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PULPING AND PAPERMAKING PROPERTIES OF SEED FLAX STRAW

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INTRODUCTION

The utilization of seed flax straw for pulp has been the subject of investigations by both private individuals and public agencies for many years. The principal objectives of such investigations have been (1) to find a profitable use for an agricultural byproduct now largely wasted in the production of linseed; (2) to relieve a scarcity, and possibly to become nationally independent in regard to the supply of linen rags used in papermaking; and (3) to provide new papermaking materials with the view of augmenting the national resources of such raw materials. In past studies as well as in the one here reported the foregoing objectives have not been attained.

As early as 1908 the Bureau of Plant Industry of the United States Department of Agriculture began studies on the pulping of fibrous plants. Flax straw received considerable attention in this program. In 1916 a publication was issued covering the results of the work on flax straw for use in the cheaper grades of paper, such as wrappings and fiber boards (8)[2]. At that time the supply of papermaking rags from Europe was greatly reduced because of the World War and interest was centered in the development of a substitute for linen rags in currency paper. Very good samples of paper, suitable for currency, were produced on a laboratory scale but unsatisfactory results were obtained in an endeavor to convert the small-scale experiments to mill-scale methods. In 1919 the work of the Section of Paper Plant Investigation of the Bureau of Plant Industry was discontinued and the files and equipment transferred to the Forest Products Laboratory at Madison, Wisconsin.

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[1] This report embodies the results of investigations by the Forest Service that have extended over more than 15 years. It has been the privilege of the authors to draw upon the vast accumulation of information that has resulted from studies on the pulping and papermaking properties of seed flax straw by various members of the Pulp and Paper Section of the Forest Products Laboratory.

[2] Reference is made by underscored numbers in parentheses to "Literature Cited", p. 21.

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The United States Department of Commerce reported in 1923 on the results of experiments conducted on flax straw in the Paper Section of the Bureau of Standards (7). The experiments indicated that the entire flax straw was suitable for wrapping paper and that a high grade of commercial tow could be converted into an equivalent of sulphite wood pulp. The conclusions, however, were that from an economic point of view the use of flax fiber for paper of any description did not appear feasible.

The work at the Forest Products Laboratory on the pulping of flax has been concerned chiefly in attempting to develop a straw pulp with qualities superior to that obtained from woodpulp. This objective appeared possible in view of the fact that the bast fiber in flax straw possesses pulping qualities not approached in any wood fiber. Although the results presented here are negative from an economic standpoint, they are not without value since they contribute many new facts to a much discussed problem (3,4,11,14,15,16,17,18), the solution of which has been attempted at frequent intervals for many years.

ECONOMIC FACTORS AFFECTING FLAX STRAW UTILIZATION

Flax Growing Area and Flax Seed Production

The average area devoted to the cultivation of seed flax in the United States during the five-year period, 1906-10, was according to the Bureau of Foreign and Domestic Commerce 2,520,000 acres. After 1913 the area declined until in 1922 it was 1,113,000 acres. This decrease has been attributed to economic and agricultural causes, the chief of which was the decrease in the development of new land. Due to advances in crop rotation practices, and to increases in consumption of flaxseed products, acreage has increased considerably since 1922. The production of seed in 1924 was more than 31 million bushels, the largest flax crop ever harvested in the United States. The area devoted to seed flax reached a high point in 1930 with 3,732,000 acres but production was less than the former peak year, by nearly 10 million bushels. Acreage declined after 1930 and in 1935 the area planted was about 2 million acres and the production of seed about 5 million bushels.

From an exporting nation prior to 1908, flax seed consumption increased until, in 1927, the United States imported more than 24 million bushels of seed. Importations declined somewhat after 1927. In 1932 imports were down to about 6 million bushels, but in 1934 they had again risen to about 18 million bushels. Nearly all of this imported seed is processed in mills along the Atlantic seaboard. At the present time approximately 3 million acres seem to be sufficient to supply the needs of the flax seed mills in the Northwest. The area under cultivation in the United States and the world production of seed are tabulated in tables 1 and 2.

Quantity and Quality of Flax Straw Available

Flax seed is harvested and threshed in much the same manner as other grains. The straw as baled consists of about 30 percent of chaff, leaves, and loose detritus. The yield of flax straw is estimated to vary from one to one-sixth of a ton per acre, depending on the locality and the prevailing weather conditions. Three-quarters of a ton per acre is considered a good average. The total annual production of straw on the basis of 2-1/2 million acres under cultivation in the United States and 1/2 million acres in Canada is, therefore, approximately 2-1/4 million tons. Accurate figures on the quantity of straw used in the manufacture of upholstery, insulating materials, and rugs are not available but it is known to be very small in comparison to the amount produced. Estimates by those in close contact with the industry indicate that the annual consumption of these three products during the years 1925 to 1929 ranged from 50 to 70 thousand tons. Since 1930 it has declined year by year and the estimated consumption for 1935 was about 10,000 tons. The quantity available for use in pulp products is therefore large.

The quality of this large agricultural waste is variable. This is mainly because of the extensive area upon which it is produced, with the attendant variations in weather, diseases, and weeds from locality to locality and from year to year. In the present utilization of flax straw, care is taken in the selection of the straw used, much of it being selected in the field before harvest. For this reason some manufacturers contend that the waste is not so large as statistics appear to show. Selecting the material is necessary because tow manufacture requires a long and relatively strong fiber. Because of freight costs, the manufacturer must confine his operations to a relatively small area and, therefore, finds difficulty at times in securing material of a quality required to meet his needs.

The mixed cropping of flax with cereal grains for the purpose of improving the seed has been practiced to a small extent in some localities for more than 40 years. In recent years there has been a marked increase in the acreage of the mixed crop with a corresponding decrease in the acreage of flax grown alone (1). Under certain conditions the yield and quality of both the flax seed and the grain are improved by growing them together. The control of weeds, however, is the chief advantage of the mixed crop and makes it possible to grow flax on land that is too weedy for flax alone. The straw from the combination crop, however, is limited in its industrial use and therefore has a low value.

Cost of Flax Straw and Tow

In Minnesota, No. 1 flax straw during an 8-year period from 1922 to 1929 had an average market value of $11 a ton, and No. 2 straw a value of $9 a ton at the point of utilization. The No. 1 grade averages 10 inches in length and may contain a maximum of 5 percent weeds. The

No. 2 straw averages 6 inches in length and may contain 10 percent weeds. The average price paid to the farmer during this period for No. 1 straw, loose in the stack, was about \$2 a ton, the baling cost \$2, balers profit \$1, and hauling to the railroad \$3. The freight charges, within a radius of 200 miles of the point of use, were approximately \$3 a ton. Although at times in recent years manufacturers have been able to purchase straw at the mill for from \$5 to \$8 a ton, the foregoing general prices have held without appreciable drop. For estimating costs in this report \$10 a ton has been used as an average price for No. 1 straw.

The average price of medium grade upholsterers tow during the 8-year period from 1922 to 1929 was about \$30 a ton and of the fine grades of tow, about \$45 a ton. Since 1934 the price of medium tow has been about \$25 a ton. The greatly increased value of these materials as compared with the straw is due principally to the large loss of material during manufacture. The waste is commonly used as fuel to operate the plant. It has not been found profitable to market the waste for any purpose although a small quantity is used at the point of production in the manufacture of insulating materials and some attempts have been made to process it to recover the short fiber and to utilize the woody parts in stock feeds.

PHYSICAL AND CHEMICAL COMPOSITION OF FLAX STRAW

The flax plant of the variety cultivated for seed grows to approximately 25 inches in height (pl. 1). The stem of the flax straw consists of a layer of cuticular cells, a layer of cortical parenchyma, the bast fibers in groups or bundles, the cambium layer, the central hollow wooden core and the pith cells (pl. 2). From the pulp maker's point of view the most important parts are the bast fiber and the core of woody tissue. The rest, which amounts to about 10 percent of the weight of the straw, has no value for pulp and offers little difficulty in removal during the process of digestion.

The bast fiber, which may be removed by mechanical processes, separates out in long filaments sometimes extending the entire length of the straw (pl. 3). The ultimate fiber of the bast ranges from 1.25 to 1.75 inches in length and from 0.001 to 0.00125 inch in diameter. The fiber in the woody core in comparison with that in the bast fiber is very small, the dimensions being on the average 0.008 inch in length and 0.0004 inch in width. The fiber dimensions of a pulp prepared from flax straw by digestion with sodium hydroxide are given in table 3. From 70 to 75 percent of the flax straw is composed of woody fiber and 15 to 20 percent is bast fiber.

The differences in the chemical constitution of the various components of the flax straw are as great as their physical dissimilarity. The bast fiber consists of relatively pure cellulose associated with other materials that are easily removed by organic solvents and dilute

Plate 1.--Bolls and blossoms of seed flax straw.

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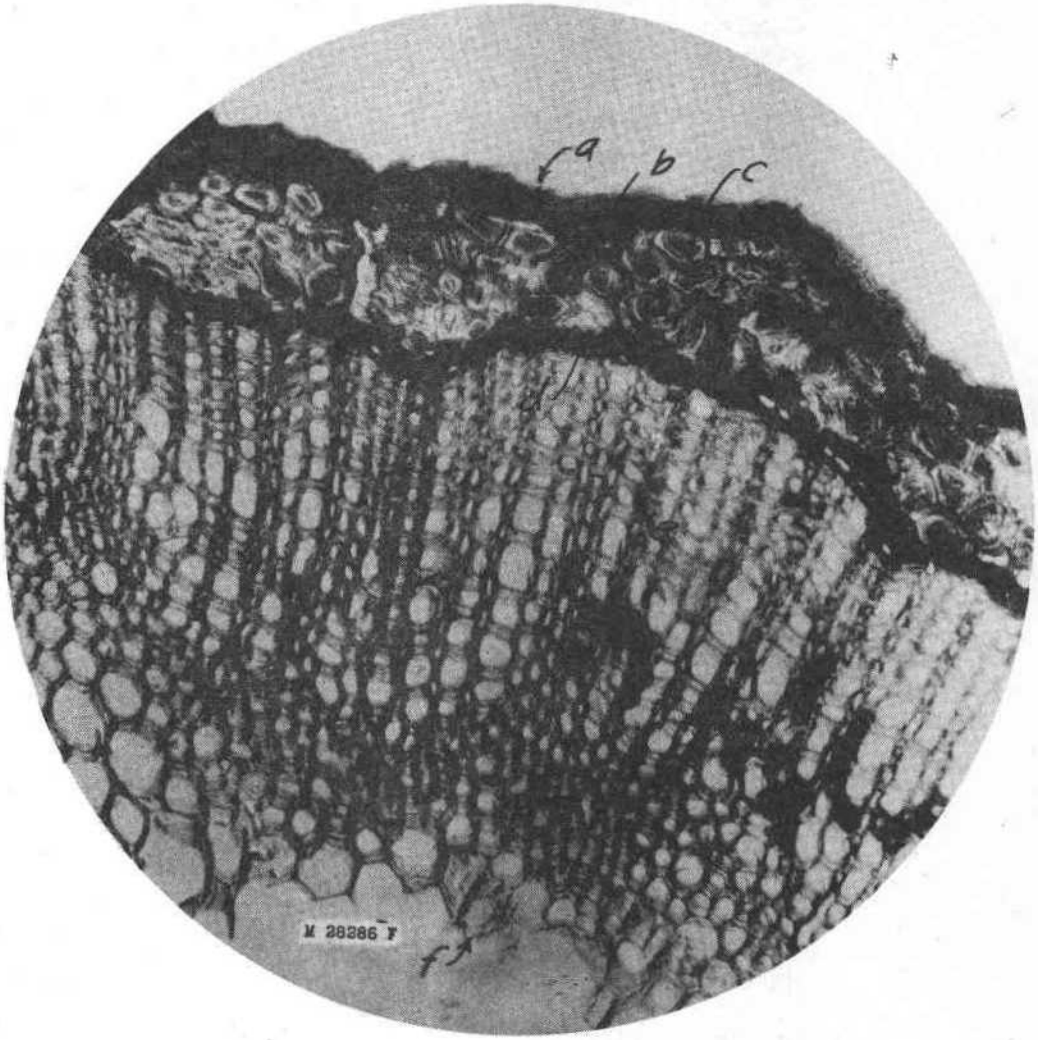

Plate 2.--Flax stem (Linum usitatissimum) transverse section. a, Cuticular layer; b, cortical parenchyma; c, bast fibers in bundles; d, cambium layer; e, central hollow woody core; f, pith cells.

