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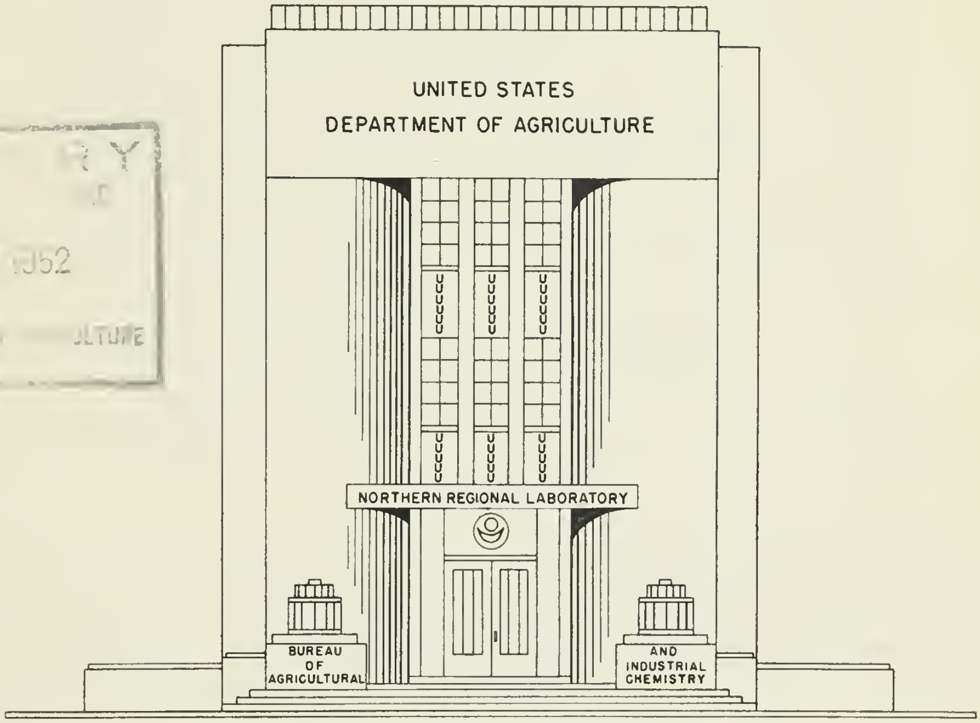
THE CHARACTERISTICS OF PULP FIBERS FROM AGRICULTURAL RESIDUES



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THE CHARACTERISTICS OF PULP FIBERS FROM AGRICULTURAL RESIDUES[1]

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INTRODUCTION

Perhaps the most critical problem presented by the rapidly increasing world demand for cellulose pulps is the supply of softwoods. The long-fibered pulps produced from them are essential for the manufacture of wrapping and other high tear-resistance papers. With few exceptions, stands of the species are found only in the Northern Hemisphere and without considering Siberia, the extent of softwood forests is known.

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In the United States, in Australia, and to a limited extent in Europe, there is an increasing production of cellulose pulps from certain hardwood species. Blends of softwood and hardwood pulps to produce a variety of paper and board products are becoming standard practice in many mills. A study of tropical woods as a source of cellulose pulp is of extreme importance.

This paper is designed to show how a partial, practical, and economic solution to the problem can be given on the basis of the chemical and physical characteristics of pulp fibers from agricultural residues. Examples of applied research will be described which point the way to success in this field.

USE OF ANNUAL PLANTS FOR PAPERMAKING

Annual plants have been used in limited quantities to produce cellulose pulps for more than a century. Examples are esparto, used mainly for fine printing papers by the English, the tow of seed flax straw to produce cigarette and fine book papers in the United States and Canada, and wheat straw to produce corrugating board and fine bleached pulp, used mainly as blends with wood pulps to make fine papers. *Arundo donax* is used in Italy to make alpha-cellulose, and sugarcane bagasse is used as a blend with wood pulps for various grades of paper in Peru, in Argentina, and in the Philippine Islands, with new mills being built for this purpose in India and in Brazil. Bamboo is used in India and Argentina. Old rope is pulped for use in making the strongest bag papers.

