally reported in milliliters (ml). The drainage characteristics of the pulps produced during this investigation were measured by freeness tests and these data are given in Table VI.

4. Yield

With the steady decrease in the availability of pulpwood, yield of pulp from the currently used pulping processes is becoming more and more a critical consideration. Yields from the different pretreatments, using the same dry weight of chips as was refined during the manufacture of mechanical pulps, were determined for chips treated in the way given in Table VI. A known weight of chips from each treatment was pulped separately in a blender and the resulting pulp washed and made into a pad. The pads were dried overnight at 221°F (105°C). Yield was calculated based on bone dry weight of chips pulped. The results of yield determination are also given in Table VI.

5. Fiber Length Classification

The importance of fiber length and fiber length fractions in the determination of pulp characteristics has been discussed in an earlier section. Fiber classification was carried out in accordance with T233os-75 of TAPPI Standards (88), using a Bauer-McNett Classifier. Screen sizes were R14, 14/28, 28/48, 48/100 and 100/200. Average fiber length measurements, for the screen fractions, were carried out by means of a projection microscope, and their moisture-free weights were determined. Weighted fiber length (L), was calculated from the relation (88):

$$L = \frac{w_1\ell_1 + w_2\ell_2 + w_3\ell_3 + w_4\ell_4 + w_5\ell_5}{W}$$

Where ℓ_1, ℓ_2, ℓ_3, ℓ_4 and ℓ_5 are the average lengths in mm of fibers in the respective fractions,

w_1, w_2, w_3 and w_4 are the moisture-free weights of pads from each fraction, and

w_5 is obtained, by difference, from the relation:

W = original moisture-free weight of pulp sample classified.

The results of the Bauer McNett classification of the different types of pulp are given in Table VII, while in Figures 4 through 7 photomicrographs of the pulps are shown.

As noted above, Forgacs has indicated that most of the physical properties of mechanical pulps can be related to the so-called L-and S-factors (31). The determination of

L-factor is based on the Bauer-McNett long fiber, R48, fraction, while S-factor is quoted as the freeness of the Bauer-McNett P48/100 fraction. The values of L-and S-factors determined for the pulps produced during these investigations are given in Table VIII.

Sulfate Pulping

Sulfate or kraft pulping involves the digestion of wood under alkaline conditions. The response of Gmelina to sulfate pulping was evaluated in the laboratory by digesting the equivalent of 4.0 kg (8.8 lb) bone dry weight of chips under the following conditions:

Liquor to wood ratio	4:1
Active alkali in white liquor	14.7%
Active alkali on wood	15.5%
Sulfidity	24.6%
Maximum temperature	$338^{o}F$ ($170^{o}C$)
Time to maximum temperature	90 min
Time at maximum temperature	120 min

These conditions are comparable to those identified by Palmer (69) and Estudillo et al. (30) as being suitable for producing good quality sulfate pulp from Gmelina.

At the termination of the cook, the digester was blown, and the pulp washed and screened on a 150-mesh flat screen. During screening, some foaming was observed. Chittenden et al. (26), earlier made a similar observation and attributed it to the high resin content of the species.

The yield of pulp was 50.05%, and the debris or reject content was as high as 2.65%. The rejects consisted mainly of incompletely pulped knots.

1. Kappa Number of Sulfate Pulp

The Kappa number is an index of the residual lignin in a chemical pulp. It is, therefore, a measure of the degree of delignification achieved in a cook, and thus represents a convenient base for the comparison of such pulp characterization parameters as yield, screenings, brightness and other physical properties. The determination of bleaching chemicals requirement, particularly for the initial chlorination stage, is also based on Kappa number.

As defined in TAPPI Standards (88), the Kappa number is the number of milliliters of O.IN potassium permanganate ($KMnO_4$) solution consumed per gram of moisture-free pulp under conditions specified in the standard. The determination was carried out in accordance with T236m-6 (88), and a value of 16 was obtained for the Gmelina kraft pulp. As indicated by Rydholm (79), for a hardwood sulfate pulp, this value corresponds to 2.08 percent residual lignin.

2. Semi-bleaching of Sulfate Pulp

The sulfate pulp was semi-bleached in a three-stage, CEH (Chlorination, Extraction and Hypochlorite) bleaching sequence. A brightness of 77 to 80 Elrepho reflectance, as determined at 457 nm wavelength on the glazed side of handsheet, was achieved.

a) Chlorination Stage

The choice of chlorine for use in this stage was based on the fact that chlorine and other halogens are capable of rendering lignin soluble through aromatic substitution in aqueous alkali (partially in water) by reaction at room temperature. Chlorine-water at a concentration of 3.58% on the dry weight of pulp was added, with stirring, to the pulp sample. Chlorine concentration on pulp is generally determined by consideration of Kappa, Roe Chlorine or Permanganate numbers or any other equivalent parameters. As cited by Rydholm (79), Roe Chlorine number roughly describes the chlorine demand expressed as a percentage of the pulp. Roe Chlorine number may, however, be influenced by the presence of resin and, on account of this, Kappa number is generally preferred.

Chlorination lasted 50 min during which time the temperature was maintained at 70^{o}F (21^{o}C). The yield of the pulp after chlorination and washing was 96.5%, and the residual liquor had a pH of 2. The low pH is due to the formation of hypochlorous acid (HOCl) during the lignin substitution and excitation reactions (61, 77). The same works showed that HOCl is a strong oxidizing agent for cellulose and may cause its organic oxidation, thereby predisposing it to alkaline degradation, although alkaline hydrolysis does not readily occur under normal conditions of bleaching, but would under more severe conditions such as may exist during chemical pulping processes.

It is important to point out that chlorine is non-specific under the prevailing chlorination conditions and its attack on cellulose, while unlikely, cannot be excluded. When oxidized cellulose is attacked by chlorine, carbonyl and carboxyl groups are formed, as shown in Figure 8. The presence of these groups in glycoside units has been shown by Rydholm (79) and others (77), and are believed to have an important effect on further reactivity of glycosidic linkages. In general, reactivity increases with the introduction of -OH, -CO, and -COOH groups into the anhydroglucose unit. This condition predominates at pH 2 (77) leading to oxidative random depolymerization of individual cellulose chains. Together with loss of fines during pulp washing after chlorination, this accounts for the loss of yield after the chlorination stage.

b) Extraction Stage

Extraction was carried out using sodium hydroxide (NaOH) solution at a concentration of 2.14% on pulp. Stirring was continued throughout the extraction period of 20 min, during which time the temperature was maintained constant at

149°F (65°C). The yield was 97.2%.

The alkali charge for extraction generally depends on the efficiency of the preceding wash in removing HCl and chlorolignin. In commercial operation, Rydholm (79) considered a concentration of 20 to 25 kg (9 to 11 lb) of NaOH per ton of pulp to be a normal charge for both sulfate and sulfite pulps.

c) Hypochlorite Stage

Calcium hypochlorite ($Ca(OCl)_2$) was used at a concentration of 0.25% on pulp. The stage lasted 90 min during which period the temperature was maintained at 95°F (35°C). The pulp was stirred throughout the entire period and the resulting yield was 99.3%.

Handsheet Making and Evaluation

The general principles concerning, and the variables affecting the preparation of laboratory handsheets have been exhaustively discussed by Schutt (80, 81).

Handsheets were prepared during the investigation in accordance with T205os-71 (88), using a Standard British Handsheet machine. In the case of the mechanical pulps, the handsheets were produced after the pulps had been hot disintegrated. The handsheets were produced at a weight of 1.20 g ± 5% (moisture-free basis), corresponding to a basis weight of 60 g/m^2. Sheet conditioning was carried out at 50.0 ± 2.0% RH and 73.4 ± 1.8^{o}F (23.0 ± 1.0^{o}C). All weighing and testing, except wet web strength testing, was carried out in the conditioning room. TAPPI standard procedures were adopted all through.

In the case of each property, ten observations were made. The calculations were based on the formulas given in the Appendix. The results of these tests are given in Tables VI, IX, X, XI, XII and XIII.

CHAPTER IV

RESULTS AND DISCUSSION

Mechanical Pulps from Gmelina

Data generated from the testing of laboratory handsheets, made from the Gmelina mechanical pulps produced are given in Table VI, for the mechanical strength and optical properties. The values obtained for the various physical properties were plotted against their respective drainage characteristics. Because a meaningful comparison of the physical properties of the various treatments can only be made under conditions of equivalent drainage or equivalent energy application, the values at a given level of drainage (90 ml Csf) were determined by interpolation from the experimental data, and are given in Table IX. A freeness of 90 ml Csf represents a reasonable drainage level for North American mechanical pulps intended for use in newsprint manufacture.

Various aspects of the mechanical pulps prepared are discussed below.

Yield

Compared to the yield values of chemical pulps, which are generally in the range 40 to 50%, mechanical pulps exhibit yields in excess of 90%, variations about this level being generally related to wood composition, presence of extractives and pretreatment. The large difference in yield between chemical and mechanical pulps is due to the fact that while chemical pulps are produced by processes involving degradation and solubilization of lignin, in mechanical pulps, lignin remains an integral part of the fiber chemical structure.

In Table VI, the yields following the different chip treatments are given. A yield of 96.8% was obtained for the untreated sample, A, and 95.7% for the presteamed sample, B. The 1% difference in yield for these two cases may be due to the fact that, while in both cases some water solubles and fines were lost, in B an additional loss of wood substance was, possibly, sustained through acid hydrolysis at the presteaming temperatures. The low yield of 89.6% recorded for the caustic-treated sample, C, was due to the cooking action of caustic on wood, and is partly responsible for the relatively high strength values obtained for the caustic-treated sample. Yield was relatively higher for the sulfite treated chips, D, 95.3%, not only because in comparison to caustic, sodium sulfite has only a mild cooking action on wood, but also because at concentrations of Na_2SO_3 up to 18%, it acts as a buffer in the solution, preventing the dissolution of wood substance (42).

Specific Energy Consumption

The manufacture of mechanical pulp by different processes involves expenditures of large amounts of energy. In Table VI the amounts of energy expended in the manufacture of mechanical pulps of Gmelina are given, while in Table IX, specific energy consumption to attain 90 ml Csf is given. It is evident from this table that more energy was required in the case of the chemically pretreated chips, 120 HPD/T for caustic and 113 HPD/T for sulfite, to obtain pulps of 90 ml Csf, than in the cases of untreated open discharge refiner groundwood and steam pretreated refiner groundwood pulps, which required 81 HPD/T and 93 HPD/T, respectively.

Statistical analysis of the results given in Table VI showed that the caustic pretreatment resulted in the best mechanical strength properties. This confirms the relationship observed by Jensen (47), and implies that the same relation between specific energy consumption and mechanical pulps also exists for mechanical pulps made from Gmelina wood. Jensen's observation, however, does not seem to hold for the other treatments tried. For example, the second highest specific energy consumption was noted for the sulfite pretreated sample, D, and yet its mechanical properties, compiled in Table VI, are not significantly different from those of the untreated sample, A, which consumed 40% less energy, and the presteamed sample, B, which consumed 20% less energy.

Specific energy consumption during refining, in general, depends on a number of factors. These include among others, wood species characteristics, type of pretreatment, refiner geometry and feed factors (50). The individual effects of these factors on energy consumption have not been clearly defined and, consequently, the actual relationship between energy consumption and the drainage characteristics of pulp is not clear. Data relating these factors should, therefore, be regarded only from the comparative standpoint and not as absolute values.

Energy consumption is generally higher in laboratory refining than for commercial refining to the same drainage. This is partly because, while it takes only two refiner passes to reduce chips to the desired drainage level in commercial operations, it takes frequently up to six or more refiner passes to attain the same drainage using a laboratory refiner. The reason for this may be partly due to the differences in consistency during refining, and partly to a higher efficiency factor with the commercial operation. Consistencies in the range of 20 to 30% result in a significant reduction in power consumption (50, 79), while as shown (11), at lower consistencies it is more difficult to put load into the refining and the available power is not fully utilized. In the present study, all refining was carried out at consistencies between 9 and 13%, this being the limit of capability of the small laboratory refiner. This implies that more energy than necessary may have been expended to prepare the Gmelina mechanical pulps, and that less may be required under commercial conditions.