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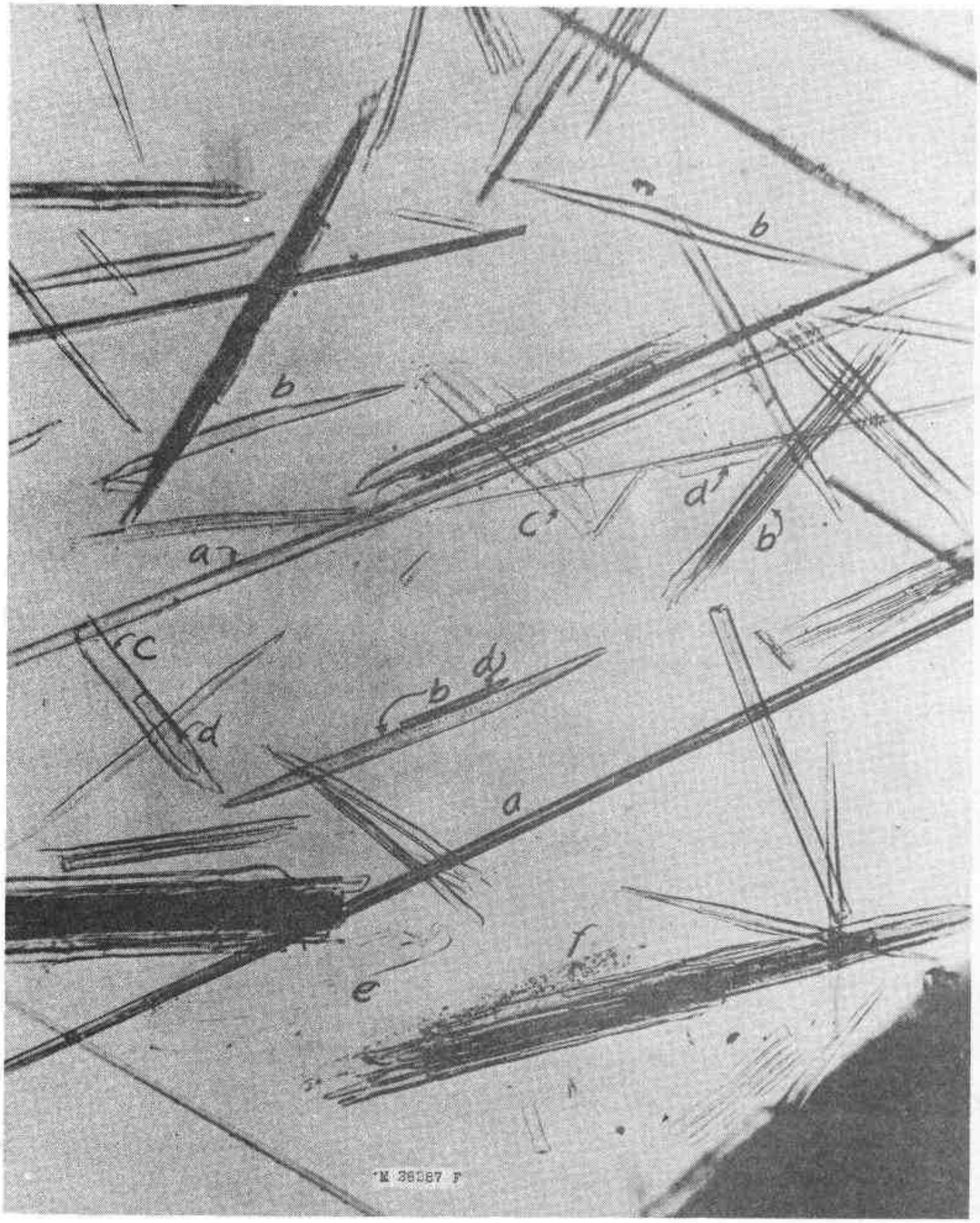

Plate 3.--Flax stem -- disintegrated. a, Bast fiber; b, wood cells; c, vessel; d, parenchyma cell; e, pith cells; f, cuticular cells.

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alkaline solutions (t. 4). The noncellulose materials in the shives, on the other hand, are closely combined with a relatively smaller quantity of cellulose and in practically the same proportions that are found in hardwoods.

SEPARATION OF BAST FIBER AND SHIVES

Commercial Method

The flax tow used in upholstery, flax rugs, insulation, and the like is manufactured by passing the loosely entangled straw, which may have been previously dried, through a series of fluted rolls called a flax brake. This machine breaks the woody core of the stems to relatively short lengths without undue shortening of the bast fibers. The fluted rolls are meshed in pairs set horizontally; as many as 60 pairs are used in breaking machines. As the straw passes successively through the meshed rolls a considerable quantity of the shives falls through the spaces between the rolls to a conveyor. This material, called towing mill waste, contains varying amounts of bast fiber. It is used as fuel for the operation of the towing mill equipment. The tow is cleaned further by shaking over screens as it passes from the breaks to the baler. Tow is graded for various purposes according to the amount of shives present, lesser amounts being present in the higher grades.

The separation of bast fiber and shives by this method, while it serves the purpose of producing a commercially usable product, is very inefficient since a bast fiber completely free of shives is never obtained. In a mill trial in which 1,500 pounds of kiln-dried straw containing about 2.5 percent of moisture were processed, the yield of fine grade tow was 31.4 percent. Further processing to an extra fine grade reduced the yield to 27.8 percent. The yield of medium grade tow is, in commercial practice, from 50 to 60 percent of the chaff-free straw.

Experimental Methods

Much experimentation has been conducted on the separation of the bast fiber and shives in seed flax straw. The work of the Bureau of Plant Industry resulted in an improvement (9) of the flax brake in which the draw or tension in the material passing from one pair of fluted rolls to another was greatly increased. This caused a violent pulling action of such intensity that the fibrous constituents of the straw were drawn over each other thereby loosening the adhering fine pieces of woody matter. The tow was much superior to the commercial product and in small-scale tests it yielded a very tough paper that appeared suited for the manufacture of bank notes. Subsequent trials both on a mill scale and on a semicommercial scale at the Forest Products Laboratory showed the tow to contain more shives than could be reduced by the milk of lime method of digesting linen rags. Cooking trials with more drastic alkaline chemicals resulted in a fairly strong paper, but lacked sufficient strength and the required color for use in currency paper.

Many experiments on the separation of bast fiber and shives have been conducted at the Forest Products Laboratory in the course of work on flax straw. Some of the experiments were unproductive of usable information, others were only indicative. The most promising series of experiments involved the processes of extraction, shredding, screening on diaphragm screens, and final separation with a Wilfley table, an apparatus in common use for classifying metallurgical ores (6). Except for the Wilfley table, all the equipment used is at the present time standard in pulp and paper mills.

Experiments with this process on semicommercial-sized equipment indicated that the power consumption on a commercial scale for the Wilfley table would be about 18-horsepower days per 1 ton each of bast fiber and shives. The power required for the extraction and screening operations prior to the Wilfley table operation was not determined. There are indications that the capacity of the Wilfley table when operating on flax fiber is low. The equivalent of passing the material over 11 commercial-sized tables was required before the two components -- bast and shive -- were considered sufficiently separated. The production rate of such an installation was estimated at 0.028 of a ton each of bast fiber and shives per 24 hours. The steps in the process preceding the Wilfley table would produce an additional 0.224 ton of shives per 24 hours. Thus an installation of this size would have a capacity of about 0.28 ton of flax straw per 24 hours. Figures 1 and 2 show flow sheets of the process.

An essential requirement of the process is the production of a fiber equivalent in papermaking properties to that of linen rags. The bast fiber obtained in these experiments contained a relatively small amount of shives (as indicated by a lignin content of about 6 percent) in the form of short particles. The fiber length was less than that of linen rag half stuff but longer than that required for papermaking. Although the impurities were small in amount they existed in a difficultly soluble form. Cooking tests showed the fiber suited to pulping by the lime or the lime and soda ash processes as employed in pulping linen rags. The type of paper produced was more suited for book and magazine papers than for bond. Since it is essential that the process result in a much higher grade of paper than that obtained, the necessity for considerable more study is evident.

In view of the small proportion of the bast fiber, and its relatively mediocre quality, it is evident that any economic solution of the flax straw utilization problems would require the finding of some use for the large quantity of shives produced. The shortness of the fiber in the lignified part of the flax limits the use of pulps obtained from it to those purposes where fiber length is of relatively no importance. One of the principal uses of short-fibered pulps is in the manufacture of