In discussing the characteristics of pulp fibers from agricultural residues, the bearing of their unique physical and chemical properties on practical papermaking is of main importance.

TYPES OF FIBERS AVAILABLE

Based roughly on chemical composition, fiber dimensions, density of raw material, and ease of pulping, those plants that have received most industrial attention as raw materials for pulpmaking fall into the five groups shown in table 1.

TABLE 1.--*Grouping of agricultural fibers*

Group	Plants chiefly used as pulp sources
1. Straws and esparto	Wheat, rye, rice, esparto
2. Canes and reeds	Sugarcane bagasse, *Arundo donax*, cornstalk, *Phragmites communis* Trin.
3. Woody stalks with bast fibers	Flax, hemp, cotton, soybean
4. Leaf fibers	Abaca (manila), sisal, henequen, pineapple, caroa
5. Bamboos	Various varieties

CHEMICAL COMPOSITION AND PROPERTIES

Table 2 shows the approximate variations in the principal chemical components of these plants or plant fibers. From these data it will be noted that the annual plants contain much more ash than do the pulpwoods. The cereal straws, particularly rice straw, have high ash contents.

In lignin content, the bast and leaf fibers are quire low; it is high in all pulpwoods, bamboos, and woody stems of plants producing bast fibers. The cereal straws and esparto contain less lignin than the stalks and reeds, but the plants of both groups 1 and 2 are lower in lignin than the pulpwoods, bamboos, and woody plant stems. These differences are reflected in the amounts of chemicals required for producing fine bleached pulps from the members of the various groups.

The pentosan content of the bast is very low while the straws, esparto, stalks, and reeds analyze highest in this component. However, the deciduous pulpwoods and the leaf fibers approach the straws in pentosan content and decreasing amounts are found in the woody stems, bamboos, and coniferous pulpwoods.

Cross and Bevan and alpha cellulose contents are highest in the bast and leaf fibers, decreasing slightly in the order, bamboos, coniferous woods, stalks, and reeds. The deciduous woods contain slightly more cellulose constituents than straws and esparto, and woody stems contain the least. Pith-free bagasse fiber compares favorably in cellulose contents with coniferous woods. The cellulose content of pith (parenchyma) is lower than that of the fiber. Bamboos analyze higher in Cross and Bevan and alpha-cellulose than the coniferous pulpwoods.

Data regarding the holocellulose content of all the material under discussion do not seem to be available. However, with the probable exception of bast and leaf fibers, the holocellulose content for the other fibers, on an ash-free basis, would appear to be at fairly uniform level near 70 percent. This suggests that differences in the fibrous carbohydrate materials in many plants are qualitative; that is, they differ in kind rather than in amount.

PHYSICAL PROPERTIES AND DIMENSIONS

Variations in fiber dimensions are listed in table 3. As is well known, the bast and leaf fibers are much longer than those of any other groups. Coniferous woods and bamboos possess fibers of substantially the same length. Such fibers produce high tear resistance in papers and, in fact, possess near the maximum length practical for good papermaking. The deciduous woods, straws, esparto, stalks, and reeds have somewhat shorter fibers. They vary about the same in length among the various groups as do the individual fibers within the groups. The tearing strength of papers made from them is low and such papers are not so suited for wrapping and bags, when papers made of longer fibers are available. Fibers of the woody stems of plants in group 3 are very short and entirely unsuited for tear-resistant papers.