Debris Content

The debris content of pulps is generally expressed as that proportion of the material which is retained on a standard screen plate having a slot width of 150 , under standard screening conditions. It generally consists of incompletely separated fibers and fiber bundles, and its particles are thus greater than one fiber diameter in width. Consequently, debris has a detrimental effect on the physical properties of newsprint. It is largely because of its presence in mechanical pulps that a separate debris handling system is necessary as an integral part of mechanical pulping process flow sheet.

From Table VI, the effect of the various types of pretreatments employed on debris content may be identified. It is clear from this table that the presteaming pretreatment caused a significant reduction in debris content over conventional open discharge refining. The table also indicates that chemical treatment caused a further decrease in debris content, indicating a more complete defiberization during the refining.

Mechanical Properties

From data in Table IX, it is evident that all three pretreated pulps exhibit somewhat better mechanical properties than those of the non-treated sample. The table also indicates that the chemically treated pulps exhibit better characteristics than those achieved by presteaming alone. It is assumed that the improved properties depend upon both fiber length preservation and improved bonding characteristics of the pulp fibers. This assumption is confirmed by Figures 4 through 7.

The improved tear strength of all samples over the untreated sample is directly related to the preservation of fiber length, while the improved burst strength is entirely related to improved bonding. The improved breaking length of the two chemically treated pulps is the result of both improved fiber length and improved bonding potential. This reasoning is in line with the interpretation of Forgacs' L- and S-Factors (31).

It is clear from the data in Table IX that the caustic-treated sample shows the greatest gain in strength properties. If maximizing the mechanical strength were the only consideration, it is evident that this type of alkline pretreatment would be the most advantageous to use.

Optical Properties

Compared to the non-pretreated pulp, both the presteamed and caustic pretreated pulps exhibit higher absorption coefficients and, consequently, decreased brightness (Table IX). The sulfite pretreated pulp, on the other hand, exhibits a decreased absorption coefficient, compared to the control, and consequently, improved brightness. While the presteamed pulp exhibits a similar scattering coefficient, both chemically-treated pulps exhibit decreased scattering coefficients, thus clearly identifying that these pulps have improved bonding characteristics over the untreated pulp. This fact is also reflected in the sheet density which was higher for these pulps than for the standard open discharge pulp.

Thus, in terms of brightness, sulfite pretreatment had the most beneficial effect, while the caustic treatment had a strongly detrimental effect. However, in view of the strong effect of caustic treatment on pulp strength properties, it would seem appropriate to use this type of treatment to maximize the mechanical properties and overcome the lower brightness by hydrogen peroxide treatment of the pulp. Alternatively, a combined treatment with caustic and sodium sulfite would aid strength improvement without severe degradation of brightness. Such optimization of chemical pretreatment and subsequent brightening was beyond the scope of this particular study.

Comparison of West Coast Groundwood and Caustic Treated Gmelina Pulp

In Table X, the characteristics of the Gmelina caustic treated pulp at 90 ml Csf are compared to those of West Coast stone groundwood at 84 ml Csf. From the data in this table, it is evident that, in terms of strength properties, mechanical pulps produced by the caustic pretreatment of Gmelina compare favorably with West Coast stone groundwood.

From this table, it is evident that the Gmelina caustic pretreated pulp exhibited higher tear, burst, breaking length and opacity, but lower density and stretch than West Coast SGW. Brightness, however, represents a problem, but, as outlined earlier, this could be overcome by modifying the form of pretreatment to a combination of caustic and sodium sulfite, or by using peroxide brightening prior to papermaking.

Chemical Pulp from Gmelina

The physical and mechanical properties of the semi-bleached kraft (SBK) pulp produced from Gmelina are given in Table XI. From this table, it is clear that the physical strength properties of SBK from Gmelina are significantly lower than those of West Coast SBK generally produced from softwoods, among which are Douglas fir and Western hemlock. Differences in the mechanical properties of these SBK pulps are largely due to the differences in their fiber characteristics, particularly the low fiber length of the Gmelina SBK compared to the West Coast SBK. These may be observed in Figures 9 through 12.

The brightness of Gmelina kraft, as indicated in Table XI, is superior to that of the West Coast counterpart. Brightness would thus be a strong positive feature of Gmelina, particularly if it were to be used in fine paper furnishes.

The Potential of Gmelina Mechanical Pulps for Newsprint

The Gmelina mechanical pulp used for the newsprint trials was that produced by the caustic pretreatment as it gave the best mechanical properties compared to the other pretreatments investigated. An overall summary of the dry strength data relating to the study of these simulated newsprint mixes is given in Table XII and the wet strength data are provided in Table XIII. Figures 13 through 23 are the plots of newsprint handsheet properties over the chemical pulp content.

From these tables and figures the effect of chemical pulp content on the mixed furnish sheet properties can be identified. The relationship between chemical pulp content and newsprint handsheet properties is essentially linear in the chemical pulp range of interest, the brightness and strength characteristics increasing, as expected, with increasing chemical pulp content while the opacity together with scattering and absorption coefficients exhibit a reduction. In general, the data indicate that the strength properties of Gmelina mechanical pulp mixtures compare favorably with those of typical West Coast newsprint mixtures, whereas mixtures containing both mechanical and chemical pulp from Gmelina are lacking in certain aspects.

The low brightness of mixtures containing Gmelina refiner mechanical pulp is a deficiency which would have to be overcome. Although the identification of the manner in which this should be achieved is beyond the scope of this thesis, it is evident that this deficiency can be overcome by approaches which have been suggested elsewhere in the thesis.

CHAPTER V

SUMMARY

Mechanical pulps covering a broad spectrum of pulps capable of being produced by refining were made in the laboratory from Gmelina arborea Roxb., a hardwood. In the case of pressurized refining, the effect of pretreatment by steaming and chemical impregnation were investigated.

In general, those pulps produced by simulated pressurized refining exhibited better mechanical properties than the open discharge refined pulp. Chip pretreatments using, in one case, sodium sulfite (20% on wood) and, in the other case, sodium hydroxide (10% on wood) resulted in further improvements in pulp characteristics. In terms of the physical strength properties the caustic treated pulp compared favorably with typical stone groundwood pulp manufactured on the West Coast of North America for use in newsprint. The caustic treated pulp, however, exhibited high adsorption coefficient and consequently low brightness. While this represents a potential problem in the commercial use of this type of pulp in newsprint, the deficiency is surmountable either by employing hydrogen peroxide brightening treatment in conjunction with the refining operation, or by using a combination of caustic and sodium sulfite pretreatment.

To evaluate the suitability of the Gmelina refiner groundwood for use as the major component of the newsprint furnish, its behavior in admixture with West Coast semi-bleached kraft was investigated. At a given level of chemical pulp equivalent to that used in standard newsprint, the properties of the mixed furnish Gmelina handsheets were found to be comparable to those of West Coast newsprint mixtures. Optimization of the pretreatment and refining process may result in Gmelina pulps suitable for the production of newsprint at lower chemical pulp levels.

The above situation clearly represents the case of a non-integrated mill using market kraft as the chemical pulp component. To cover the case for the integrated mill, a brief study was also carried out to assess the response of Gmelina to kraft pulping and to evaluate the behavior of this pulp in admixture with Gmelina mechanical pulp. As expected, in view of the shorter mean fiber length of Gmelina compared to softwoods in general, Gmelina kraft was significantly weaker, mechanically, than typical North American kraft pulps. Its strength deficiencies were clearly reflected in the mechanical properties of mixed furnish handsheets at normal mixture ratios.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1. A wide variety of refiner mechanical pulps can be produced from *Gmelina arborea* Roxb.
2. Caustic pretreated Gmelina refiner mechanical pulp has comparable mechanical properties to West Coast stone groundwood used in newsprint furnishes, and is, therefore, also suitable for use in newsprint manufacture.
3. The use of caustic pretreated Gmelina refiner groundwood in admixture with softwood semi-bleached kraft in normal newsprint ratios (3:1) resulted in mixed furnish handsheets with properties comparable to handsheets from North American newsprint furnishes.
4. Newsprint furnish handsheets produced from mixtures of Gmelina refiner pulp and Gmelina semi-bleached kraft exhibit mechanical properties which are inferior to those of similar handsheets from North American newsprint mixtures.

Recommendations

1. The strong potential indicating the suitability of chemically pretreated mechanical pulp from *Gmelina arborea* Roxb. for newsprint manufacture should be exploited.
2. The extent of *Gmelina arborea* Roxb. plantation resources in Nigeria, coupled with the rapidly increasing demand

for paper and paperboard, call for development programs which cater to the nation's demand for fiber and fiber products.

3. Indigenous hardwood species should be evaluated for their potential for use as supplementary materials for pulp and paper, and additional plantations should be established to guarantee regular and adequate supply of pulpwood to the mills.

4. Further work should be conducted to optimize the chemical pretreatment for thermomechanical pulp from *Gmelina arborea* Roxb. with regard to mechanical properties, and particular attention should be directed towards brightening technology.

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TABLE I

IMPORT OF PAPER AND PAPERBOARD
FEDERAL REPUBLIC OF NIGERIA

Product Type	1963		1964		1965	
	Kg	$	Kg	$	Kg	$
Newsprint	4,808,079	926,271	4,236,553	979,073	4,717,361	1,076,121
Printing & Writing	8,119,303	2,388,002	6,196,072	2,439,049	9,253,284	3,588,362
Kraft Paper & Board	3,011,853	935,542	1,469,639	566,658	5,170,953	1,507,951
Cigarette Paper	199,581	195,644	263,084	212,394	326,587	207,766
Machine-Made Paper and Board	1,279,130	628,712	1,741,795	725,690	2,340,537	922,771
Fiberboard & Other Building Board	2,404,040	486,312	1,778,082	367,609	2,159,100	498,050
Hand-Made Paper	18,144	11,497	907	804	136,078	36,520
Paper & Paperboard	20,865,249	824,975	6,985,322	2,010,476	6,622,449	883,420
Subtotal	21,926,655	6,396,955	22,671,454	7,301,753	30,817,066	8,722,641
Packing Containers	10,886,217	4,030,720	11,430,528	4,451,821	6,059,994	3,633,504
Filling Containers	444,521	220,548	562,455	253,392	417,305	200,794
Envelopes, Writing Blocks, etc.	961,616	659,851	1,288,202	886,071	1,170,268	781,301
Exercise Books, Stationery, etc.	--	997,105	--	1,046,172	--	1,024,607
Articles of Pulp, Paper & Board	--	2,491,196	--	3,116,403	--	3,517,517
Subtotal		8,402,220		9,753,859		9,157,722
GRAND TOTAL		14,799,175		17,055,612		17,882,363

Source: FAO Rome No. TA2529 (8).

TABLE II

FIBER CHARACTERISTICS OF GMELINA ARBOREA

Statistic	Observation
Fiber length (μm)[1]	1010
Fiber width (μm)[1]	28
Fiber wall thickness (μm)[1]	3
Lumen width (μm)[1]	22
Length-width ratio	36
Runkel ratio[2]	0.27
Flexibility ratio[3]	0.79

1. 1000 microns (μm) = 1 mm.
2. Runkel ratio = $\frac{2W}{L}$

   where W = cell-wall thickness
   L = Lumen diameter.
3. Flexibility ratio = Coefficient of flexibility[4] expressed in percent.
4. Coefficient of flexibility = $\frac{\text{Width of Lumen}}{\text{Width of fiber}} \times 100$

Source: FAO Rome Fo: MISC/75/31 (10).