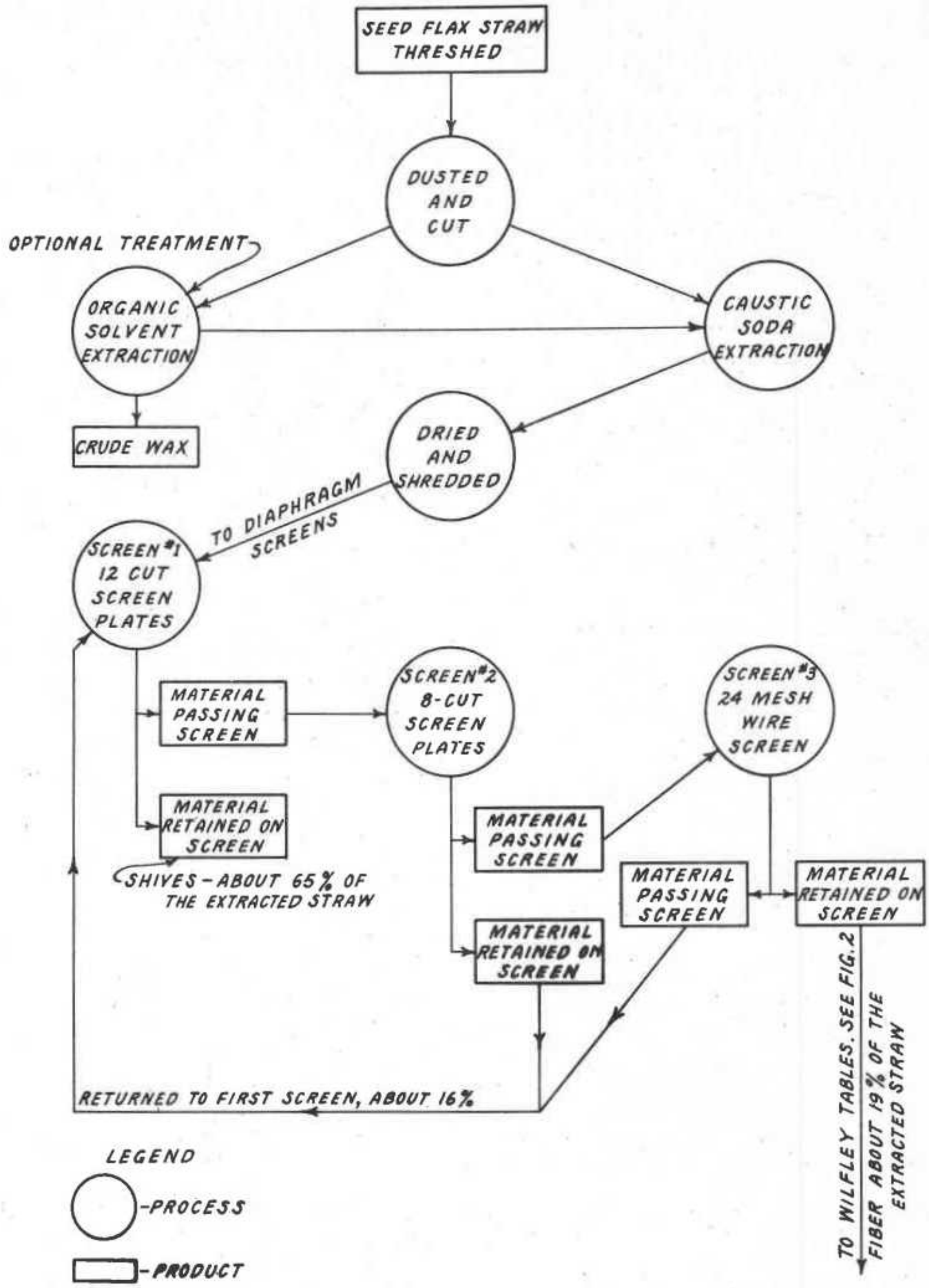

FIG. 1

INVENTOR

BY

ATTORNEY

Figure 1.--Flow sheet for separating bast fiber and shives in seed flax straw by means of diaphragm flat-plate screens.

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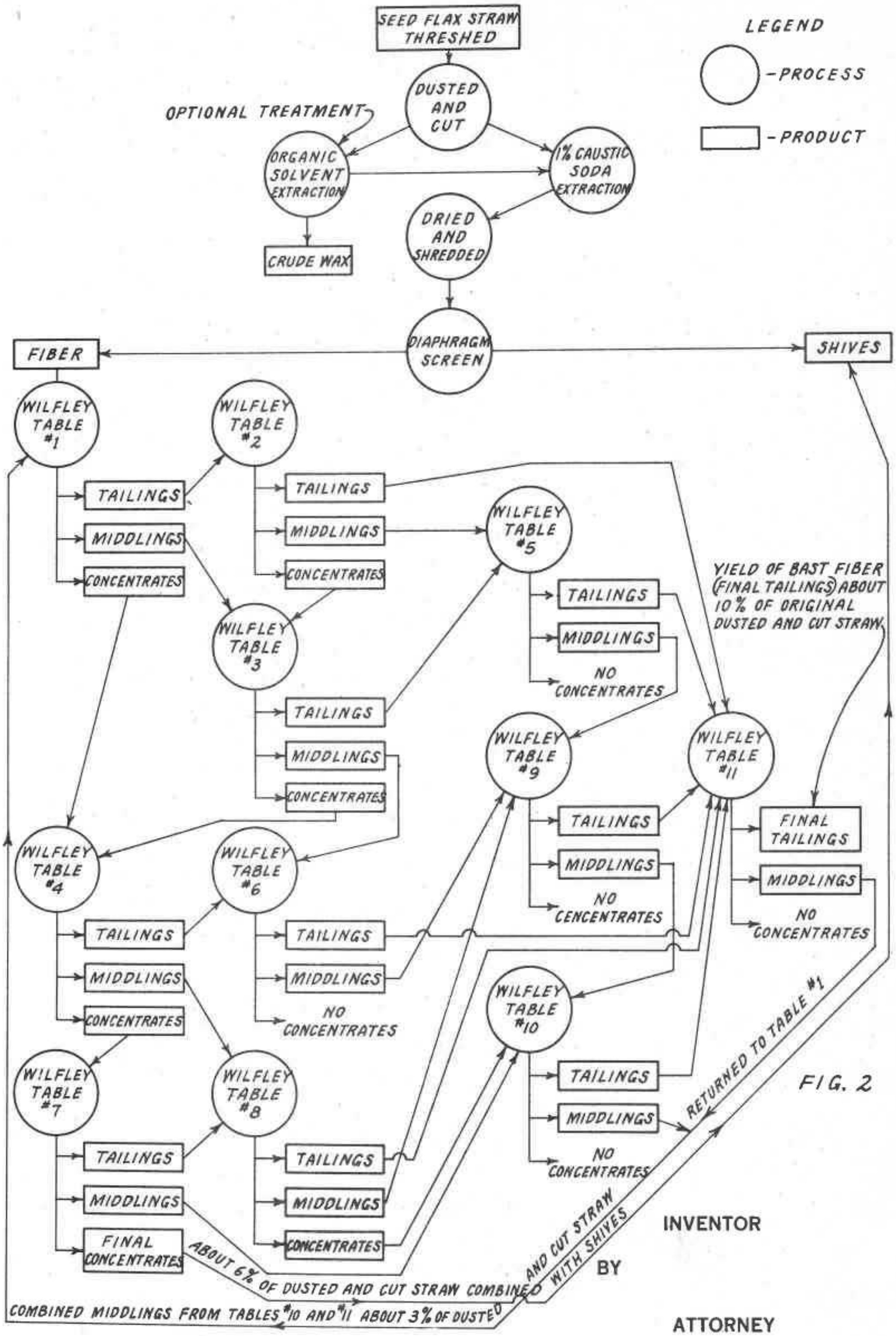

FIG. 2

INVENTOR

BY

ATTORNEY

Figure 2.--Flow sheet for separating bast fiber and shives in seed flax straw by means of diaphragm flat-plate screens and Wilfley tables.

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printing papers. Experiments on the digesting of the shives produced by this process are discussed on pages 15 to 16.

DESCRIPTION OF PULP AND PAPERMAKING EXPERIMENTS

Processing Operations

The methods used at the Forest Products Laboratory for processing the seed flax straw may be classified according to a general sequence of operations but since many variations of treatment were employed all operations were not carried out in every experiment. The operations consisted of (1) dusting and cutting, (2) cooking and washing, (3) dewatering and shredding, (4) bleaching and chlorinating, (5) beating and papermaking. This sequence, it will be observed, is general for most pulp and papermaking processes. A more complete description of the various equipment used in these experiments is given in the appendix. (p.23).

Types of Material

At the start of the work a number of digestions were made in autoclaves with a fine grade of commercial tow. Most of the work carried on later, however, was with a medium grade of tow. In a great many tests the medium tow was dusted with a loss of from 25 to 30 percent of its weight and thus it approached the grade of fine tow in quality. Both autoclave and semicommercial digestions were made with the dusted and undusted medium tow.

A large loss of bast fiber occurs in the commercial towing operation. In an experiment to recover some of this fiber a tow manufacturer produced a product which he called shaker tow. It was prepared by shredding and dusting the towing waste on shaking screens. This material was much shorter fibered than upholsterers tow. An analysis showed it to contain a high percentage of bast fiber and about half the lignin content of the original flax straw (t. 30). Several bales of this material were obtained for cooking tests.

Considerable study was also accorded the pulping of the entire straw. This included both straw containing a large amount of chaff and other extraneous matter and straw that had been dusted.

The pulping of nearly pure bast fiber was discussed in connection with the Wilfley table separation experiments (p. 6). In the course of work in a commercial laboratory on the utilization of seed flax straw for textile products, a fiber was produced by methods common to that industry, that is, by retting, breaking, picking, and carding. This fiber contained only a small amount of shives and appeared to be equal in grade to the fiber of unbleached linen. The material thus seemed suitable for high grade papers, such as bonds, writings, and condenser papers, for which new unbleached linen cuttings are now used. A quantity of this material was furnished to the Forest Products Laboratory for pulping tests. In addition to these relatively pure fiber materials, several cooks of unbleached linen rags were made, chiefly to determine the limitations of the experimental equipment in the handling of materials of known commercial value.

In any scheme for the utilization of seed flax straw in pulp and paper it is desirable that the entire straw be utilized, otherwise the venture may not be an economic possibility. For this reason some tests were made with commercial towing mill waste although this material did not receive so much attention as the entire straw or the several grades of tow mentioned.

In further regard to the complete utilization of the straw, experiments were made at the Forest Products Laboratory on the properties of flax wax. It was found in the separation experiments with the Wilfley table that the straw might to advantage (although not essential to the process) be extracted with an organic solvent, such as alcohol-benzol mixture, in the first step of the process. Upon evaporation of the solvent, a dark green, waxy and gummy residue was obtained. The properties and possible commercial value of this substance are discussed on page 17.

Effects of Various Pulping Chemicals

Upon the recommendation of persons experienced in the treatment of flax straw and linen the investigation here reported embraced pulping experiments with calcium hydroxide, sodium hydroxide, sodium sulphide, and combinations thereof. The basis of the recommendation was that in the processing of linen the physical properties of the fiber were much less impaired by lime treatments than by the stronger alkalies. Pectin is known to be closely associated with the cellulose of linen fiber. It was considered possible that the lime would cause a precipitate of calcium pectate to form on the fiber and thus produce a protective coating.

A number of other chemicals both alone and in various combinations were employed. Most of these were alkaline reagents. With the exception of the experiments made with chlorine, little work was done with acid reagents since the results of scout tests showed little promise. The complete list of the chemicals used in these tests and the data obtained are given in the appendix. Only the more important of these reagents are discussed here.

Calcium Hydroxide

Calcium hydroxide (milk of lime process) had been used in previous work at the Bureau of Plant Industry on an extra fine grade of tow. That work as well as some other tests made later in this study demonstrated that lime is suitable either for the treatment of bast fiber containing a very small amount of shives for the production of fine papers, or for the treatment of the entire straw for the production of a strawboard, although in the latter case it was found, as shown later, that lime is not the best chemical that may be used. The amount of chemical available for reaction at any given time in a digestion with the relatively insoluble calcium hydroxide apparently has very little deleterious effect on the bast fiber. However, the resolving action of the chemical on the ligneous shives is also very mild and as a result little pulping action is obtained when shives in any appreciable quantity are present.