TABLE 2.--*Agricultural fibers and pulpwoods. Variations in principal chemical components*

Fiber	Ash	Lignin	Pentosans	Cross and Bevan cellulose	Alpha-cellulose
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
Group 1. Straws and esparto	6-8	17-19	27-32	50-54	33-38
Rice straw	14-20	12-14	23-25	46-49	28-36
Group 2. Stalks and reeds	3-6	18-22	28-32	52-5B	33-43
Sugarcane fibers	2	19-21	30-32	59-62	40-43
Group 3. Woody stalks with bast fibers					
A. Woody stems	2-3	23-27	15-22	40-48	31-33
B. Bast fibers	1-2	1-6	2-6	70-80	60+
Group 4. Leaf fibers	0.6-1.2	7-10	17-24	70-80	53-64
Group 5. Bamboos	1-2	24-29	16-18	60-63	50+
Group 6. Coniferous woods	<1	26-34	7-14	53-62	40-45
Group 7. Deciduous woods	<1	23-30	19-26	54-61	38-49

TABLE 3.--*Agricultural fibers and pulpwoods. Variations in fiber dimensions and ease of pulping*

Fiber	Average length	Average diameter	Ratio: length to diameter	Relative density	Relative ease of pulping
	Microns	*Microns*			
Group 1. Straws and esparto	1,100–1,500	9–13	110–120:1	open	1
Rice straw	1,450	8.5	170:1	open	1
Group 2. Stalks and reeds	1,000–1,800	8–20	80–120:1	open	2
Sugarcane fibers	1,700	20	85:1	open	2
Group 3. Woody stalks with bast fibers					
A. Woody stems	200–300	10–11	$<$ 30:1	dense	4
B. Bast fibers	20,000–25,000	16–22	$>$ 500:1	open	3
Group 4. Leaf fibers	6,000–9,000	16–18	250–300:1	open	3
Group 5. Bamboos	2,700	14	200:1	dense	4
Group 6. Coniferous woods	2,700–3,600	32–43	75–90:1	dense	4
Group 7. Deciduous woods	1,000–1,600	38–50	$<$ 50:1	dense	4

It is now generally recognized that the ratio of fiber length to fiber diameter is one of the most important criteria for evaluating papermaking fibers. With the exception of the fibers of the woody stems, this ratio is higher for all agricultural fibers than those of the pulpwoods. The values for bast and leaf fibers are exceptional. The ratios for rice straw and bamboos are about twice those of coniferous woods, which are also exceeded by straws, esparto, and some of the reeds. Sugarcane bagasse fibers compare very favorably with the conifers in respect to this ratio. The fibers of the deciduous woods as compared with those of groups 1 and 2 show less than one-half to one-third of their ratio, while the ratio in the case of the woody stems is exceedingly poor.

PULPING CHARACTERISTICS

Table 3 classifies the various groups of fibers in relation to density and to ease of pulping. Fibers in group 1 are easiest to pulp because of the very open plant structure and their relatively low lignin content. The chemical reactions involved are undoubtedly surface reactions. The open structure and thin walls of the straws and esparto present a large initial surface for chemical attack and minimize the problem of diffusion encountered with all of the pulpwoods. The pulping reaction is therefore rapid and the chemicals required for pulp production are lower than with other fibers.

Next in order come the canes and reeds. These plants require somewhat more chemicals and somewhat more vigorous pulping conditions. This is due to the fact that the rind fibers of these plants are generally denser and the fiber walls thicker than those encountered in group 1. In some cases, especially with sugarcane bagasse, the lignin content may be higher. For example in Florida sugarcane, which is harvested 9 to 11 months after planting, the lignin content was 18 to 19 percent while Hawaiian cane cut after 22 months contained from 22 to 23 percent lignin. Naturally, more chemicals are required to pulp the particular Hawaiian bagasse.

Bast and leaf fibers frequently present a problem in pulping because of associated impurities, but such fibers alone, being very low in lignin and high in cellulose, pulp with greater ease and with less chemical requirements than pulpwoods, bamboos, and the fibers of woody stems.