TABLE III

EFFECT OF CHIP SPECIFICATION IN PULPING PROCESS

Chip Parameter	Kraft	Sulfite	NSSC	Refiner-Mechanical
Length	Not too critical	Critical	Not known	Not known
Preferred Range, mm	15-25	25-35		
Width	Not critical	Not critical	Not critical	Not known
Thickness	Very critical	Not critical	Not known	Not known
Preferred Range, mm	1.5-4 (solid wood)			
Chip Density	Constancy critical		Constancy critical	
Bark Content	Critical for production economy	Very critical	Critical for production economy	Critical
Preferred Range, mm		1%		
Hard Impurities (sand, metal)	Critical for high yield	Critical for dissolving pulp	Very critical for plate life	
Chip Damage	Not critical	Very critical	Not critical	Not known
Moisture Content	Not critical	Not critical	Not critical	Very critical

TABLE IV

EFFECT OF CHEMICAL PRETREATMENT ON THE CHARACTERISTICS
OF OPEN DISCHARGE AND PRESSURE REFINER PULPS MADE FROM SOFTWOODS

Refined by	Open Discharge		Pressure Ref, 280°F	
Pretreatment	None	2% Na_2SO_3 10 min, 250°F pH 6.5	None	2% Na_2SO_3 10 min, 250°F pH 6.5
Csf, ml	121	134	81	116
Density, g/cc	0.36	0.37	0.39	0.42
Tear Factor	78	92	86	82
Burst Factor	13	19.5	24	20
Breaking Length, m	3180	4090	4730	3770
Opacity	97.1	92.6	97.2	96.1
Brightness				
Elrepho	45	57.5	51.3	54.8
1% ZnS_2O_4	58.6	64.1	59.5	58.7
1 hr. Reversion, 105°C	55.4	59.8	56.3	54.6

Source: Personal communication (33).

TABLE V

DEPENDENCE OF PHYSICAL PROPERTIES
OF MECHANICAL PULP ON L AND S FACTORS

Model: $Y_i = {}_aL + {}_bS + {}_c$

Physical Property, Y_i	Linear Regression Equation	
	Stone Groundwood	Thermomechanical Pulp
Freeness, ml	-170.4S + 1.20L + 278	9.2L - 104S - 116
Bulk, cm^3/g	-0.419S + 0.0067L + 3.03	0.043L - 0.65S - 2.23
Burst Index, $kPa.m^2/g$	0.68S + 0.014L - 0.35	0.96S - 0.019L + 0.24
Breaking Length, m	2173.7S + 20.9L - 897	1270S - 53L + 2874
Tear Index, $mN.m^2/g$	0.063L + 0.943S + 1.03	0.14L + 1.93S - 3.6
Wet Web Strength, g/cm	40.8S + 32.8	28S - 0.40L + 45

Source: Personal Communication (46).

TABLE VI

RESULTS OF EVALUATION OF THE PROPERTIES OF THE GMELINA MECHANICAL PULPS

Pretreatment	None			Presteamed, 10 min, 265°F, 24 psig			Presteamed, 10 min, 265°F, 24 psig, 1% NaOH 10% on Wood			Presteamed, 10 min, 265°F, 24 psig, 2% Na_2SO_3 20% on Wood, pH 6.5		
Sample Ident.	A3	A4	A5	B3	B4	B5	C4	C5	C6	D4	D5	D6
Yield, %		96.8			95.7			89.6			95.3	
Specific Energy, HPD/T	64.2	80.1	87.2	71.5	92.0	98.1	98.6	109.2	116.0	94.0	106.2	116.5
Debris, %	1.6	0.4	0.2	0.9	0.4	0.3	0.1	0.1	0.0	0.2	0.2	0.1
Csf, ml	205	94	46	373	89	47	235	153	120	187	116	76
Basis Weight, g/m^2	62.0	62.6	61.4	60.5	62.4	61.0	60.8	62.5	61.5	57.6	61.1	62.1
Density, g/cm^3	0.25	0.28	0.29	0.24	0.29	0.31	0.33	0.35	0.35	0.27	0.29	0.31
Tear Index, $mN.m^2/g$	1.0	1.4	1.5	1.3	1.8	2.1	4.0	3.7	3.7	1.7	1.7	1.6
Burst Index, $kPa.m^2/g$	0.2	0.3	0.4	0.2	0.3	0.4	0.8	1.0	1.0	0.3	0.4	0.5
Breaking Length, km	0.7	1.1	1.4	0.6	1.0	1.1	2.3	2.6	2.7	0.9	1.2	1.4
Stretch, %	0.5	0.6	0.6	0.5	0.6	0.5	0.6	0.7	0.7	0.5	0.5	0.6
TEA Index, mJ/g	20.9	35.7	50.4	12.8	28.2	28.3	32.7	45.3	45.7	24.3	31.6	39.9
Brightness, (Elrepho), %	52.5	53.9	54.5	48.4	49.8	50.5	39.6	40.4	40.7	56.2	56.8	56.5
Opacity, %	97.6	98.5	99.2	95.7	99.6	99.7	97.6	99.3	99.0	94.8	97.2	96.9
Scattering Coeff., cm^2/g	771	900	1066	576	1056	1089	590	773	776	664	787	763
Absorption Coeff., cm^2/g	73.2	78.5	92.1	67.8	131.2	130.3	98.2	126.8	127.2	47.3	58.7	55.0

TABLE VII

RESULTS OF BAUER McNETT CLASSIFICATION
OF THE GMELINA MECHANICAL PULPS

Sample Identification	Parameter	Screen					
		R14	14/28	28/48	48/100	100/200	P200
A_5	Weight, g	0.0066	0.1301	1.2585	2.6572	2.2257	3.7219
	Length, mm	0.943	1.347	0.920	0.748	0.456	0.1
	Weighted Fiber Length (WL)	0.0062238	0.1752447	1.15782	1.9875856	1.0159192	0.37219
B_4 (Presteamed)	Weight, g	0.0084	0.1276	1.3347	2.9225	2.6075	2.9993
	Length, mm	0.943	1.347	0.920	0.748	0.456	0.1
	Weighted Fiber Length (WL)	0.0079212	0.1718772	1.227924	2.18603	1.18902	0.29993
C_6 (Caustic Pretreatment)	Weight, g	0.0001	0.0214	3.3414	2.1641	2.0164	2.4566
	Length, mm	0.943	1.347	0.920	0.748	0.456	0.1
	Weighted Fiber Length (WL)	0.0000943	0.028858	3.074088	1.6187468	0.9194784	0.24566
D_5 (Sulfite Pretreatment)	Weight, g	0.0108	0.1789	3.53172	2.0802	1.7203	2.4781
	Length, mm	0.943	1.347	0.920	0.748	0.456	0.1
	Weighted Fiber Length (WL)	0.0101844	0.2409783	3.249164	1.5559896	0.7844568	0.24781

TABLE VIII

L- AND S-FACTORS OF THE GMELINA MECHANICAL PULPS

Sample Identification	L-Factor	S-Factor ml
A_4 (No Pretreatment)	13.95	705
B_4 (Presteamed)	14.71	737
C_6 (Caustic Pretreatment)	33.63	650
D_5 (Sulfite Pretreatment)	37.21	724

TABLE IX

VALUES OF GMELINA MECHANICAL PULP PROPERTIES
EXTRAPOLATED AT 90 ml Csf

Sample Identification Pretreatment	A None	B Presteamed	C Caustic	D Sulfite
Csf, ml	90	90	90	90
Specific Energy, HPD/T	81	93	120	113
Density, g/cm^3	0.28	0.30	0.36	0.30
Tear Index, $mN.m^2/g$	1.4	1.9	3.6	1.6
Burst Index, $kPa.m^2/g$	0.33	0.35	1.1	0.47
Breaking Length, km	1.2	1.0	2.8	1.3
Stretch, %	0.6	0.6	0.8	0.6
TEA Index, mJ/g	40	28	52	3.7
Brightness (Elrepho), %	54	50	41	57
Opacity, %	98.5	99.4	99.9	97.3
Scattering Coefficient, cm^2/g	960	1038	854	795
Absorption Coefficient, cm^2/g	80	127	142	58

TABLE X

RESULTS OF EVALUATION OF GMELINA (CAUSTIC TREATED) PULP AND WEST COAST STONE GROUNDWOOD

Sample Identification	Gmelina (Caustic Treated)	West Coast SGW
Csf, ml	90	84
Basis Weight, g/m^2	61.6	61.2
Density, g/cm^3	0.36	0.37
Tear Index, $mN.m^2/g$	3.6	3.4
Burst Index, $kPa.m^2/g$	1.1	0.8
Breaking Length, km	2.8	2.5
Stretch, %	0.8	1.4
Brightness (Elrepho), %	41	52.2
Opacity, %	99.9	97.8
Scattering Coefficient, cm^2/g	854	781
Absorption Coefficient, cm^2/g	142	76.9

TABLE XI

RESULTS OF EVALUATION OF WEST COAST AND GMELINA SEMI-BLEACHED KRAFT (SBK) PULPS

Sample Identification	Gmelina SBK	West Coast SBK
Csf, ml	520	684
Basis Weight, g/m^2	59.0	63.2
Density, g/cm^3	0.66	0.58
Tear Index, $mN.m^2/g$	10.6	23.5
Burst Index, $kPa.m^2/g$	2.7	4.6
Breaking Length, km	4.2	5.7
Stretch, %	1.9	2.1
TEA Index, mJ/g	590.8	835.1
Brightness (Elrepho), %	72.5	62.8
Opacity, %	81.0	72.9
Scattering Coefficient, cm^2/g	390	260
Absorption Coefficient, cm^2/g	6.2	4.2

TABLE XII

RESULTS OF EVALUATION OF SIMULATED NEWSPRINT HANDSHEETS

Sample Identification	WC/SBK and Gmelina Mech.			WC/SBK and WC/SGW			G/SBK and Gmelina Mech.		
Proportions (Mech/SBK)	85/15	80/20	75/25	80/20	75/25	70/30	75/25	70/30	60/40
Csf, ml	195	236	254	169	209	237	180	194	233
Basis Weight, g/m^2	62.1	61.4	58.7	60.9	61.4	61.8	62.4	63.8	64.9
Density, g/cm^3	0.37	0.38	0.39	0.40	0.41	0.42	0.39	0.42	0.42
Tear Index, $mN.m^2/g$	7.8	9.3	10.0	7.8	9.1	9.8	4.7	5.1	6.0
Burst Index, $kPa.m^2/g$	1.2	1.3	1.4	1.5	1.7	1.9	1.4	1.4	1.5
Breaking Length, km	2.8	3.2	3.2	3.2	3.4	3.7	3.1	3.0	3.4
Stretch, %	0.7	0.9	0.9	1.9	2.0	2.1	0.9	0.9	1.0
Brightness (Elrepho), %	41.7	42.1	42.3	52.4	53.2	54.3	43.5	43.5	45.2
Opacity, %	96.7	96.0	93.5	96.0	95.6	93.9	96.8	96.8	96.7
Scattering Coefficient, cm^2/g	545	530	454	633	608	583	550	540	550
Absorption Coefficient, cm^2/g	81.0	77.5	68.2	59.6	52.9	45.6	76.7	75.4	69.6

WC/SBK West Coast Semi-Bleached Kraft

WC/SGW West Coast Stone Groundwood

G/SBK Gmelina Semi-Bleached Kraft

TABLE XIII

WET STRENGTH TEST RESULTS
OF THE SIMULATED NEWSPRINT MIXES

Sample Identification		WC/SBK and Gmelina Mech.			G/SBK and Gmelina Mech.		
Level	Property	85/15	80/20	75/25	75/25	70/30	60/40
Low Pressing	Stress, g/cm width	55.5	55.1	57.5	47.6	51.6	54.7
	Strain, %	4.3	6.0	6.0	5.8	6.0	6.3
	Solids, %	28.6	24.1	28.4	28.8	28.1	28.8
High Pressing	Stress, g/cm width	90.2	89.8	85.8	79.9	81.9	83.9
	Strain, %	5.3	5.0	5.1	4.4	5.1	5.2
	Solids, %	38.7	38.9	38.9	38.7	38.6	38.9