Sodium Hydroxide and Sodium Sulphide

Sodium hydroxide or caustic soda (soda process) and a mixture of sodium hydroxide and sodium sulphide in various proportions (sulphate process) were used under many variable conditions. From detailed studies of the reactions of these chemicals on straw and tow in the bomb and autoclave digesters (tables 17 to 22) the following may be summarized: A chemical analysis of the pulps shows an increase in the purity of the soda pulp as the amount of sodium hydroxide and time of digestion at a given constant temperature were increased. This is shown by an increase in the content of cellulose and by a lowering of the copper number and the solubility of the pulp in 1 percent caustic soda solution. At the same time, however, increased purity was accompanied by greater losses of cellulose. The caustic-sulphide mixture (sulphate process) causes the solution of more lignin with only a little more solution of cellulose than does a sodium hydroxide digestion under the same conditions. In the course of a sulphate digestion the solution of the lignin is much slower than that of those soluble substances that may collectively be called "other than lignin", which include pentosans, easily hydrolyzed cellulose, and extractives. In a sulphate digestion the sodium hydroxide is rapidly consumed during the rising temperature period. The sodium sulphide, on the other hand, does not appear to enter the reaction until at the end of that time. During the maximum temperature period both the hydroxide and the sulphide are consumed at slow but uniformly constant rates.

Combinations of Calcium Hydroxide, Sodium Hydroxide, and Sodium Sulphide

The digestions of fine and medium tow made with combinations of calcium hydroxide, sodium hydroxide, and sodium sulphide are given in tables 5 and 6 . The addition of calcium hydroxide was noted to retard the reaction on both fiber and shives alike. When cooking conditions were made of sufficient severity to pulp the shives, by increasing the proportion of sodium hydroxide, the fiber was greatly impaired. It thus appeared that the same results would be obtained without the addition of lime. Papers made from some of the well cooked pulps produced with these chemicals are discussed on page 13.

Combinations of Sodium Sulphite, Sodium Hydroxide, and Sodium Sulphide

Digestions of both straw and tow with sodium sulphite alone, in mixture with sodium hydroxide, and alternately with sodium hydroxide or sodium hydroxide-sodium sulphide mixtures have shown this chemical to be a mild pulping reagent (tables 10,12,16). The speed and severity of the reaction, when measured in terms of yields of pulp residues, is less for sodium sulphite than for the hydroxide or hydroxide-sulphide mixtures discussed in the foregoing paragraphs (fig. 3). For equal degrees of lignin removal, less cellulose is lost by digesting with sodium sulphite than with sodium hydroxide. For equal amounts of the two chemicals, more lignin is removed by sodium hydroxide than by sodium sulphite.

When straw was digested first with 20 percent of its weight of sodium sulphite and then the residue digested with 10 percent (original straw base) of sodium hydroxide the amount of lignin dissolved was practically equal to the sum of the lignin losses caused by the action of the two chemicals directly on the straw; but when the order of the digestions was reversed the solubility of the lignin in the sodium sulphite solution was found to have been lowered by the preliminary mild treatment with sodium hydroxide. Further, when 20 percent of sodium sulphite and 10 percent of sodium hydroxide were mixed together the combination exerted only a slightly greater pulping action than the sulphite alone. This and other effects noted indicate that in a digestion with sodium sulphite alone the solution of the material, particularly of the lignin constituent, is a reaction of the bisulphite radical mainly, whereas a digestion with the mixture of chemicals the reaction of the bisulphite radical (although present in as great amount) is suppressed and the principal reaction is with the hydroxyl radical. These effects are shown by the data given in tables 23 and 24.

Combinations of Sulphur and Sodium Hydroxide

The effect of a combination of sulphur and sodium hydroxide as compared with sodium hydroxide alone in the cooking of wood, is known to be of benefit in the increasing of yields and the decreasing of bleach requirements. A study of several combinations of these chemicals in the digestion of medium tow (tables 8 and 9) showed that the degree of pulping obtained was dependent more on the amount of excess sodium hydroxide

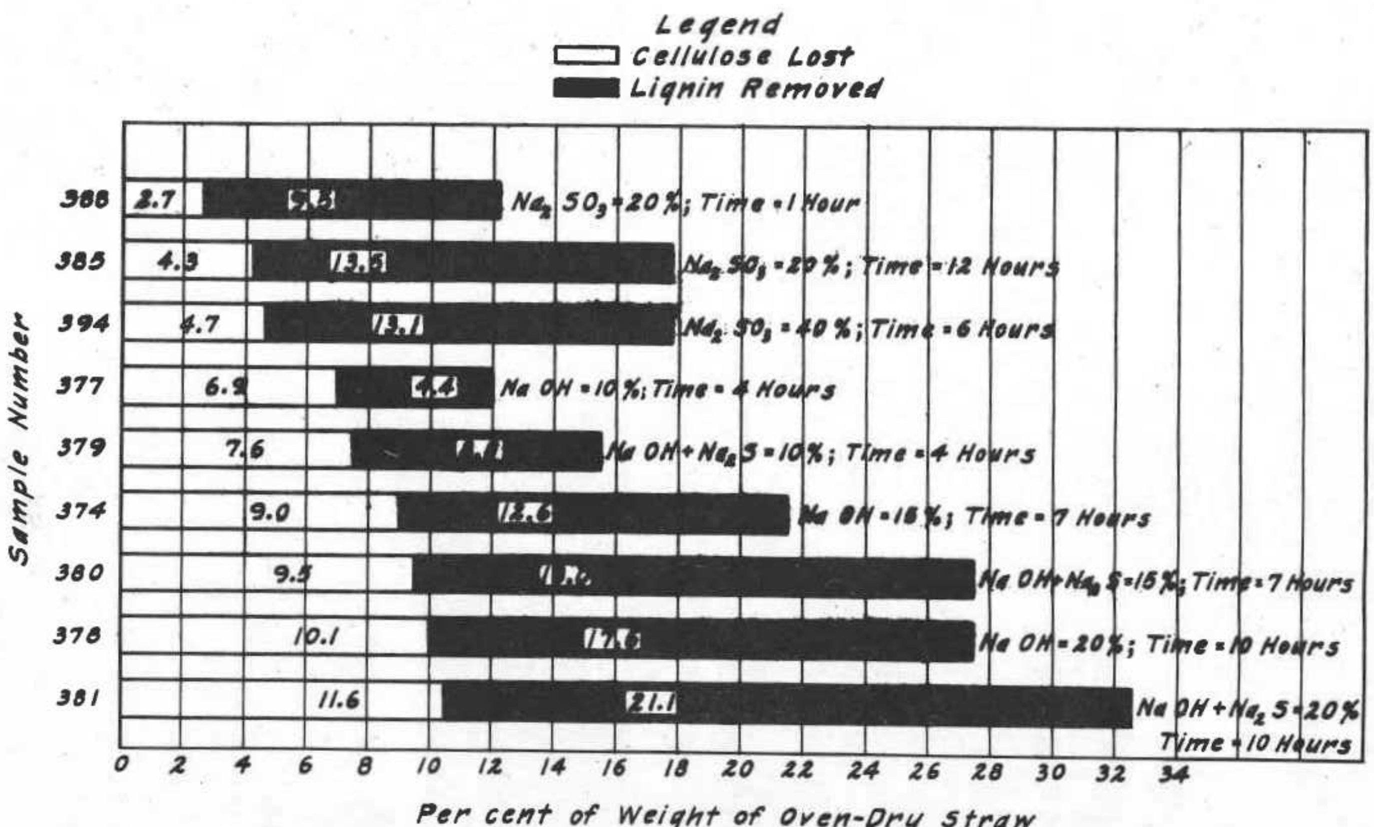

Figure 3.--Lignin removal and cellulose loss in flax straw digested with sodium sulphite, with sodium hydroxide, and with a mixture of sodium hydroxide and sodium sulphide.

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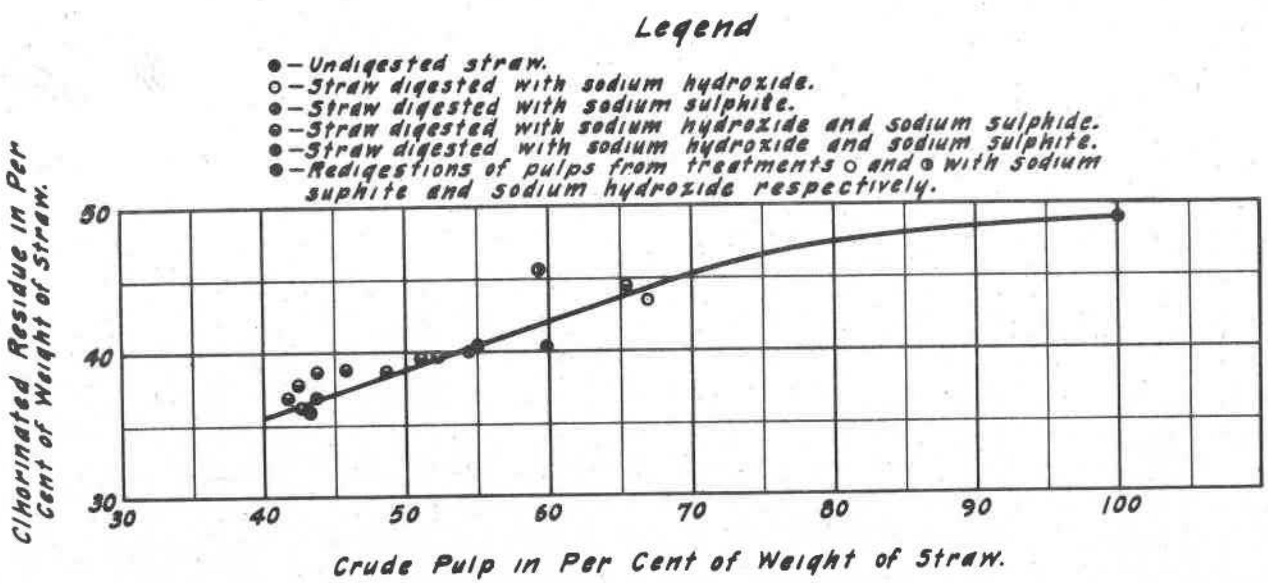

Figure 4.--Relative yields of chlorinated residue and of crude pulp, expressed as percentages of the weight of the uncooked oven-dry straw.

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present than upon the total available alkali that might be calculated theoretically. The reactions involved are not well known but the evidence indicates the following to be the most probable. When sulphur is heated in an excess of sodium hydroxide solution, about 75 percent of it is converted to sodium sulphide and about 25 percent of it to sodium sulphate. After the excess of sodium hydroxide has been partially consumed in the cooking reaction the sodium sulphide is converted into almost equal parts of sodium hydroxide and sodium sulfhydrate. The total available alkalinity of this type of cooking liquor is, therefore, the excess sodium hydroxide plus the sodium hydroxide produced by the transition of the sodium sulphide.

There was also evidence that when the tow was changed into the digester at the same time as the sodium hydroxide and sulphur, the material consumed most of the hydroxide before the reaction with the sulphur occurred. When the two chemicals were allowed to react before charging the tow the degree of cooking was reduced. Although well digested and bleachable pulps were obtained, the results did not indicate that this method of cooking was more advantageous than the ordinary sulphate process. It was also demonstrated in this series of experiments that when the required amounts of the chemicals to pulp the material were present, the quality of the pulp was about the same, whether low temperatures for long periods of time or high temperatures for shorter periods of time were used.

Chlorine

Chlorine has been used in the laboratory for many years in the isolation of cellulose from plant materials. It is only in the past 15 years that manufacturing processes have been developed in which it is used as a pulping agent. The chlorine has been employed both as a gas and as a water solution, but the reactions taking place are, in principle, the same in both processes, the difference being only in the method of operation. In the commercial application of both processes the treatment consists of alternate digestions with sodium hydroxide and treatments with chlorine; consequently the success of the developments depend on the efficient utilization of electrolytic caustic soda and chlorine.