These data show that industry is not limited to the conifers to obtain fibers of optimum length for making tear-resistant papers. Bamboos provide fibers similar in length while the bast and particularly the leaf fibers provide fibers of greater length. Indeed, it is well known that leaf fiber pulps (abaca) are now used as blends with wood fibers to make the strongest of our bag and wrapping papers. These fibers, as well as bast fibers, are used in the manufacture of currency, bank note, and high tear- and scuff-resistant papers. In many cases the length of the fibers of straws, esparto, canes, and reeds equals or exceeds that of the deciduous woods, and from the viewpoint of producing strong papers their pulps often exceed pulps made from hardwood species.

PRACTICAL PROBLEMS IN PULPING AGRICULTURAL FIBERS

The overwhelming preference of the pulp and paper industry for wood fibers is partly due to inertia. This has been generated in the minds of the operators by the great advances in the technology and wide application of wood pulps as compared with the relatively neglected technology and limited use of agricultural pulps.

While a variety of reasons, all of them important, are given for the small use of residue plants, such as dirt, bulkiness, difficulties incident to their collection, transportation, and storage, etc., the most important reason probably is the feeling that yields of pulps are low, strengths are not high, and that clean pulps are costly to produce.

In the cases of esparto and seed flax tow, industry recognizes that better grades of papers for specific uses can be made from them than from wood pulps. In addition, such papers command a high-priced market. With these incentives, industry has attacked the problems connected with esparto grass and flax tow procurement with a will comparable with that found in solving like problems in harvesting hardwood species or pulpwoods from farm lots.

CLEAN PULPS ESSENTIAL

In the past, sufficient attention has not been devoted to the production of clean pulps. Straws contain, in addition to dirt, undesirable material such as nodes, heads, and grain kernels. In the development of the newer pulping methods for straw at the Northern Regional Research Laboratory, simple, effective methods in equipment standard in the pulp industry have been applied to the production of clean pulps. For example, in the mechano-chemical pulping process, the nodes, heads, and wheat grains are not pulped nor disintegrated. After washing the pulp, these may be removed by a simple riffling system prior to screening. The screenings and material from the riffler may then be further defibered by means of a machine operating on the general principle of the Hydrapulper. The defibered material is again riffled and screened. The rejects are discarded or used in making board or other pulp. Passing the screened pulp through a Vortrap, Dirtec, Hydraclone, or other dirt-removing machines is probably desirable before and after bleaching.

It has long been recognized that the pith cells in sugarcane bagasse, cornstalks, or other pith-bearing plants lower the quality and raise the cost of making pulp from them. Very recently the Northern Regional Laboratory has developed a simple method for removing pith from sugarcane bagasse at the sugar mill. It is suggested that pith and blackstrap molasses, if mixed and sold as a feed base, will result in higher profits to the sugar industry. At the same time the process would provide a high-grade clean fiber at reasonable cost for making fine papers. This process not only removes the pith but the dirt and carbon present on the burned cane. Yields of unbleached strong fiber of more than 60 percent, based on pith-free fiber, have been produced from Florida bagasse by cooking with 15 percent caustic soda in the Hydrapulper for 1 1/4 hours

While considerable progress has been made in preparing seed flax tow for use by the cigarette paper industry, there is still room for improvement in methods of removing the woody material from the tow. The woody stem requires much more severe conditions for pulping than the tow, so the tow because of the presence of the woody flax shives must be overcooked with a resulting much lower yield and quality of pulp than should be obtained.

HIGH-YIELD SPECIALTY PULPS THE GOAL

It is most important in this era of great expansion in the pulp and paper industry and in the search for desirable pulp sources to redefine problems. In the first place, the problem concerns all countries and is of long rather than of short range, since the paper industry must expand as literacy, commerce, and standards of living advance. The viewpoint of producing substitutes from residues, tropical woods, hardwoods, or any other plant sources does not lead to industrial stability; only by finding the best combinations is permanence assured.