WC/SBK West Coast Semi-Bleached Kraft

G/SBK Gmelina Semi-Bleached Kraft

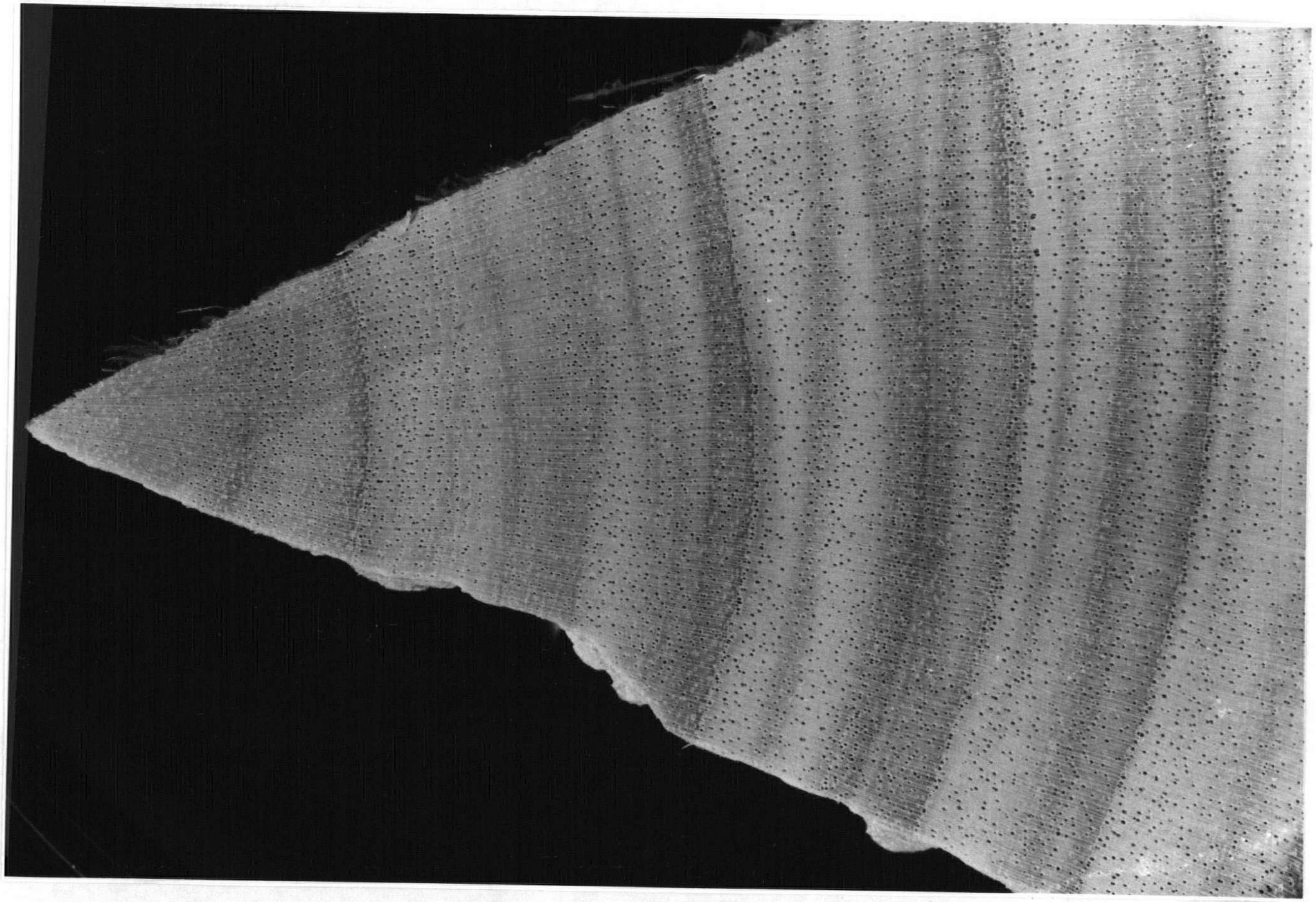

FIGURE 1. Part Cross-Section Stem of <u>Gmelina</u> <u>arborea</u> Roxb. (2.4X)

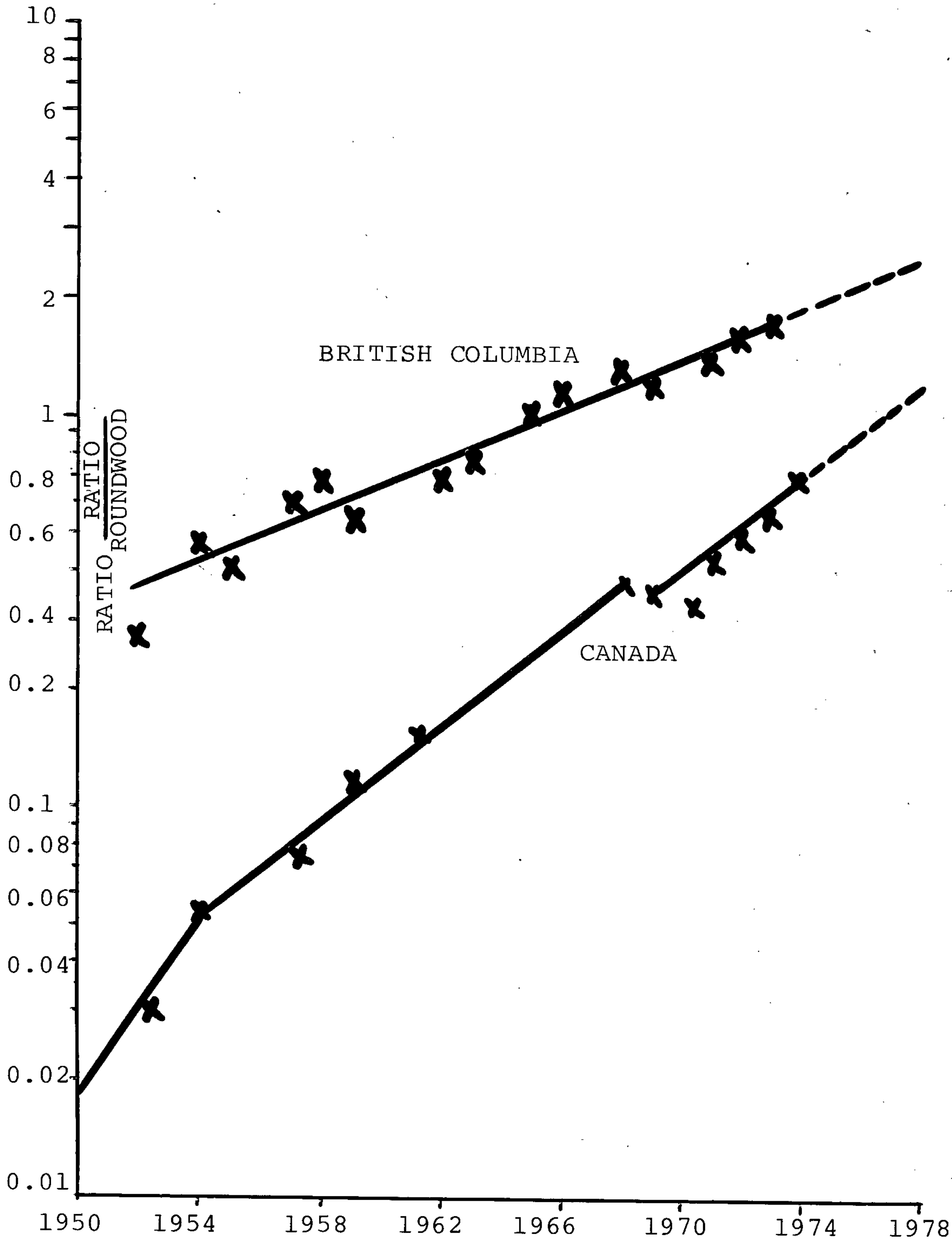

FIGURE 2. Use of Residue Materials for Pulping in British Columbia and Canada

Source: Statistics Canada (24).

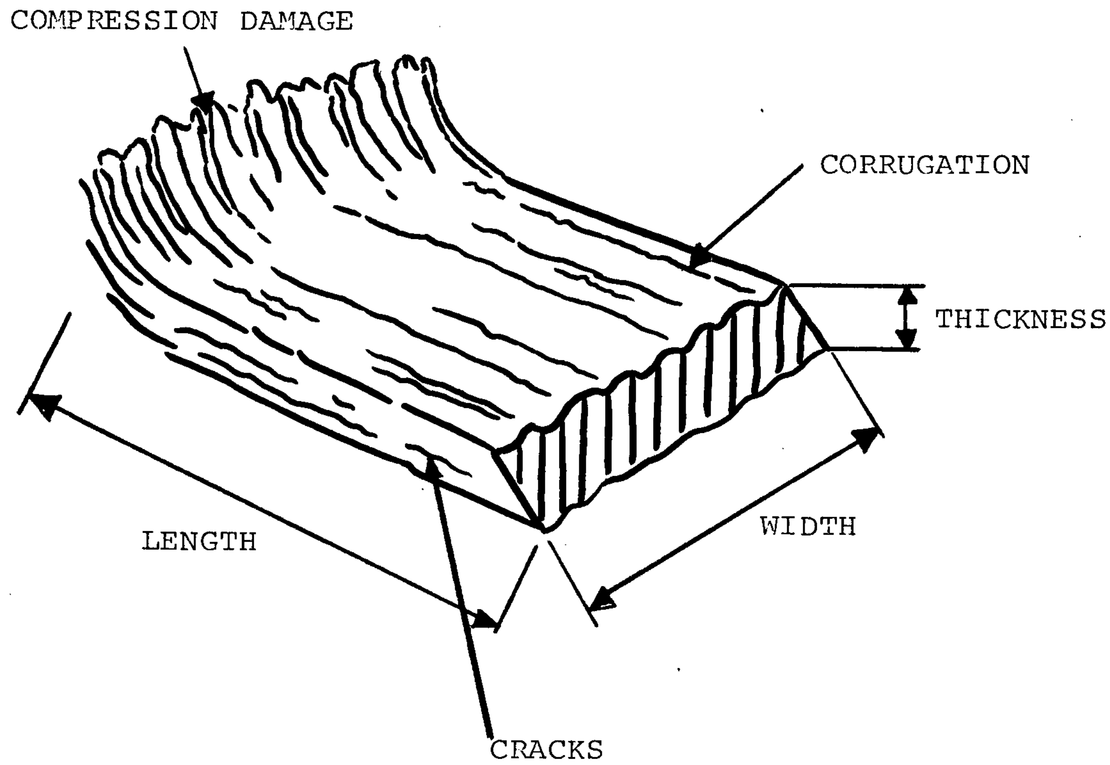

FIGURE 3. Diagramatic Representation of a Typical Chip

FIGURE 4. Photomicrograph Untreated Mechanical Pulp Sample (A) (40X)