The following summarizes a study of the application of the chlorine water process to the pulping of flax straw which resulted in a sequence of operations of: (1) predigestion, (2) mechanical processing or refining, (3) chlorine treatment, and (4) refining of the pulp for the paper machine. The predigestion was not confined to the use of sodium hydroxide alone, but other chemicals were used both singly and in combination. The study with sodium hydroxide alone under a wide variety of conditions showed a linear relation between the sodium hydroxide consumed in the predigestion and the chlorine requirement in the chlorine treatment (tables 17 to 19). For each percentage (based on straw) increase of sodium hydroxide consumed about 2 percent (based on straw) less of chlorine was required. Other chemicals used in the predigestion were sodium hydroxide-sodium sulphide mixture, sodium hydroxide-sodium sulphite mixture and sodium sulphite alone. Although the degree of pulping accomplished by these chemicals was found to be of more importance in influencing the quality of the finished chlorinated pulps than the specific properties of the chemicals themselves, certain slight advantages of the hydroxide-sulphide mixture over the hydroxide alone were noted and the pulps prepared from predigestions containing sodium sulphite were of brighter color and higher strength but more hydrated.

The weight of chlorine required to render the lignin soluble in the crude predigested pulp was found to be nearly equal to that of the lignin regardless of the type of predigestion. The yield of chlorinated residue was observed to bear a definite relation to the yield of the crude pulp from which it was isolated. Between the limits of 35 and 45 percent yield of chlorinated pulp (based on original straw) the average gain in cellulose in the chlorinated pulp was 1 percent for each 3 percent increase in the yield of crude pulp (fig. 4).

Pulps prepared by the chlorine process become gelatinized or hydrated very rapidly when processed mechanically. The flax chlorine pulps (tables 25,26) were so susceptible to this effect that it was found necessary to beat or rod mill them after the predigestion and prior to the chlorine treatment. Since the chlorination of a pulp containing iron causes a discoloring that is practically impossible to remove, the usual steel construction of beaters and rod mills must be supplanted with bronze and rubber or other noncorrosive materials. The strength of the chlorine flax pulps was generally in proportion to the amount of chlorine required. On the other hand, the degree of whiteness decreased as the amount of chlorine required increased. At best, however, the color was grayish white. An addition of bleached soda wood pulp to the chlorine flax pulp increased the opacity and softness and slightly reduced the strength of waterleaf paper made therefrom.

PAPER, BOARD, AND CHEMICAL PRODUCTS

PRODUCED FROM FLAX STRAW

Bond and Ledger Papers

The work of both the Bureau of Plant Industry and the Forest Products Laboratory has shown that high grade bond and ledger papers cannot at the present time be made from material containing more shives than may be digested by the milk of lime process and that the use of more drastic cooking agents greatly reduces the strength of the bast fiber. A carded fiber prepared for textile purposes (p. 7), when cooked with calcium hydroxide, bleached, and beaten in a manner similar to that employed in the making of linen paper, yielded a strong white bond paper. These tests demonstrated that high grade paper of the type produced from rags could be made from the bast fiber of seed flax straw. The results are summarized in table 32.

Although it was not possible to produce high grade rag type papers from tow or straw, because of the necessity of using cooking conditions that impaired the strength of the bast fiber, a few bond type papers were made from tow of the grade ordinarily produced from chemical wood pulp. In this class of papers, those made from the pulps of cooks D-39, D-40, and D-46 shown in tables 6 and 11, were among the best produced from medium tow. These pulps were prepared by digesting the material in mixtures of sodium hydroxide, calcium hydroxide and sodium sulphide.

Papers that may be classified as equivalent to medium grade wood-pulp bond were made from the entire flax straw. They were lower in whiteness and contained more dirt particles than those made from the tow just described. Best among those made entirely from the straw were the papers from the pulp of cook B-217-1, shown in the tables in tables 25 and 26. Part of this pulp was treated successively with chlorine water and calcium hypochlorite bleach and part was bleached with the hypochlorite only as indicated by machine runs 1 and 3, respectively. Machine run 2 of this series was a mixture of 85 percent of the hypochlorite-bleached flax straw pulp and 15 percent of a commercial bleached soda-process wood pulp. The addition of bleached soda pulp lowered the strength but increased the whiteness and softness of the sheet.

Bond and writing papers were produced from shaker tow, which is a short fiber recovered from towing waste, by digesting with a mixture of sodium hydroxide and sodium sulphide. Cook D-163, machine run 4 (t. 31) was the best paper produced from shaker tow from the standpoint of color and texture. Cook D-164 machine run 1 was not so white as cook D-163, indicating that more bleach should have been used, but it was stronger. The papers may be classed as equivalent to medium grade rag bonds.

Greaseproof and Tissue Papers

The entire flax straw dusted prior to cooking was found to be suitable for the production of greaseproof and tissue papers. The data for these tests are given in table 27. Several conditions of cooking were employed but it may be of interest to note that the conditions that produced the best results (cooks D-154 and D-158) were very similar to those used for the production of the bond paper from the entire straw as just described except that a higher temperature and longer duration of cooking were used.

A high loss of material occurred on dusting the straw before the cooking, and in addition the yields of pulp on the dusted straw were low when compared with yields obtained from wood. Thus the total loss of material might be considered exorbitant. The use of undusted straw for this grade of pulp may be possible, a fact that was apparently demonstrated in the predigestion of the straw in the chlorination studies previously mentioned, but not investigated in this series of tests. The pulps were partially bleached, that is, to a light cream color. The conditions of beating of these pulps were found to be very important in developing the greaseproof properties. The duration of processing in the laboratory beaters was very prolonged. Apparently a more efficient method of hydrating the stock would be required in a commercial application of the process. Two of the best greaseproof sheets were supercalendered and waxed in a mill producing these specialities and acceptable grades of glassine paper were obtained. Several of the lighter weight sheets demonstrated the possibility of using this type of pulp for tissue manufacture.

Sodium sulphite may also be used to obtain a pulp from medium tow that is suitable for greaseproof paper. Data for cooking by this method are given in table 10 and the paper test data in table 11. Pulp prepared with sodium sulphite was easily hydrated and the resulting papers possessed greaseproof quality to a pronounced degree.

Container Boards

The utilization of flax straw for corrugating board and for heavier boards, such as egg-case filler, has so far as it is known not been attempted although some experimenting has been done toward using it in leather boards (8). The usual method of preparing cereal straws for strawboard is by a relatively mild digestion with lime. In these experiments flax straw, flax towing waste, and oat straw were cooked by the lime process separately and in various mixtures as shown in table 28. None of the boards made from the flax (straw or waste) or of the flax-oat straw mixtures was so good as the oat straw alone.

Flax towing waste was digested mildly with a mixture of sodium hydroxide and sodium sulphide (t. 33) and the pulp combined in various proportions with a partially cooked jack pine sulphate-process pulp for the purpose of making a high test board. The experiments were on a small scale, only sufficient pulp being used to form test sheets by hand. These were tested for bursting strength. The results show that additions of the short-fibered towing waste pulp to the longer-fibered pine pulp caused an increase in the strength of the test sheet until the towing waste pulp exceeded 75 percent of the total. Additions greater than 75 percent caused a decrease in the strength.

In addition to cooking the entire flax straw with calcium hydroxide it was also cooked with sodium carbonate, with sodium bicarbonate, with mixtures of sodium carbonate and sodium sulphite (12), mixtures of sodium carbonate and sulphur (19), and mixtures of sodium hydroxide and sodium sulphide. Calcium hydroxide was found to be the least suitable chemical for softening the shives; soda ash the best. Mixtures of sodium carbonate and sulphur, and of sodium hydroxide and sulphide were particularly effective in increasing the folding strength. The board produced by the latter mixture of chemicals was probably not stiff enough for a corrugating board but it possessed an exceptionally pleasing appearance (t. 29) and might find use where considerable flexibility in the board is required.

A study of the processing of these pulps indicated the rod mill to be more efficient than the beater in respect to both power consumed and the quality of the stock produced. The comparison, however, is subject to qualification as the variables of the beater were not studied in so much detail as those of the rod mill. It was possible to produce a board from rod-milled flax straw pulp, as indicated in table 29 by cook B-210-1, machine run 2, that was superior in strength to the lime-cooked oat strawboard prepared in the Laboratory, as well as a commercial lime-cooked wheat strawboard used for comparison.

A 12-inch width roll of this paper was corrugated in a fiber board mill and gave evidence that the stock would work satisfactorily in a commercial-sized roll. Both single and double lined corrugated boards were made. Although in the estimation of the operators the stock had snap and stiffness, the resulting board had a soft corrugation, that is, the corrugation was easily crushed. The results indicate the possibilities of flax straw in this grade but it is evident some technical details remain to be worked out.

Book Paper

In addition to the experiments on the use of commercial towing mill waste in container boards some work was done on this material for the production of a bleached pulp suitable for book and similar papers. These tests are given in table 34. The high chemical requirement for cooking, the large amount of calcium hypochlorite bleach needed, and the low yield obtained would not encourage the utilization of the material in this manner.

Better results from the standpoint of pulp quality were obtained by digesting shives obtained from the screening and Wilfley table experiments (p. 6). The straw from which this material was obtained had been extracted with alcohol-benzene mixture and boiling 1 percent sodium hydroxide solution prior to screening. The material used for the cooking test was the portion retained on an 8-cut screen plate and represented about 50 percent of the original straw. It was digested with 22.5 percent (oven-dry basis) of sodium hydroxide and 5.5 percent of sodium sulphide for 5 hours, 3.5 hours being at the maximum temperature of 160° C. The yield of pulp was 54.5 percent of the shives taken. The pulp bleached to a light-cream color with 20 percent of calcium hypochlorite bleach. It was a soft, short-fibered pulp and test sheets indicated it to have properties suited for use as part of the fiber composition of book paper. The yield on the basis of original straw is very low when compared to other papermaking materials. Only a low monetary value could, therefore, be set upon it as a raw material if it were to compete with the more commonly used materials. Its use might be feasible in a mill utilizing the entire straw on the basis that any returns from it could be credited to the cost of processing the more valuable bast fiber.

Miscellaneous Paper and Board Products

The use of flax straw in the semirigid type of insulating board is well known but little has been done on the production of a rigid insulating board from this material. A few experiments were made in forming boards of this type from the pulps secured in cooks B-223 and B-225 (t. 29). The pulps were processed in both the beater and the rod mill prior to forming the boards on a small mold about 1 foot square. The rod mill was more efficient than the beater in obtaining a suitable stock. The boards possessed a dark-brown appearance and although no tests were made they seemed to be more flexible than similar commercial boards of the same density.

One of the toughest papers produced was made from medium grade tow cooked according to the conditions shown for cook D-100, in table 13 with a mixture composed of sodium sulphite and sodium sulphide. The pulp was practically impossible of bleaching with calcium hypochlorite. The paper was light brown and of a dense, hydrated texture. It is possible the paper might find use in electrical products where high density and strength are required.

The relative ease with which flax tow pulps hydrate upon beating and when formed into sheets to produce what is called a well closed sheet suggests their probable use in electrical papers. Electrical puncture tests were made[3] on two flax tow papers (cooks D-35 and D-36, Ts. 5,6,11). The tests were made on the sample of paper as submitted, after drying at 110° C. for 30 minutes and after immersion in mineral seal oil at 100° to 110° C. for 15 to 30 minutes. The results shown in table 38, with the dielectric strength of several other materials for comparison, indicate these papers to have excellent insulating properties. Whether such papers from flax will meet the strength requirements is not known. It is probable that much care would be necessary in the manufacture of these papers to insure removal of dirt particles that would be detrimental to the electrical insulation properties.