The examples mentioned show how problems specific to each pulp source may be solved. It must be recognized that pulping methods used for wood are probably not suitable as such for residues. Experience shows that, in general, alkaline chemicals produce the most satisfactory results. An attempt to duplicate the properties of wood pulps by pulping residues should not be considered. Rather, the effort should be directed to preparing pulp in such a manner that the unique properties inherent in its fiber dimensions and chemical properties result. This will require a certain amount of research, but the reservoir of knowledge on fundamental physical and chemical properties, pulping methods and machines, methods of screening, cleaning, refining, and paper machine operation contains the information, which with slight modifications, will solve most of the problems. The problems of mechanisms for collection, handling, and storage of plant fibers are not as difficult as those which required solution in the gathering of pulpwoods.

HIGH-YIELD PULPS POSSIBLE

With emphasis placed on the use of residues to produce high-yield, high-quality, clean specialty pulps, industry will awaken to the wide horizon of opportunities for new and improved products to which residues can contribute. Improved or new products signify higher prices and enlarged markets.

It has already been demonstrated with straw and sugarcane bagasse that very high-yield, high-strength pulps can be obtained by the newer procedures designed especially for pulping them. Over-all costs of chemicals, steam, and power are lower than for pulpwood, and these together with the high pulp yields bring production costs into line with softwood pulp.

METHODS FOR PRACTICAL UTILIZATION OF AGRICULTURAL FIBERS IN PAPERMAKING

Our knowledge of the relationship between the physical and chemical properties of fibers and their utility in papermaking has become extensive. Even though we did not have definite knowledge of the place of certain of the fibers under discussion in papermaking, it would be possible to predict this from their known intrinsic properties.

For example, tearing strength is known to be primarily dependent on fiber length. Poor formation in papers is due to the clotting or clumping together of fibers so that they are not uniformly distributed in the sheet of paper. Experience has demonstrated that long fibers or fibers which are fibrillated both contribute to poor paper formation. A combination of long fibers and highly fibrillated fibers produces the least desirable formation. Poorly formed papers do not possess a level surface and represent inferior sheets for printing and many other purposes.

In the poorly formed sheet the maximum strength which the individual fibers could contribute is not obtained because the clumps of fibers contribute very little to strength. Since paper strength is believed to be fairly related to the number of fiber bonds, it follows that fibers of a high ratio of length to diameter will, other things being equal, contribute greater strength than broader fibers of the same respective lengths.

Fibers with a high pentosan content hydrate or swell more rapidly on beating than those of low pentosan content. The drop in freeness of easily hydrated pulps is generally so rapid that very little if any fibrillation takes place in them during their refining for paper machine operation. Chemical pulps are generally less opaque than more highly lignified or mechanical wood pulps. Chemical pulps containing high amounts of pentosans are less opaque than those of lower pentosan content. Grease-proof or glassine papers with good formation may be made only from pulps high in pentosans.

Semi-chemical pulps high in pentosans produce stiffer and more crush-resistant papers than do pulps of low pentosan content. For this reason, wheat and rye straws and sugarcane bagasse are especially useful for the manufacture of corrugating papers. It is possible that respective blends of these pulps with semi-chemical hardwood pulps would be beneficial.

From the fibers in groups 1 and 2 (that is, straws, stalks, and reeds) it is possible to make excellent greaseproof and glassine papers so far as good transparency or resistance to grease and oil is concerned. The tear resistance of such papers might be improved by blends of softwood pulps and particularly pulps from bast, hard fibers, or bamboo if these were available and not too costly. Good writing or printing papers can be made wholly from such fibers. But except in papers from esparto, fillers are required generally to obtain the desired opacity. In our opinion, however, these pulps will find their greatest usefulness as blends with other pulps to produce superior types of papers.