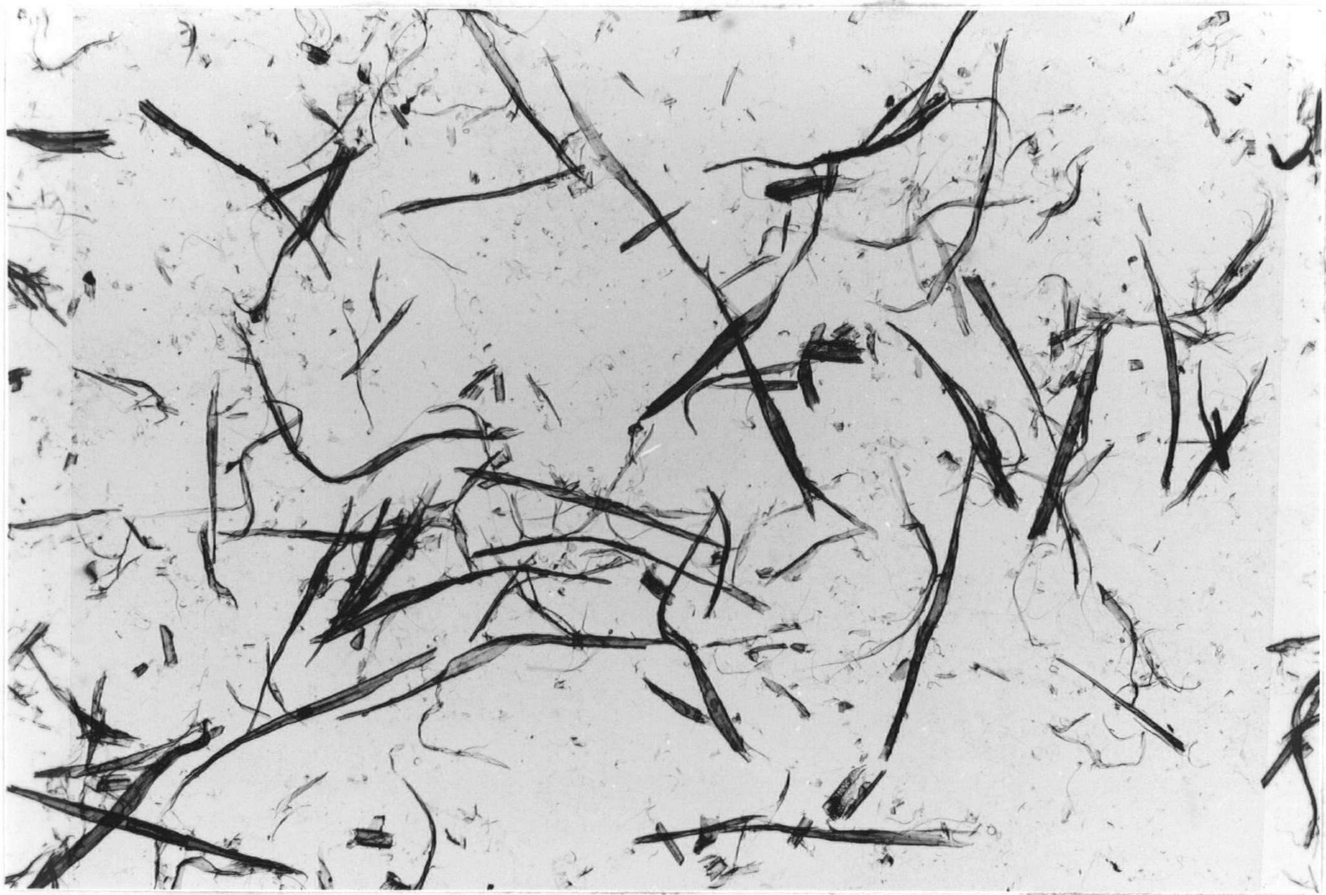

FIGURE 5. Photomicrograph Steam Pretreated Pulp Sample (B) (40X)

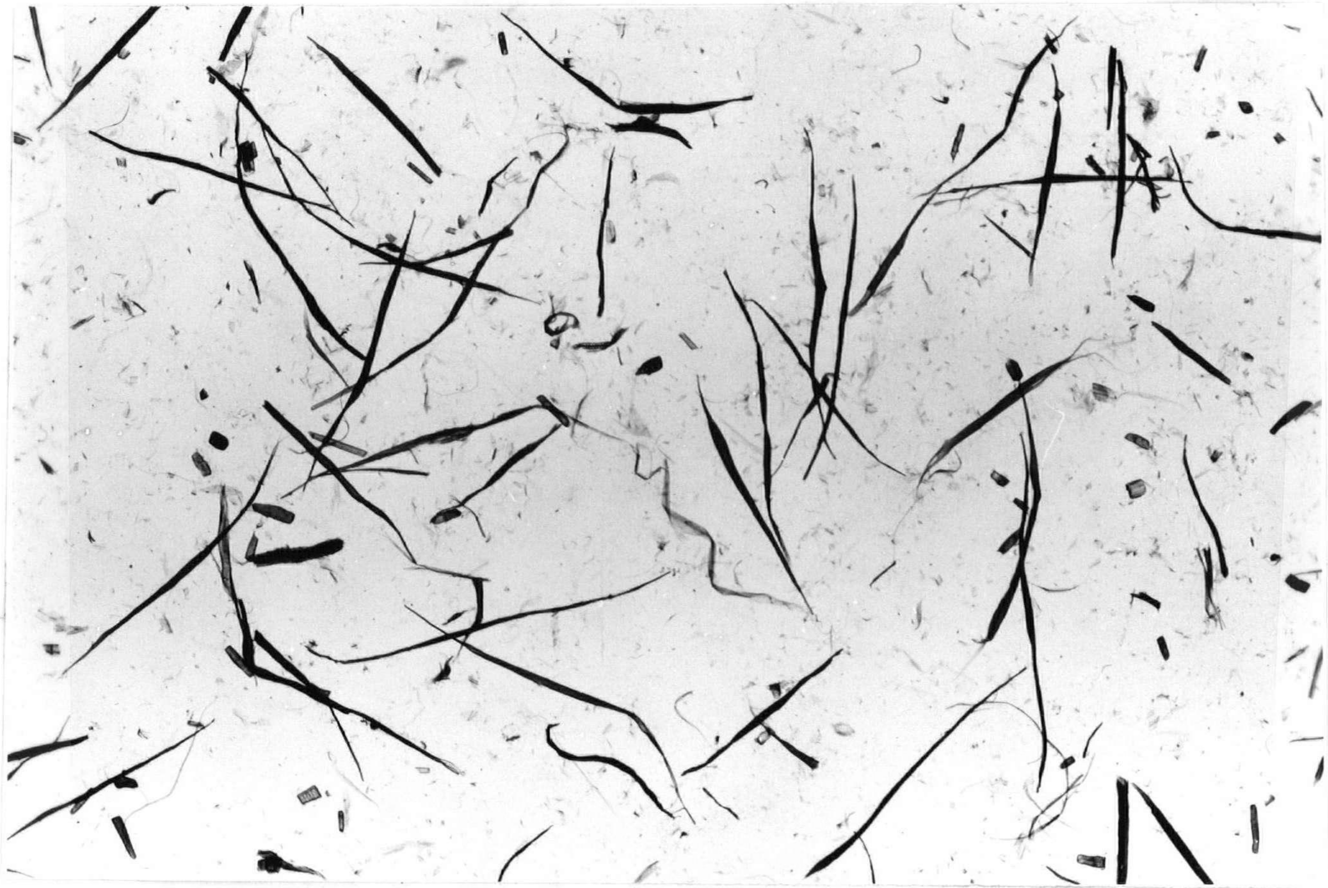

FIGURE 6. Photomicrograph Caustic Pretreated Pulp Sample (C) (40X)

FIGURE 7. Photomicrograph Sodium Sulphite Pretreated Pulp Sample (D) (40X)

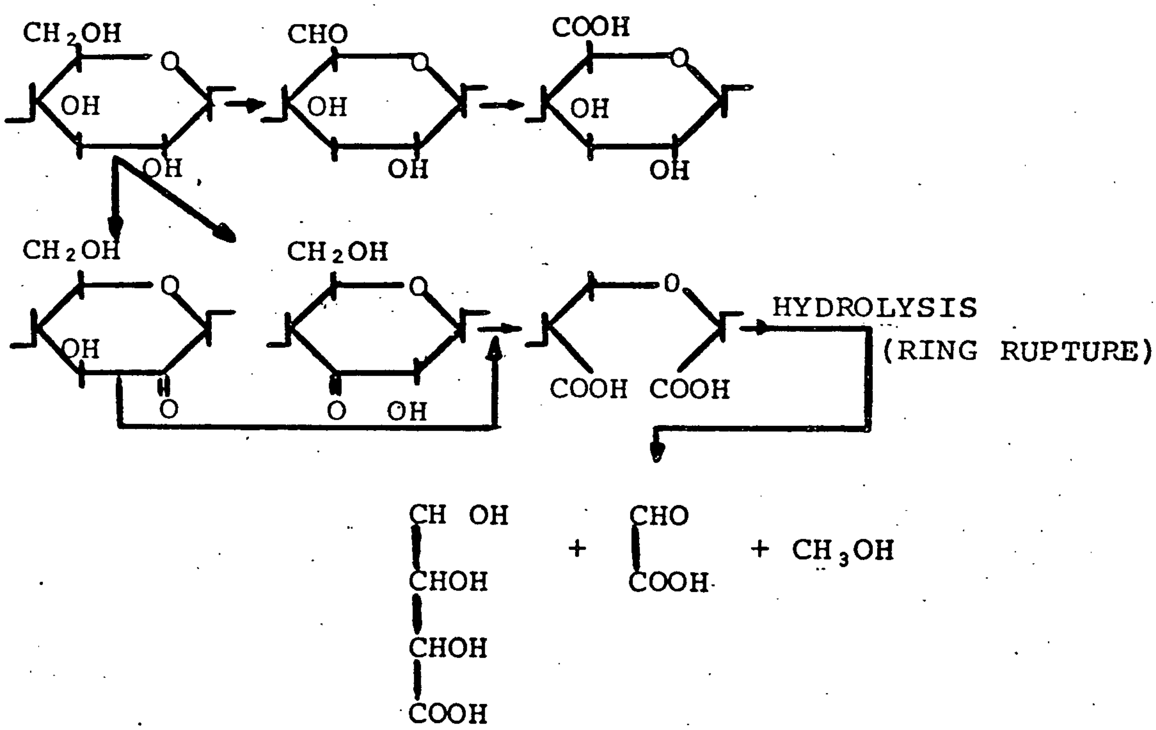

FIGURE 8. Cellulose Oxidation

Source: The Pulping of Wood (61)

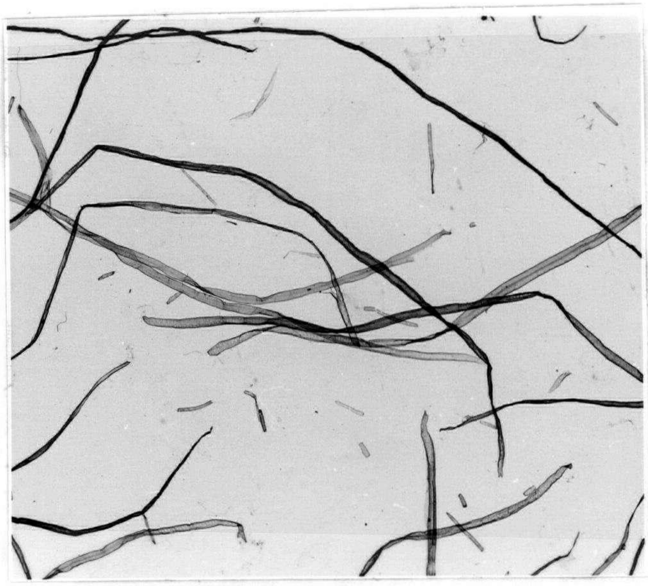

FIGURE 9. Photomicrograph West Coast Semi-Bleached Kraft Pulp (26X)

FIGURE 10. Photomicrograph Gmelina Semi-Bleached Kraft Pulp (26 X)