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[3] Tests made by the Electrical Engineering Department, University of Wisconsin.

Flax Wax

The amount of fatty and waxy substances that may be extracted from seed flax straw by a mixture of 1 part of ethyl alcohol and 2 parts of benzene, by volume, is high in comparison with the amount obtained from other straws. Consideration of the possible commercial value of this extractive is of interest because of the desirability of making a relatively complete use of the straw in any proposed scheme of utilization.

The quantity of the extractive that may be obtained by analytical methods is shown in table 4 to be 3.7 percent. The amount will, of course, vary from sample to sample. When the extraction was carried out on from 10 to 20 pounds of straw the yield of extract was somewhat less, being from 2.5 to 3.0 percent by weight of oven-dry straw. The material obtained is a heterogeneous mixture of dark green, sticky substances and of brown, gum-like substances. When heated to the temperature of the water bath the green materials become fluid and may be poured off. The data in tables 36, 37 give some of the properties of the material and an outline of a series of treatments that caused the separation of a number of its constituents.

Commercial uses for these substances were not studied extensively but the following tests indicated certain possibilities.[4] The fats in the crude wax were saponified with potassium carbonate and the soap emulsion diluted with a water solution of an alkali resistant coal-tar dye. This material was found to produce a smooth, nonoily polish when applied to wood or leather. However, an analysis of costs indicated the cost of extracting the wax from the straw to be from three to four times the market price of the commercial waxes generally used in such preparations.

The crude extract was treated with potassium hydroxide and alcohol to saponify the fatty constituents, dried, and extracted with petroleum ether to dissolve the unsaponifiable constituents. The residue of unsaponifiable matter obtained by evaporating the petroleum ether extract was of a yellow, coagulated, waxy character. The yield was about 18 percent of the crude extract or about 0.5 percent of the straw. Qualitative tests indicated the presence of sterols and an analysis showed the amount to be approximately 1.2 percent of the unsaponifiable matter or about 0.005 percent of the basis of the straw. Although the amount of sterol available appeared to be very small the importance of this compound in nutrition studies prompted the following investigation.

A quantity of the unsaponifiable matter was prepared, dissolved in ethyl ether, and subjected to the radiation of a quartz mercury vapor lamp[5]. Portions of the irradiated wax preparation were added to a basal

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[4] This work was done by the Section of Derived Products, Forest Products Laboratory.

[5] This work was done by Harry Steenbock, Professor of Agricultural Chemistry, University of Wisconsin.

ration in quantities of 1 part, 10 parts, and 100 parts in 50,000, respectively, and fed to rachitic rats for a demonstration of its rickets-curing properties. The basal ration when fed alone to the rats was known to develop a very pronounced rachitic condition that could be readily cured by the introduction of vitamin D. At the end of a 10-day period on the irradiated ration the rats were killed and the distal ends of the radii and ulnae examined for calcium deposits. The degree of calcium deposition was found to be pronounced and indicated that the material submitted to the test contained considerable amounts of an antirachitically activatable sterol which was presumed to be ergosterol.

COST OF PRODUCING FLAX PULPS

The cost of producing pulps from flax straw is shown in table 35. Representative pulps of the various grades that may be produced from straw or tow were selected. The analysis is based on prices of chemicals prevailing in 1935. In calculating the cost of the chemicals, sodium hydroxide was considered as being prepared from soda ash and hydrated lime, sodium sulphide from salt cake, sodium sulphite and bisulphite from soda ash and sulphur, and bleaching powder from hydrated lime and chlorine.

The average overhead or operating cost for a sulphate pulp mill, in the United States, according to cost information gathered by the Timber Conservation Board in 1931, was $12.78 per ton, exclusive of chemicals. The items entering into this cost were as follows:

Labor.....................	$ 3.68
Steam.....................	2.81
Power.....................	1.42
Repairs...................	.28
Mill supplies.............	1.65
All others................	.80
Depreciation..............	2.14
Total.......	$12.78

In the sulphate process the sodium content of the spent liquor is recovered in the form of soda ash (carbonate) and used again in the cooking process. The efficiency of recovery will vary from 80 percent (on the basis of the sodium oxide equivalent) in some of the older installations to 93 percent reported for the more modern plants. For purposes of calculation the average of 87 percent has been used in this analysis. Salt cake is introduced during the recovery operation and reduced to sodium sulphide. The efficiency of the reduction of the salt cake may be assumed to be about 90 percent.

The foregoing operating costs and efficiency ratings have also been used in estimating the cost of producing those pulps made by processes not strictly sulphate since the general methods are the same.

Information on the overhead costs of operating a modern bleaching plant is not generally available. For a bleaching plant representing an investment of $80,000, the overhead cost of operating the plant may be estimated at approximately $3.70 per ton of air-dry bleached pulp, divided as follows:

Operation	$1.07
Maintenance	.11
Depreciation	.50
Taxes	.27
Insurance	.02
Maintenance material	.03
Supervision	.44
Steam	.10
Power	.86
Water	.30
Total	$3.70

In modern bleaching systems about 1.2 pounds of hydrated lime are required per pound of chlorine to be absorbed. Of this chlorine, 0.99 pound is available for the bleaching reaction. Hence, each pound of standard bleaching powder (p. 26) used in bleaching the pulp represents the consumption of 0.354 pound of chlorine and 0.425 pound of hydrated lime. In the cost analysis it was assumed that the flax pulps lost 10 percent in weight by bleaching. This loss may have been an overestimate in some cases.

Conforming with customary practice, the material and manufacturing costs have been estimated on the air-dry basis with the usual arbitrary assumption that air-dry pulp contains 10 percent moisture. All cost items have been rounded off to the nearest 5 cents.

This analysis shows that the amounts and cost of chemicals required to pulp flax are not greater than are required for wood pulp. The yields, however, are from 10 to 20 percent lower for flax than for wood. The relation between the prices of flax straw and tow and that of wood is, therefore, the governing factor from the standpoint of costs in the utilization of flax for pulp and paper.

SUMMARY AND CONCLUSIONS

The waste flax straw from linseed production consists of a mixture of long, relatively pure, cellulose fibers and of short, lignified fibers similar to those of the hardwoods. The reactions of various chemicals, alone and in combination, on this material were found to be very similar to the reactions with wood and, therefore, the methods of cooking developed for the production of flax straw pulp are very similar to those employed in the pulping of wood.

By mechanical processes the shives, chaff, and other detritus may be separated in various degrees from the long, strong bast fibers. The relative proportions of bast fiber and shives in the mixture determine the severity of the chemical treatments required and the quality of the resulting pulp. Thus, depending on the choice of reagents and the proportions of bast fiber and shives in the material, a wide variety of papers was produced. When the bast fiber was freed from shives to such a degree that it could be reduced to a bleachable pulp by the milk of lime process, a high grade of pulp similar to that produced from linen rags was obtained. This pulp was suitable for use in bond and ledger papers. The processing of material containing varying proportions of bast fiber and shives and requiring relatively more drastic treatment resulted in an impairment of the natural strength of the bast fiber so that the pulps obtained were equivalent in quality to wood pulps. These pulps were found suitable for the medium grade bonds, greaseproof, tissue, book, and magazine papers, and for container and wall boards.

A study of the organic solvent extractives from seed flax straw indicated that they have potential commercial value.

The versatility of the seed flax straw might appear to favor its utilization since it would seem possible to turn from one grade of paper to another as conditions warranted. The complete equipment to carry on such an operation, however, would undoubtedly require a large capital investment. Assuming that a satisfactory and efficient process for the separation of bast fiber and shives was developed a balance between the production of the high grade papers and the cheaper papers would be necessary; possibly with the higher grade papers absorbing some of the cost of manufacture of the lower grade in order that the latter could compete with similar papers made from wood.

The problem of seed flax straw utilization resolves into the relation of the cost of equivalent quantities of the proposed material and the standard materials in common use. This cost must include, not only the cost of the materials themselves, delivered to the mill yard, but also the cost of handling, storage, and deterioration. It has not been possible in this investigation to analyze the cost of producing high grade paper from flax as compared with the cost of production from linen rags. In regard to the lower grades of paper, however, it appears that the price of pulpwood must rise considerably above its present level before it will be feasible to replace it with flax straw.

The relatively ideal objectives of this investigation as enumerated in the introductory pages have not been attained. There appears to be no immediate possibility of a complete utilization of what is now a large agricultural waste in linseed production or of becoming nationally independent in regard to the supply of material for paper for which linen rags now form the chief raw material. The information gained in the pulping of seed flax straw has, however, added to the store of facts relative to possible future supplies of raw materials. This study, as well as studies on wood and other plant materials, indicates that there probably will never be a lack of material from which to manufacture cellulose.

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Description of Equipment

Since many variations of treatment were employed in the experiments here reported, all the equipment described in the following pages was not used in every test. It has been classified, however, to conform in a general way to the sequence of operations performed on the material in process.

Dusting and Cutting

The straw or tow was dusted by hand over a 4-inch mesh wire screen, approximately 2 feet wide and 4 feet long, to remove extraneous chaff, leaves, and the like.

To facilitate packing into the digesters or for other subsequent treatment the material was cut or chopped into lengths varying from 2 inches for the longest strands of bast fiber to 1/8 of an inch or less for some of the shives. The equipment used was a rag cutter such as is employed for the preparation of rags for cooking. For small scale cooking tests (bomb tests) the material was ground further so as to pass a 40-mesh standard sieve.

Cooking and Washing

The material was digested or cooked in several types of pressure vessels. A large number of tests were made to study the chemical reactions with numerous chemicals and conditions of treatment. If an accurate study of these reactions was being made a small bomb containing 25 grams of the finely ground material was used. The cubic capacity of the bomb was 350 cc. The bomb was immersed in an oil bath where the temperature was controlled by an electrical thermostat to within $\pm$ 0.15° C. of the desired temperature (10).

Larger scale digestions were made in a battery of three rotating, spherical, steel autoclaves of approximately 3 gallons capacity, shown in figure 5. The amount of material used in these autoclaves was from 1.5 to 2.0 pounds. The autoclaves were steam jacketed and the temperature was controlled by means of steam regulating valves. A description of the construction of these autoclaves has been published (15).