The strength properties of bleached fine straw pulps produced by the two new high-yield processes developed by the Northern Regional Laboratory as compared with industrial samples of bleached softwood and hardwood pulps are shown in figure 1. The neutral sulfite straw pulp has a brightness of 70, a pentosan content of 30 percent, and a yield of 50 percent based on original dry straw, while the mechano-chemical pulp has a brightness of 82, a pentosan content of 33 percent, and a yield of 47 percent. The straw pulps exceed the wood pulps in both bursting and tensile strength at 500 Schopper-Riegler freeness, and they develop their maximum strength in about one-half to two-thirds the time required for the wood pulps. Also their maximum strength develops at a higher respective freeness. The mechano-chemical straw pulp shows higher folding endurance than either of the wood pulps, and the neutral sulfite pulp shows a higher value than the hardwood pulp.

The mechano-chemical pulp is the stronger of the two straw pulps. It contains more pentosans and shows a considerably more rapid strength development on beating. This pulp was used for machine runs on the experimental paper machine at the United States Forest Products Laboratory in the spring of 1951. The neutral sulfite straw pulp is similar in properties to that used in making the industrial newsprint run at the Ontario Paper Company, Thorold, Ontario in the

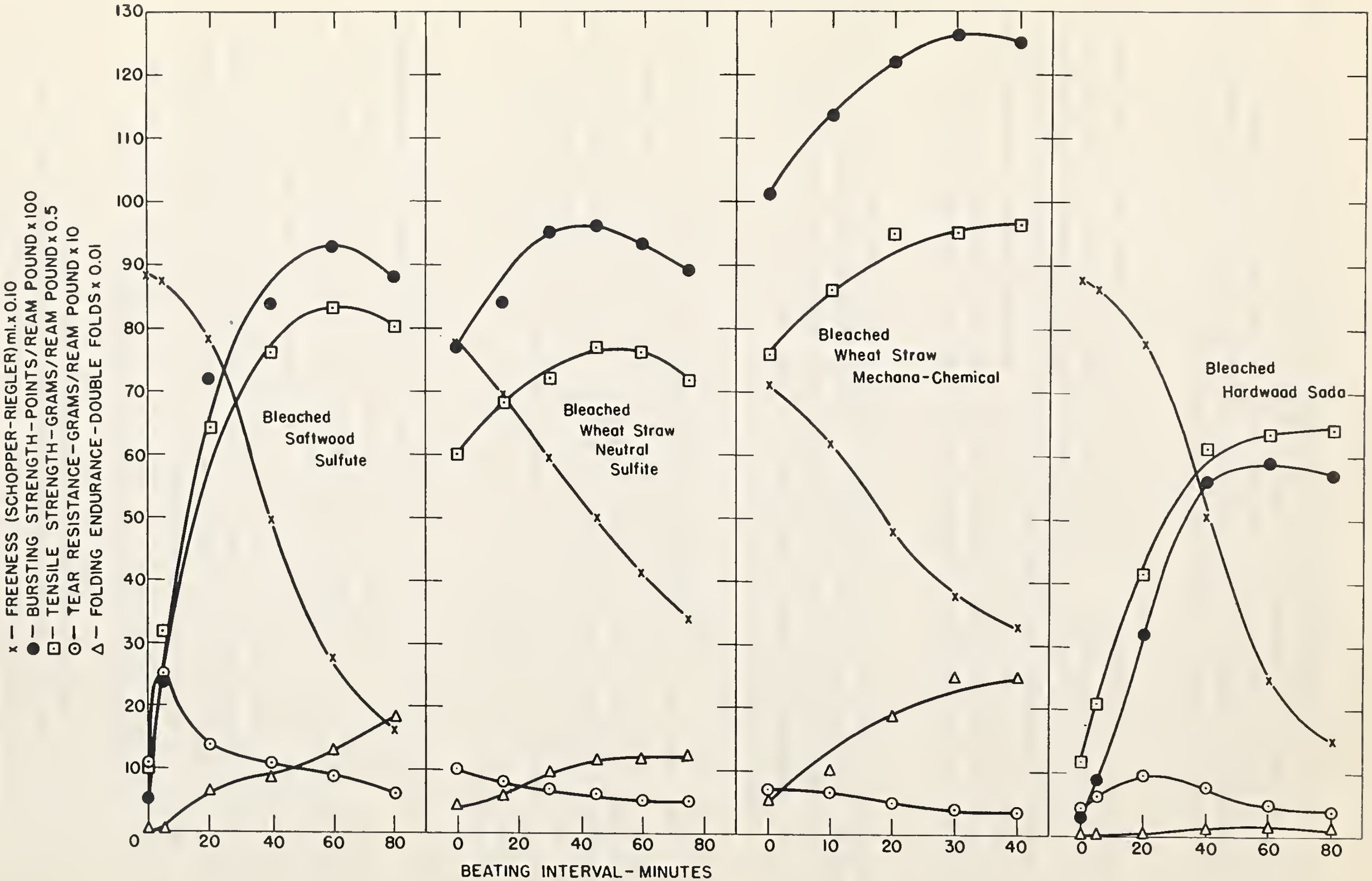

Figure 1.--Comparative strength properties of bleached wheat straw, neutral sulfite and mechano-chemical pulps, softwood sulfite pulp, and hardwood soda pulp.

spring of 1948. Pulps very similar in character may be obtained from depithed sugarcane bagasse fiber by the respective pulping processes.

These pulps, when blended in proper proportions with softwood pulps, will improve formation of the sheet, will improve the surface characteristics and printability, and will tend to reduce pick and fuzz. They are to be particularly recommended for use in uncoated papers such as writing and bond, tablet, ledger, mimeograph, and book. They are very useful in improving the smoothness and surface of supercalendered papers. They are also useful in coated papers and lithograph or label papers where a better coating surface is produced, and in waxing papers where better formation and greater transparency is obtained. They may replace part or all of the softwood sulfite in groundwood and magazine book