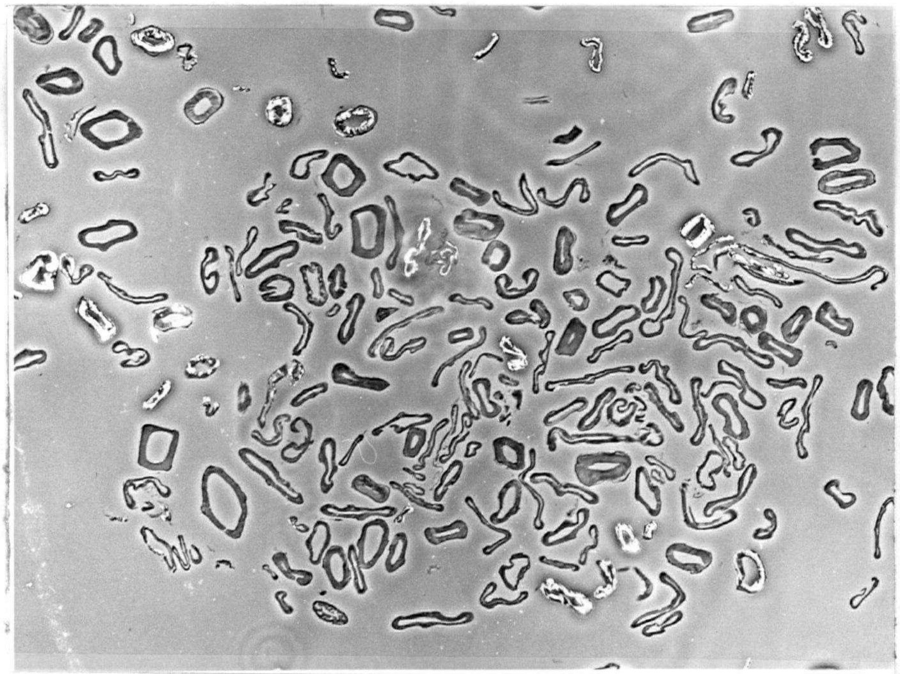

FIGURE 11. Photomicrograph Cross-Section West Coast Semi-Bleached Kraft Pulp (160X Phase Contrast)

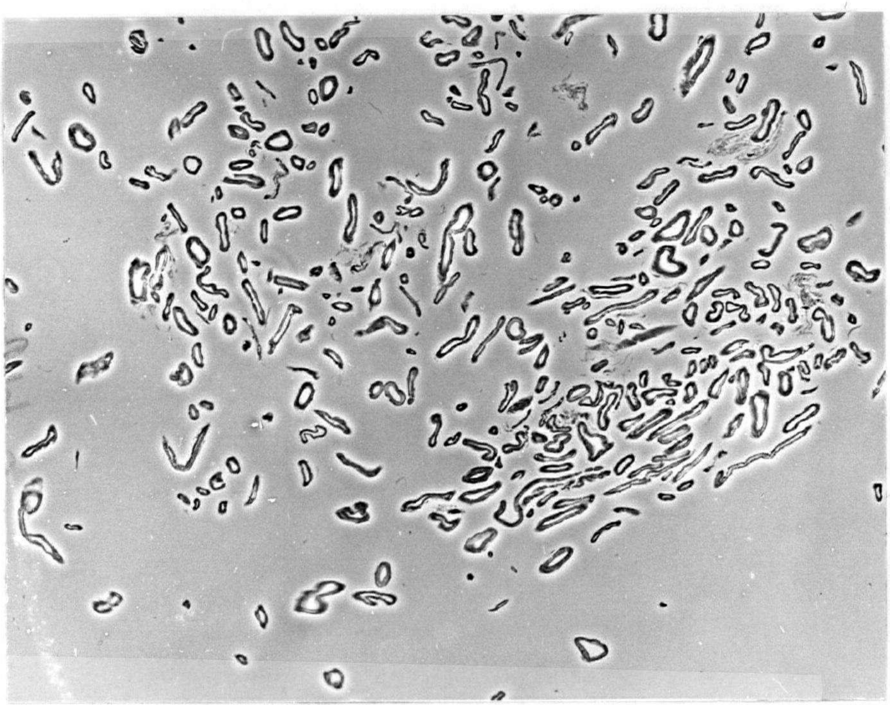

FIGURE 12. Photomicrograph Cross-Section Gmelina Semi-Bleached Kraft Pulp (160X Phase Contrast)

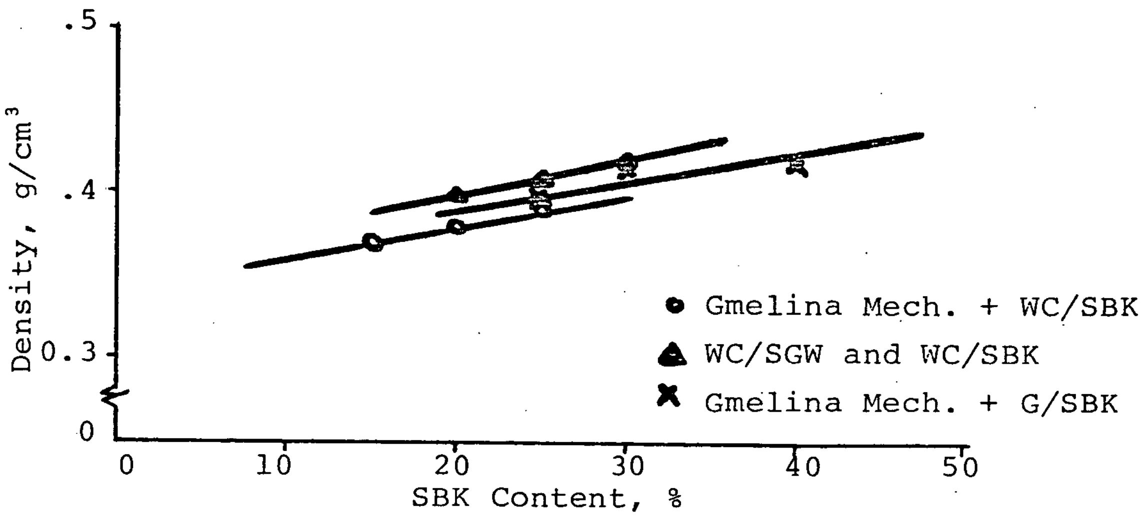

FIGURE 13. Density on Semi-Bleached Kraft Content of Simulated Newsprint Handsheets.

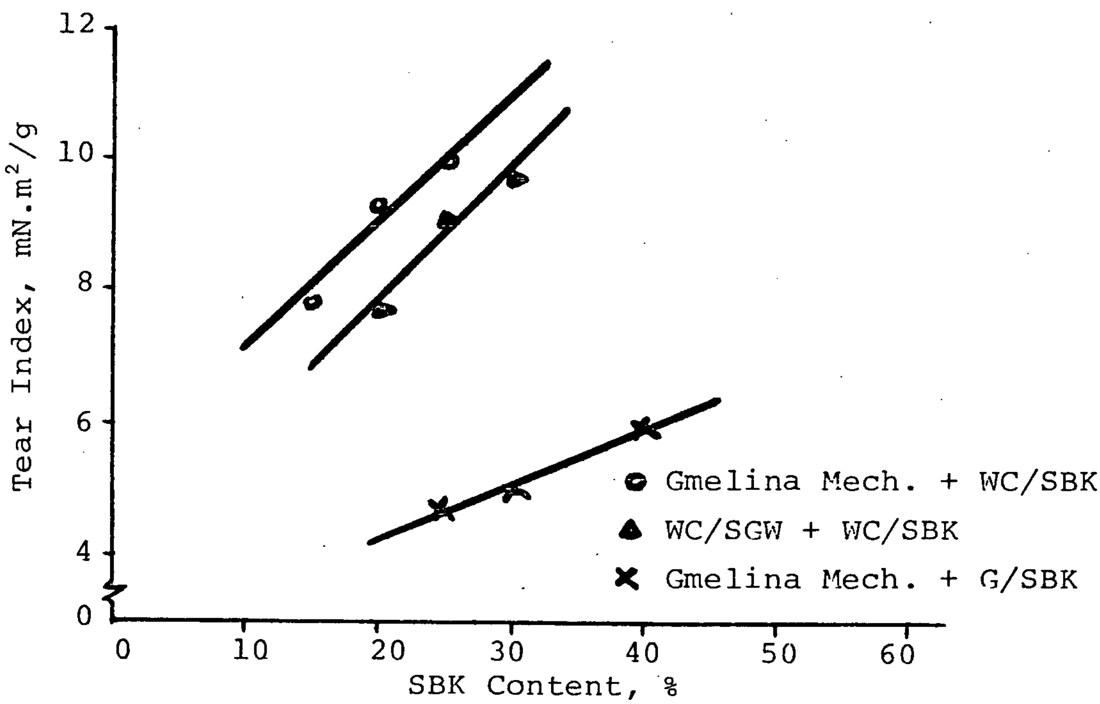

FIGURE 14. Tear Index of Simulated Newsprint Handsheets.

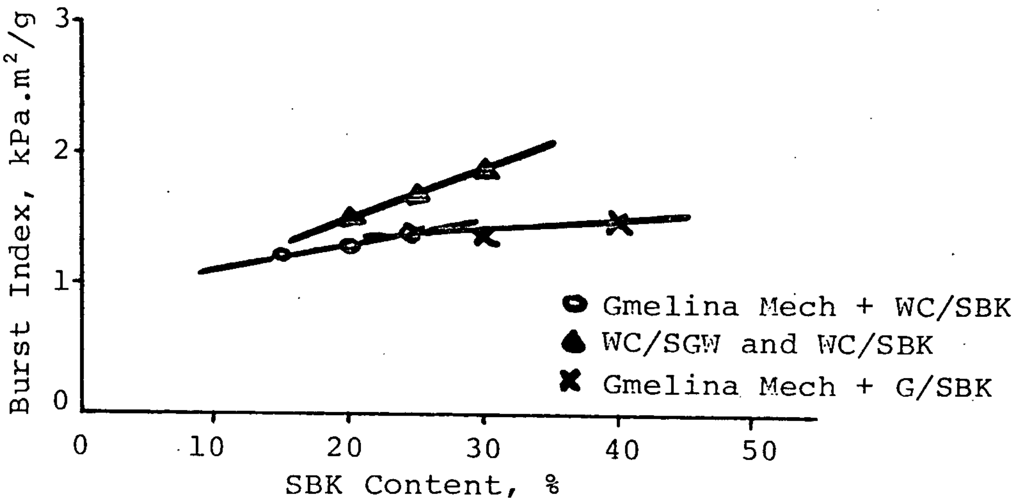

FIGURE 15. Burst Index on Semi-Bleached Kraft Content of Simulated Newsprint Handsheets

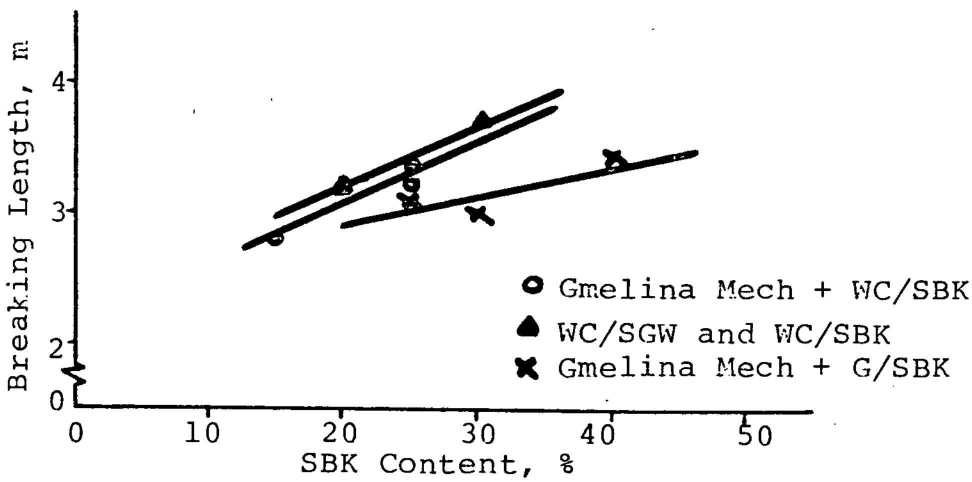

FIGURE 16. Breaking Length on Semi-Bleached Kraft Content of Simulated Newsprint Handsheets