Semicommercial digestions were made on a 50 to 75-pound scale in a rotating, vertical-type digester (20, p. 14) and on a 200 to 300-pound scale in a rotating, horizontal, boiler-type rag digester. The

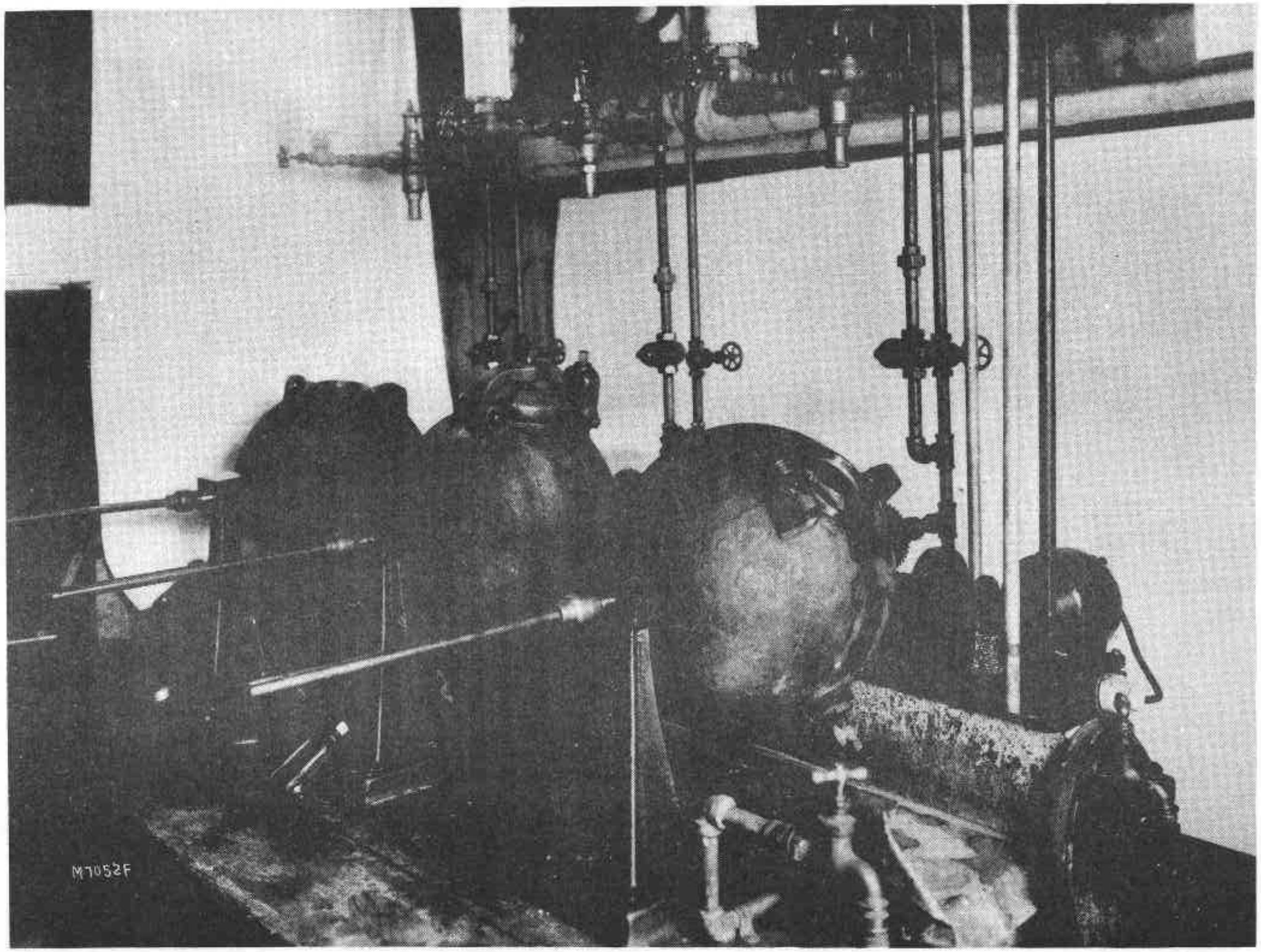

Figure 5.--Forest Products Laboratory cast-steel autoclaves.

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horizontal digester, formerly used by the Bureau of Plant Industry and subsequently installed at the Forest Products Laboratory, has been described by Brand and Merrill (2, p. 22). The vertical digester was heated both by steam directed into the digester and by steam in a jacket that covers the lower half. The heating of the horizontal digester was by direct steam only. At the end of a digestion in the vertical type digester the contents were discharged by means of high steam pressure into a wooden tank with a perforated metal bottom where the spent liquors were permitted to drain away. The horizontal digester could not be emptied in this manner, but had to be cooled by exhausting the steam pressure to the atmosphere and the admission of cold water. When sufficiently cool, the lid was removed and the contents washed into a drainer situated below the digester.

The pulps were washed free of spent cooking liquors in boxes provided with fourdrinier wire bottoms. The hose used in washing the pulps was sometimes fitted with a nozzle to obtain agitation of the pulp in the box. The force of the water from the nozzle also caused much finely divided material to be washed out. This fine material, consisting principally of disintegrated shives, was highly colored, and its removal, although causing a loss of fibrous material, aided in the securing of a whiter pulp upon bleaching.

Dewatering and Shredding

To facilitate subsequent storage and handling, the water content of the digested material was reduced by pressing in hydraulic presses, two sizes of which were available, commensurate with the scale of the digestion. The press cakes of pulp from the 2-pound cooks were broken by hand and sampled directly for the determination of the moisture content. Those from the larger scale digestions were disintegrated in a semicommercial sized, swing-hammer shredder, and the shredded pulp sampled for the moisture determination. The shredder was also used to disintegrate dried material in the experiments on separation of bast fiber and shives.

In some of the work, particularly that in connection with the Wilfley table, water was removed from the pulp by passing it over a semicommercial-sized wet machine. It was necessary, in these cases, to shred the pulp finely in order to operate the wet machine successfully. Also in some experiments the pulp prior to passing over the wet machine was screened on a flat-plate diaphragm screen. Experiments in which this equipment was used were principally those on the separation of bast fiber and shives.

Bleaching and Chlorinating

The ordinary process of bleaching with calcium hypochlorite was done in small scale tests in glass jars provided with motor-driven glass stirrers, or in the porcelain jars of a pebble mill from which the charge of pebbles had been removed. Larger quantities of pulps were bleached in a special bleaching barrel similar in design to a small cement mixer (5), or in the various small-sized beaters described later.

Pulps were treated with chlorine water in a wooden drum of about 125 gallons capacity into which quantities of the chlorine water of known strength and volume could be charged from a mixing apparatus while the drum was rotating with the pulp charge. The operation of the apparatus, shown in figure 6, has been described previously (16).

Beating and Papermaking

Beaters with capacities of 5, 20, and 40 pounds each were used for processing the pulps. These beaters were equipped with the usual type of drum washers. A rod mill, 3 feet in diameter by 5 feet in length and lined with plates heavily coated with rubber, was also used (13), particularly for processing the pulps prior to the treatment with chlorine water and in the strawboard experiments. A semicommercial-sized jordan was used for the final processing before making the pulp into paper.

The pulps processed on a semicommercial scale were made into paper or strawboard on a 15-inch width paper machine (20, p. 19) equipped for forming the sheet on either a cylinder mold or a fourdrinier wire. The machine was equipped with two pairs of press rolls, eight steam-heated driers, and a stack of seven, cold, calender rolls. The majority of papers made in this work were waterleaf, that is, without size or loading.

Tabular Data

During the course of the work described in the preceeding pages much data was collected on the pulping of flax. From these data only the following representative tables have been selected for presentation. Their chief value lies in placing detailed information in the hands of research workers in order that duplication in future work on flax pulping may be avoided.

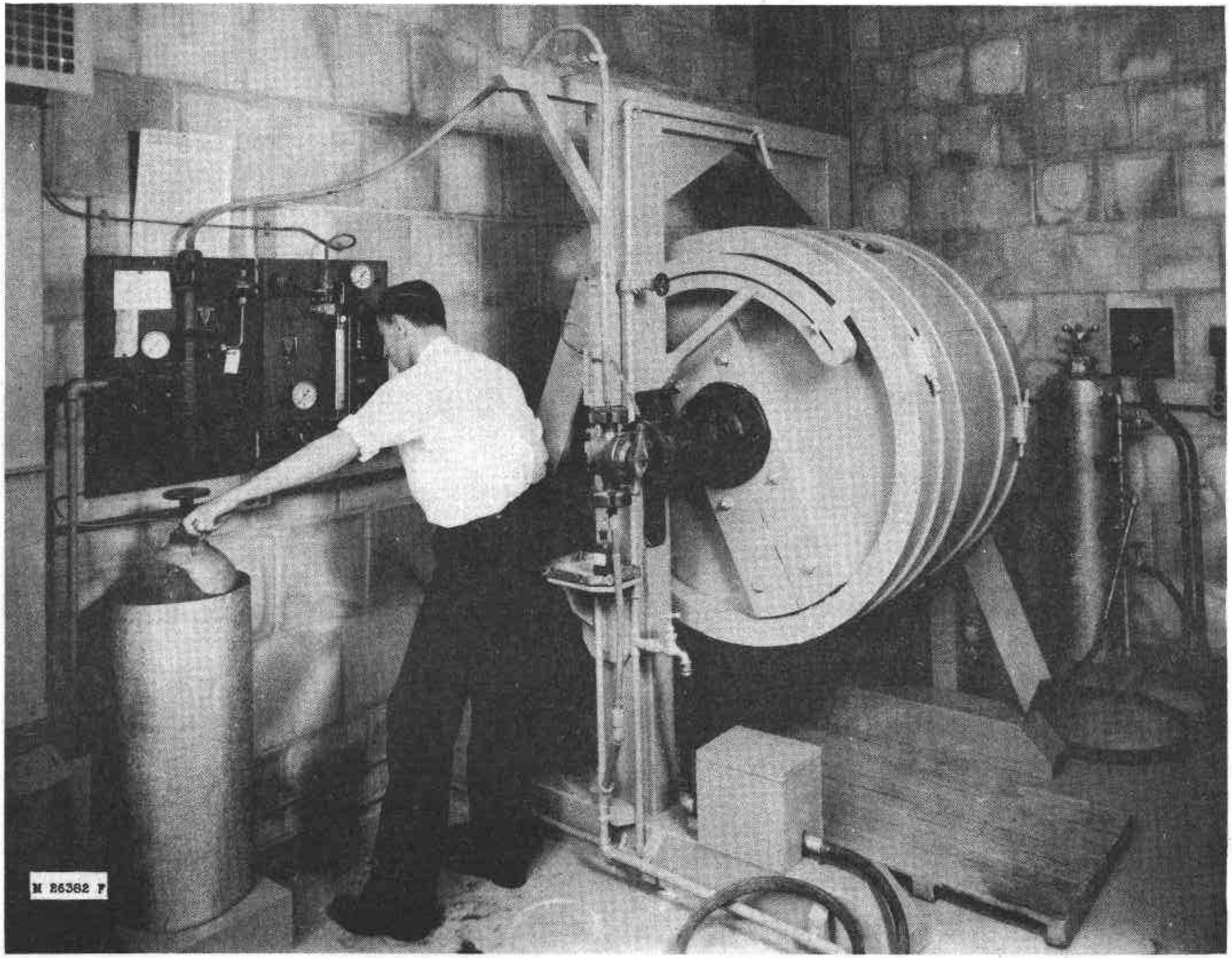

Figure 6.--Apparatus for the treatment of pulp with chlorine water.

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Definitions of Terms and Units of Measurements Used in Tables

Footnote 1 appearing in each table refers, except where otherwise noted, to the following definitions of terms and measurements used in the column headings.

Chemical symbols: Na(OH), sodium hydroxide; Na_2S, sodium sulphide; NaHS, sodium sulfhydrate; Na_2SO_3, sodium sulphite; $NaHSO_3$, sodium bisulphite; $Na_2S_2O_4$, sodium hydrosulphite; Na_2CO_3, sodium carbonate; $NaHCO_3$, sodium bicarbonate; Na_3PO_4, sodium phosphate; Na_2O_2, sodium peroxide; NaCl, sodium chloride; Na_2SO_4, sodium sulphate; $Ca(OH)_2$, calcium hydroxide; $Ca(SH)_2$, calcium sulfhydrate; $CaSO_3$, calcium sulphite; Cl_2, chlorine; S, sulphur; Zn, zinc.