papers where the addition of well-hydrated agricultural residue pulps not only increases strength and improves formation but also improves the normally limp sheet by adding the "snap" formerly present in magazine papers made wholly from chemical pulps. These pulps can replace the sulfite pulp used in newsprint manufacture. It is possible that a newssheet might be manufactured from waste deinked news plus a liberal percentage, e.g., 25 percent or more, of such pulps.

The foregoing statements are not just conjectures. They have been borne out in actual pulp and paper mill operations in many countries and in fairly large-scale experimental paper machine trials in this country. In Algeria, mixtures of straw and esparto pulps are used for fine paper manufacture in which high quality of product is maintained and costs of production somewhat lowered.

The use of the pulps from fibers of groups 1 and 2 will lead not only to improved paper products but will result in savings of power in beating and refining if the pulps are treated separately and blended just before final jordaning and the paper machine operation. There is also evidence that the use of these pulps in amounts up to 25 or 30 percent in blends with sulfite or kraft softwood pulps to make wrapping and bag paper may be justified in order to conserve softwood pulps. In that case, the wood pulp would be refined only to its maximum tear resistance and the residue pulps would be refined so that the final pulp blend would have the necessary freeness required on the paper machine. This is essentially the practice now used in Australia in making wrapping and bag papers from eucalyptus and imported softwood kraft pulps.

In general, the above statements are applicable to the use of bamboo pulps. Like esparto, bamboo pulps may be used 100 percent to manufacture a variety of papers. The long fibers adapt them for use in wrapping papers. It is suggested that blends of bamboo pulp with straw, sugarcane bagasse, or hardwood pulps might be suitable for wrappings and bags. This would be worth investigating.

It is well known that cigarette papers from bast fibers are highly preferred. In Spain rice straw is used for this purpose. It will be noted that rice straw fibers are of smaller diameter than any of the fibers in groups 1 and 2. Bast fibers have long been used for the manufacture of very high grade and expensive book, ledger, writing, condenser, and like papers which must resist handling.