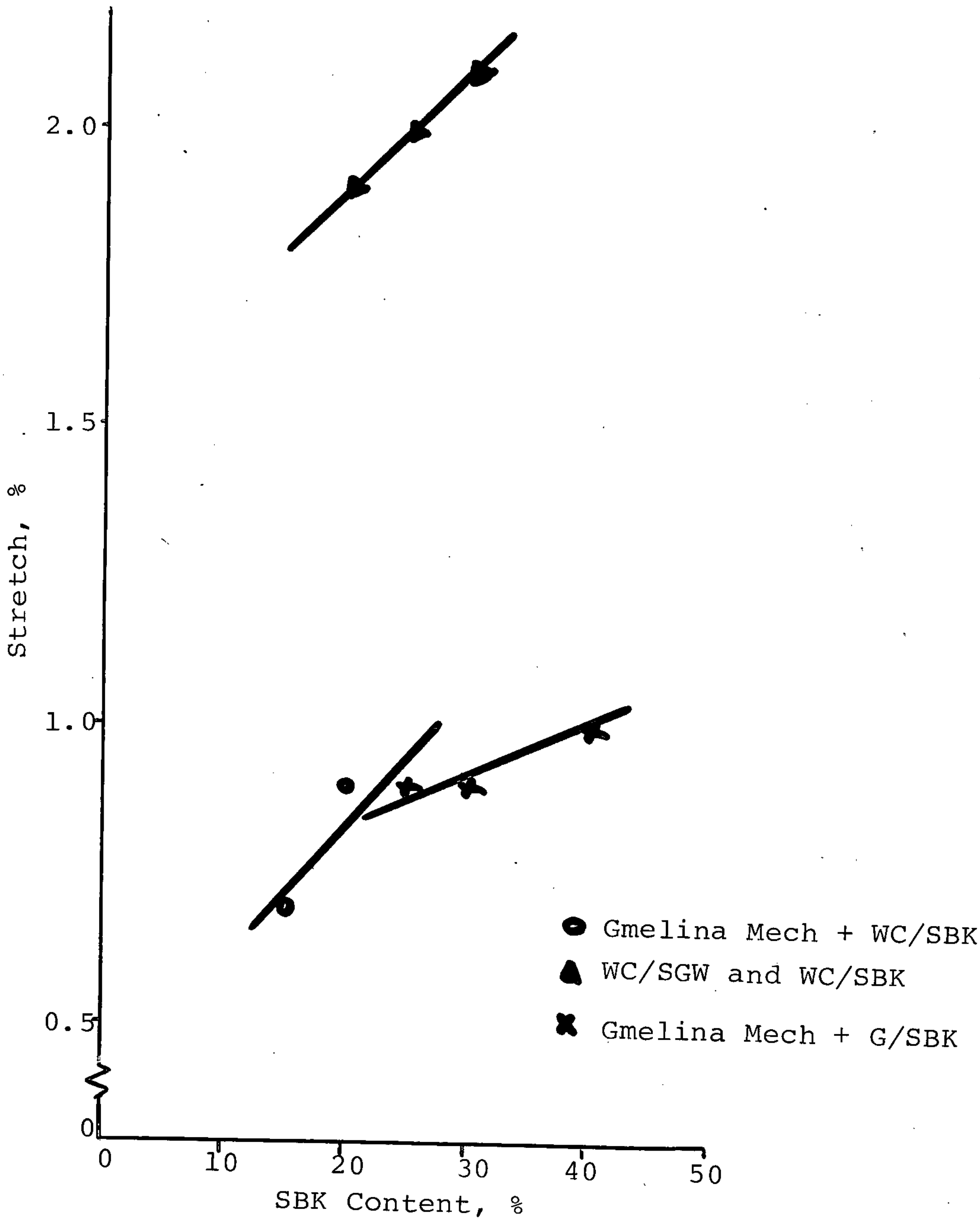

FIGURE 17. Stretch on Semi-Bleached Kraft Content of Simulated Newsprint Handsheets

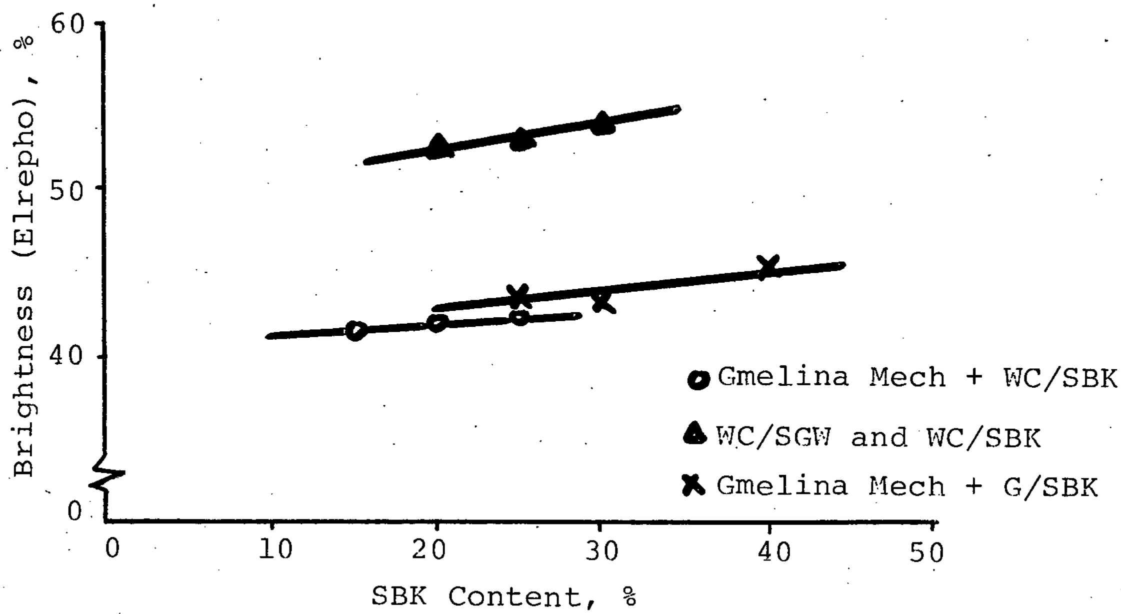

FIGURE 18. Brightness on Semi-Bleached Kraft Content of Simulated Newsprint Handsheets

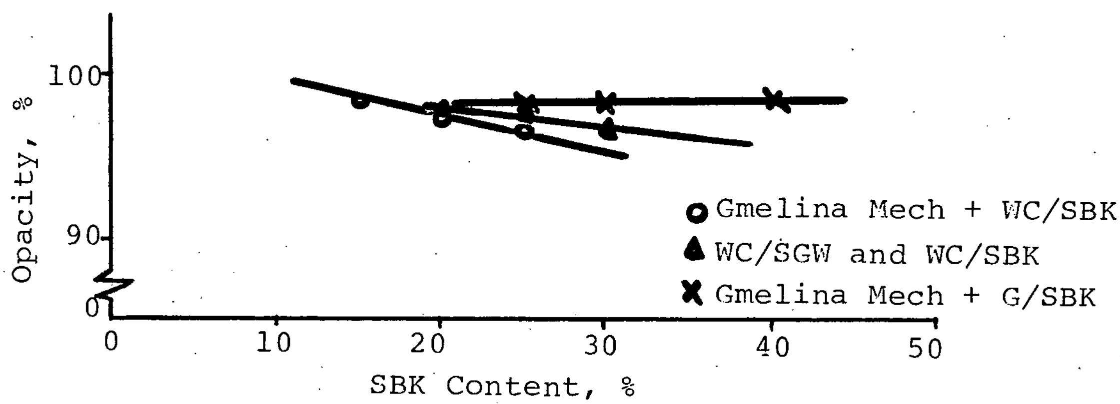

FIGURE 19. Opacity on Semi-Bleached Kraft Content of Simulated Newsprint Handsheets

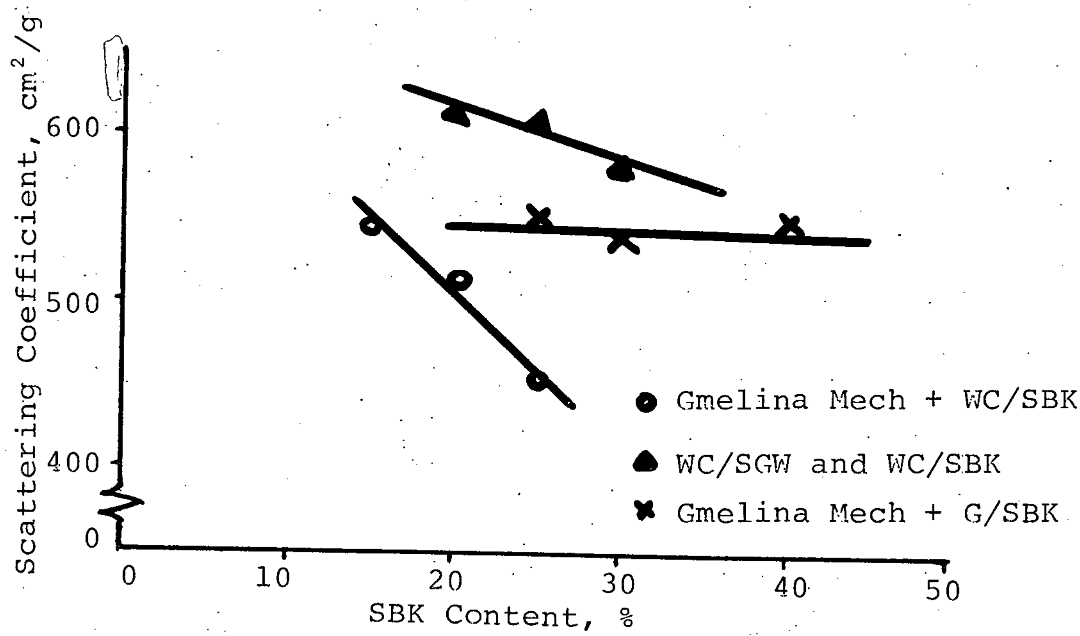

FIGURE 20. Scattering Coefficient on Semi-Bleached Kraft Content of Simulated Newsprint Handsheets

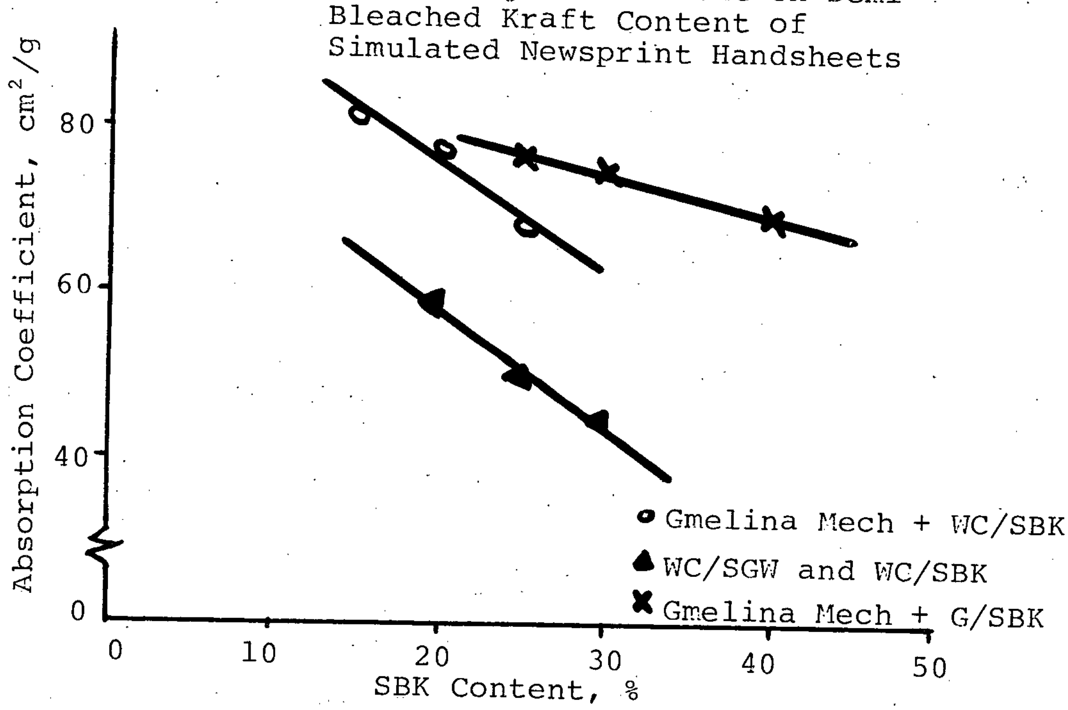

FIGURE 21. Absorption Coefficient on Semi-Bleached Kraft Content of Simulated Newsprint Handsheets