United States currency paper contains seed flax tow pulp fibers because they increase tear and particularly scuff resistance. In the manufacture of certain book and writing papers made from bast fibers, blends of straw, bagasse, or other similar fibers could probably be used to advantage whereby costs might be reduced and quality maintained. The bast fibers must be reduced in length by beating and refining but their low pentosan and lignin contents and their narrow fiber diameter may be considered responsible for the very high qualities of the papers made from them.

The leaf or hard fibers, generally in the form of old rope, are used to produce our strongest papers. From the properties of the fibers their use might be predicted. They not only possess the fiber length necessary for the high tear resistance required in flour sacks, cement bags, and the like, but because of their narrow fiber diameter many more fibers are present in any area, all of which have to be broken to puncture the paper. Such fiber properties are also responsible for the high scuff resistance of the paper. Since the formation of the paper is superior to that obtainable with softwood pulps the paper has a much more closed and smoother surface. The low lignin and medium pentosan content with high consequent cellulose content make also for ease of conversion to pulps having comparatively rapid drainage on the paper machine. Waste from the production of manila fiber is now being used for papermaking in Costa Rica. With improvements in recovering waste in hard fiber manufacture, low-cost sources other than old rope should become available. Evidently, if costs permit, blends of agricultural or hardwood pulps with hard fiber pulps would produce good wrapping and bag papers. Blends of pulps from straw, stalks, or bast fibers with pulps from hard fibers should produce the strongest and the most tear-resistant very thin papers.

Papermaking is essentially concerned with the high-speed, continuous production of fibrous webs, now being put to use in thousands of ways. Of secondary concern are the raw materials used for pulping as long as quality products are produced at competitive prices. When raw materials are limited to a consideration of pulp production wholly or predominately from wood fibers, as at present, much too narrow a view is taken of the possible expansion in the paper industry. The above discussion clearly shows that new and improved opportunities exist in the use of agricultural fibers as pulp sources not only to relieve pulp shortages now or in the near future, but that by judicious use of these fibers as blends with other fibers a wide horizon of new and improved papers is open to development by the industry.

METHODS FOR PRACTICAL UTILIZATION OF AGRICULTURAL RESIDUES IN MAKING INSULATING, HARD BOARD, BOXBOARD, AND SIMILAR PRODUCTS

Sugarcane bagasse has been used for 30 years to produce high-grade, rugged, insulating building materials in board form. Straw, cornstalks, flax shives, and licorice root have also been used successfully. Research at the Northern Regional Laboratory has shown that the rugged strength and high impact value of products made from such residues is due primarily to the incorporation in them of long fiber bundles. Such bundles can be produced from the above residues by mechanical means but they cannot be made from wood. This is due primarily to the difference in structure of wood and the various agricultural fibers.

Hard board has been successfully produced from sugarcane bagasse and from straw. Recently the Northern Regional Laboratory announced a process to produce from straw boxboard which can replace wood veneer in wire-bound shipping containers. Undoubtedly a large number of new uses in heretofore unexplored fields for the use of raw cellulose fibers will eventually be found. The agricultural residue fibers should be used where they will do a better job than may be done by wood fibers.

CONCLUSION

Agricultural fibers of diverse nature are readily available in most parts of the world. Research into their physical, chemical, and papermaking properties backed up with a considerable industrial experience in their use shows that they can greatly benefit the expanding paper industry not only by increasing pulp supplies but even more important, when properly used, to produce new and improved paper and board products. Now, industry is somewhat reluctantly extending the present limited use of these fibers. The greatest challenge to industry in this period of expansion lies in a reorientation in viewpoint so that raw materials are not confined to any particular type but are sought and used on the basis of producing better, newer, and more useful paper and board products. With such a reoriented viewpoint, the very great possibilities in the use of agricultural fibers become apparent. Also, with such a viewpoint, research and industry can proceed with confidence to solve the problems facing them.

The mention in this article of commercial products under proprietary names does not constitute an endorsement by the U. S. Department of Agriculture.