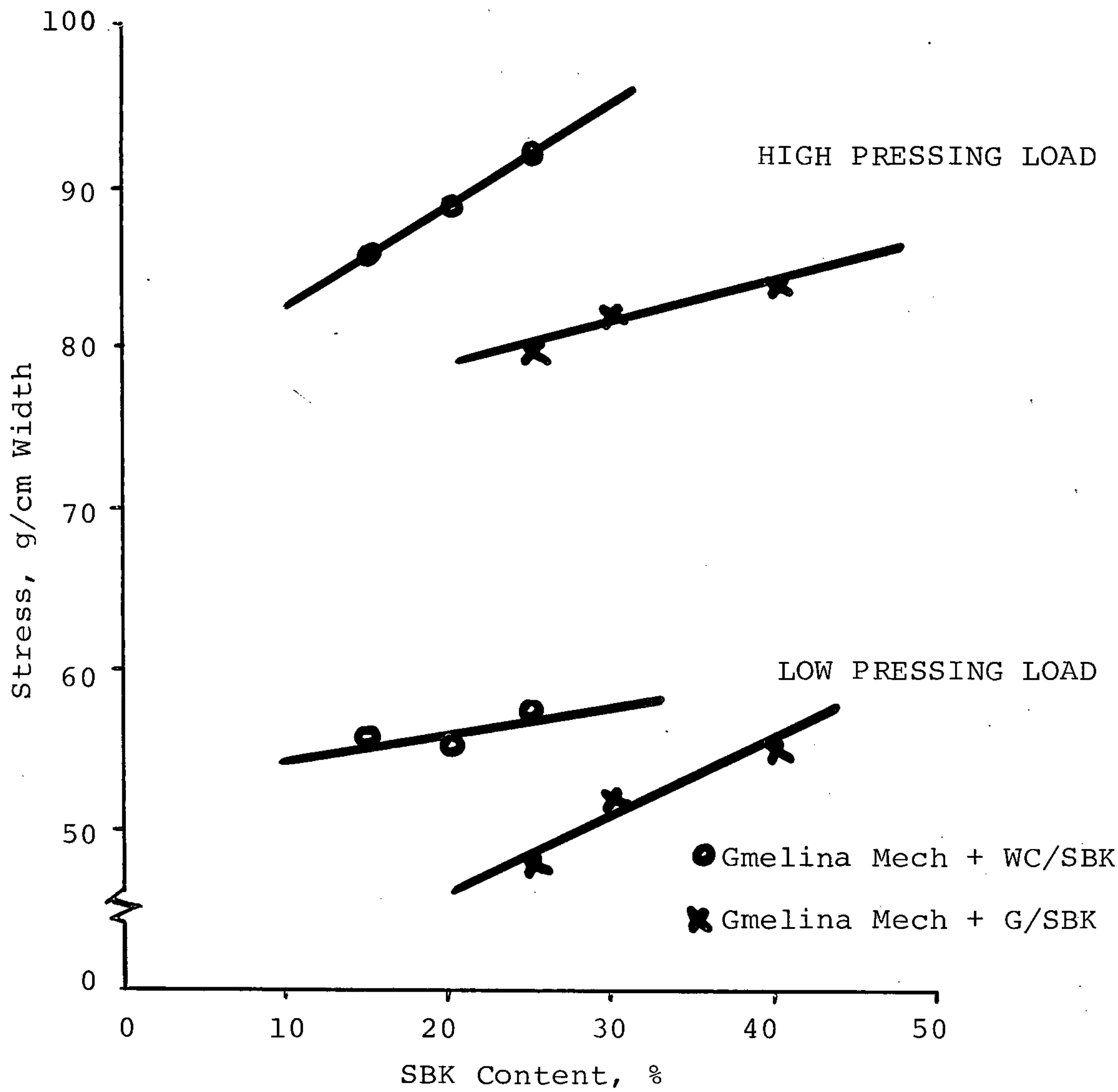

FIGURE 22. Wet Strength Characteristics (Stress) on Semi-Bleached Kraft Content of Simulated Newsprint Handsheets

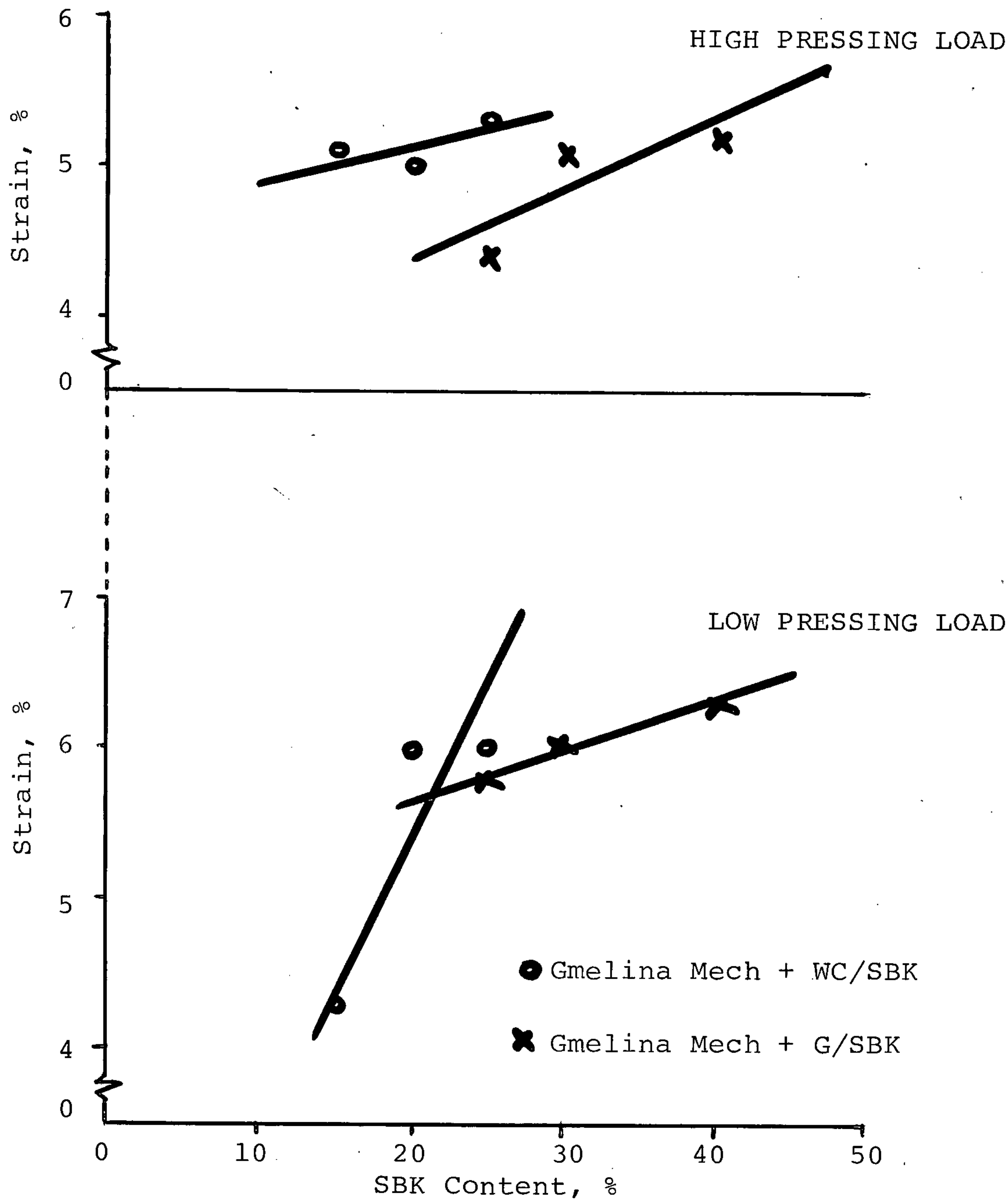

FIGURE 23. Wet Strength Characteristics (Strain) on Semi-Bleached Kraft Content of Simulated Newsprint Handsheets

APPENDIX

FORMULAS APPLIED IN THE CALCULATIONS

1. Horse Power Day Per Ton, HPD/T $= \frac{\text{Min x KW x 1.86}}{\text{O.D., lb}}$

   Min = minutes of run
   KW = average Kilo Watt reading over the run
   O.D. lb = Oven dry weight of pulp refined, in lb.

   Factor 1.86 = Min to days $= \frac{\text{min}}{60 \times 24}$

   KW to Horse Power $= \frac{\text{KW}}{0.746}$

   O.D. lb to Tons $= \frac{\text{O.D., lb}}{2{,}000}$

2. Basis Weight, g/m^2

   Handsheet $= \frac{\text{50 x Sample wt in g}}{\text{No of sheets in Sample}} \times \frac{\text{100 - \% moisture}}{100}$

   = wt of one sheet x 50 x % solids

   Paper $= \frac{\text{Sample wt in g}}{\text{Area of sample in m}^2}$

3. Density, g/cm^3 $= \frac{\text{Basis Weight}}{\text{Caliper}}$

4. Tear Strength, mN per Sheet $= 9.807 \times \frac{16^*}{\text{\# of sheets}} \times$ scale reading

   * = 32, if heavy pendulum is used
   = 8, if light pendulum is used

5. Tear Index, $mN.m^2/g$ $= \frac{\text{Tear in mN}}{\text{Basis Weight in g/m}^2}$

6. Burst Strength, kPa = Burst in psi x 6.90

7. Burst Index, $kPa.m^2/g$ $= \frac{\text{Burst strength in kPa}}{\text{Basis weight in g/m}^2}$

8. Tensile Strength, kN/m $= 0.65378 \times \text{average load in Kg}$

9. Tensile Index, N.m/g $= \dfrac{653.78}{\text{Basis weight in g/m}^2} \times \text{average load in Kg}$

10. Breaking Length, m $= \dfrac{66667}{\text{Basis weight in g/m}^2} \times \text{average load in Kg}$

11. Tensile Rupture Modulus, Pa (pascals) $= \dfrac{6.5378 \times \text{average load in Kg}}{\text{Caliper in} \quad \times \text{Stretch in \%}} \times 10^{10}$

12. Stretch, % $= 0.0277778 \times \text{average distance in mm}$

13. Tensile Energy Absorption, (TEA), J/m^2 $= \dfrac{0.196 \times \text{counts} \times \text{load} \times \text{span}}{\text{span} \times \text{width}}$

14. TEA Index, mJ/g $= \dfrac{1000 \times \text{TEA in J/m}^2}{\text{Basis wt in g/m}^2}$

15. O.D. Basis Wt., g/m^2 $= \dfrac{\text{Dry wt of sample} \times 333.65}{\text{No. of strips}}$

16. Basis Wt. Correction Factor $= \dfrac{\text{Target basis weight}}{\text{Calculated basis weight}} = \dfrac{49}{\text{Calculated basis weight}}$

17. Stress, g/specimen $= \text{Average scale reading} \times b \pm a$

b = slope
a = intercept

18. Corrected g/specimen $= \text{Stress in g/specimen} \times \text{basis wt correction factor}$

19. Strain, mm strain/g cm = Scale reading x 1.32 x 0.07

20. Strain, % = Strain x $\frac{10}{9}$

21. Opacity, % = $\frac{R_O}{R_\propto}$ x 100

22. Scattering Coefficient, cm^2/g = $\frac{1}{\text{O.D. basis wt in } g/m^2} \times \frac{10^4}{1/R_\propto - R_\infty}$ $. \ln \frac{(1-R_O R_\infty)}{1-R_O R_\infty)}$

23. Absorption Coefficient, cm^2/g = $\frac{S\ (1-R_\infty)}{2\ R_\infty}$