Percentages or proportions are based on oven-dry weights.

The amounts of chemicals charged or used in the digestions, unless otherwise noted, are expressed as pounds per 100 pounds of fibrous material undergoing digestion.

The concentration of chemicals is expressed as grams per liter of cooking solution.

The volume of cooking liquor used is expressed as gallons per 100 pounds of fibrous material undergoing digestion.

The amounts of chemicals consumed in the digestion, unless otherwise noted, are expressed as percentages of the amounts of chemicals used. In some cases where mixtures of chemicals are used the consumption of each chemical may be given; in other cases the consumption may be based on the total chemicals charged or on the total available alkali expressed as sodium hydroxide.

The yield of pulp, unless otherwise noted, is expressed as a percentage of the oven-dry weight of the material put into the digester.

Cook numbers with prefix "A" were made from 1.5 to 2.0 pounds of fibrous material; prefix "B", 200 to 300 pounds; prefix "D", 50 to 70 pounds; no prefix, 25 grams of material ground to a sawdust-like powder.

Bleaching powder is expressed on the basis of standard powder, that is, calcium hypochlorite containing 35 percent of chlorine available for the bleaching reaction. The equivalent amount of the standard powder used is expressed as a percentage of the pulp undergoing bleaching treatment.

The machine made papers and pulp test sheets were tested in accordance with methods given in the Forest Products Laboratory Manual of

Standard Methods.[6] The samples prior to testing were brought to a moisture equilibrium in an atmosphere of 65 percent relative humidity at 72° F. The ream weight basis used is the weight of 500 sheets each 24 by 36 inches. The bursting strength is expressed in points, that is, the pounds per square inch bursting strength divided by the ream weight in pounds. The tearing strength, which is the force required to tear the sheet, is expressed in grams per pound per ream. The tensile strength is expressed as the length in meters of a strip of the paper 15 milimeters wide, which if suspended at one end would break by its own weight. The tearing, tensile, and folding strengths reported are the average of an equal number of tests of the paper in each direction, that is, the length and width of test sheets or, the "in the machine" and "across the machine" directions of machine made papers. The whiteness of the paper is expressed on the basis of the whiteness of magnesia as 100.

The chemical constituents determined by analysis of the raw materials or of the pulps, unless otherwise noted, are expressed as percentages of the samples analyzed.

Index of Chemicals Used in Pulping Tests

Chemical	Table
Sodium hydroxide........................	5, 17, 18, 19, 21, 22, 23, 24, 25, 26.
Sodium phosphate........................	15.
Sodium sulphite........................	10, 16, 23, 24, 25, 26, 27, 35.
Sodium carbonate........................	29, 35.
Sodium bicarbonate......................	29.
Calcium hydroxide.......................	28, 29, 32.
Calcium sulfhydrate.....................	14.
Chlorine................................	17, 19, 20, 25, 26.
Sodium hydroxide and sodium **sulphide**....	5, 7, 20, 21, 22, 23, 24, 25, 26, 27, 29, 31, 34, 35.
Sodium hydroxide and sodium sulphite....	7, 23, 24, 25, 26.

[6] Manual of Standard Testing Methods for Pulpwood, Pulp, Stuff, and Paper. Compiled by Section of Pulp and Paper, Forest Products Laboratory (1928). Mimeographed report.

Chemical	Table
Sodium hydroxide, sodium sulphite, and sodium sulphide..................	13.
Sodium hydroxide, sodium bisulphite, and sodium sulphide......................	12.
Sodium hydroxide, sodium sulphite, and calcium hydroxide.....................	5, 6, 35.
Sodium hydroxide, sodium sulphite, and calcium hydroxide.....................	7.
Sodium hydroxide and calcium hydroxide..	5.
Sodium hydroxide and sulphur............	8, 9, 35.
Sodium hydroxide, sulphur and calcium hydroxide...........................	8.
Sodium hydroxide and sodium phosphate....	15.
Sodium hydroxide and sodium hydrosulphite............................	7.
Sodium hydroxide, sodium hydrosulphite, and calcium hydroxide................	7.
Sodium hydroxide and calcium sulphite...	7.
Sodium hydroxide, zinc, and calcium hydroxide...........................	7.
Sodium hydroxide and sodium peroxide....	7.
Sodium carbonate and sulphur............	29.
Sodium carbonate and sodium sulphite....	29.
Sodium carbonate and calcium hydroxide..	7, 32.
Sodium sulphite and sodium sulphide.....	13, 35.
Sodium sulphide and calcium hydroxide...	7.
Sodium sulfhydrate and sodium chloride..	14.
Sodium sulfhydrate and sodium sulphate..	14.
Ethyl alcohol and benzene..............	34, 36, 37.

Table 1.--Area devoted to flax seed culture[1] in the United States, by thousands of acres, 1899-1935

Year	Iowa	Kansas	Michigan	Minnesota	Missouri	Montana	Nebraska	North Dakota	South Dakota	Wisconsin	Wyoming	Other States	Total
[2]1899	126	192	1	567	101	(3)	76	774	302	11	....	2	2,153
[2]1909	15	45	.....	355	21	38	3	1,068	519	9	1	(3)	2,074
[2]1919	10	12	1	288	......	129	1	650	159	7	1	.....	1,258
[4]1922	8	20	.....	310	......	84	3	521	162	4	1	.....	1,113
[5]1924	8	57	(6)	712	(6)	246	8	1,873	548	8	(6)	9	3,469
[5]1926	15	38	(6)	814	(6)	165	7	1,380	475	11	(6)	[7]2	2,907
[5]1928	19	25	(6)	726	(6)	183	8	1,143	554	9	(6)	8	2,675
[5]1930	20	37	.....	742	2	481	28	1,677	702	7	36	.....	3,732
[4]1932	19	46	.....	689	2	214	3	826	165	6	5	.....	1,975
[4]1934	16	50	.....	580	2	19	.....	268	17	5	1	[7]11	969
[4,8]1935	18	50	.....	679	3	76	4	1,005	190	6	2	[7]38	2,071

[1]The amount of straw produced may be estimated approximately by assuming three-quarters of a ton per acre.

[2]Bureauof Census, U. S. Dept. of Commerce.

[3]Less than 100 acres.

[4]Bureau of Agricultural Economics, U. S. Dept. of Agriculture.

[5]Bureau of Foreign and Domestic Commerce, U. S. Dept. of Commerce.

[6]Separate record not available.

[7]One state only.

[8]Preliminary estimate.

Table 2.--Flax seed production[1] in thousands of bushels for world and selected countries -- 1920-1934

Crop year[2]	World	Selected countries							
		Argentina	Canada	India	Lithuania[3]	Poland	Union of Soviet Socialist Republics	United States	Uruguay
1921	113,534	60,006	7,998	16,760	1,011	637	9,204	10,900	966
1923	98,745	47,577	5,008	17,440	1,108	1,816	11,043	10,520	719
1925	131,221	45,084	9,695	18,520	1,332	1,872	16,960	31,237	1,542
1927	153,945	80,783	5,995	16,080	1,574	2,472	20,877	18,537	1,970
1929	150,000	78,377	3,614	13,920	1,000	2,413	23,690	19,140	2,030
1931	155,100	70,264	4,399	15,200	1,532	2,335	29,957	21,287	5,056
1933	133,000	62,006	2,719	16,640	626	1,640	31,494	11,671	1,475
1935	149,000	79,720	910	15,040	1,014	2,179	27,558	5,213	3,402

[1]Bureau of Agricultural Economics, U. S. Department of Agriculture, biennial survey.

[2]Harvest year in Southern Hemisphere included with preceeding year in Northern Hemisphere.

[3]Flax and hemp.

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Table 3.--Dimensions of the cells of flax straw pulp[1]

Component	Length			Width			Ratio total length to total width
	Maximum	Minimum	Average	Maximum	Minimum	Average	
	Mm.	Mm.	Mm.	Mm.	Mm.	Mm.	Mm.
Pith cells (from central portion of the stalk)	0.14	0.08	0.10	0.08	0.06	0.06	1.5
Epidermal cells	.11	.07	.08	.03	.01	.02	4.3
Short parenchyma cells	.13	.09	.11	.02	.01	.02	7.2
Long parenchyma cells	.40	.18	.29	.04	.02	.03	9.2
Spiral, pitted and other vessels	(2)	(2)	(2)	.02	.009	.011	....
Wood fibers (from the woody portion of the stalk)	.426	.16	.20	.013	.009	.011	17.5
Bast fibers (the long fiber of the plant)	64.0	5.0	....	.039	.010	.019	....

[1]Utilization of American flax straw in the paper and fiber board industry, U. S. Dept. Agr. Bull. 322.

[2]Extending throughout the length of the plant.

Table 4.--Chemical composition of seed flax straw

(Expressed as percentages by weight of the oven-dry material)

Constituent	Bast fiber	Shives	Entire straw
Original materials	100.0	100.0	100.0
Soluble in ethyl alcohol-benzene mixture	2.3	6.5	3.7
Insoluble in ethyl alcohol-benzene mixture:			
Soluble in one percent sodium hydroxide solution	29.2	24.2	32.1
Insoluble in one percent sodium hydroxide solution:			
Cross and Bevan cellulose	67.2	47.1	48.5
Pentosans in cellulose	2.1	12.8	8.5
Pentosans	2.8	18.3	12.3
Lignin	2.9	24.1	15.8
Soluble in hot water	11.1	5.1	9.9
Cross and Bevan cellulose	71.9	57.0	51.3
Pentosans in cellulose	2.4	11.4	8.2
Pentosans	6.0	25.6	19.4
Lignin	10.1	27.9	24.2
Lignin			25.8
Ash	4.7	3.5	6.0
Ash soluble in water	2.8	1.3	2.1

Table 5.--Digestion of fine flax tow with mixtures of sodium hydroxide, sodium sulphide, and calcium hydroxide[1]

Cook number	Previous treatment	Chemicals charged: Kind	Chemicals charged: Amount	Chemicals charged: Concentration	Volume of cooking liquor	Duration of cooking: To maximum temperature	Duration of cooking: At maximum temperature	Maximum temperature	Total chemicals consumed	Yield of crude pulp	Remarks
			Pounds	G. per l.	Gallons	Hours	Hours	°C.	Percent	Percent	
A-1	Dusted, not cut	NaOH Na_2S	16.7 4.7	16.9 4.8	118	1.00	4.00	168	.....	46.0	Shives partially digested.
A-2	do	NaOH Na_2S	13.8 4.0	9.8 2.8	168	1.00	4.00	166	.....	52.0	do.
A-4	do	NaOH Na_2S	14.0 4.0	9.8 2.8	171	.75	4.35	166	87.0	57.0	do.
A-6	do	NaOH Na_2S	14.0 4.0	9.8 2.8	171	1.00	7.00	148	77.0	58.0	Not so well digested as A-4.
D-13	Cut, not dusted	NaOH Na_2S	13.0 4.5	17.3 8.4	91	4.25	3.75	148	.....	54.0	15 percent of bleaching powder insufficient to bleach all the shives.
A-3	Dusted, not cut	NaOH Na_2S $Ca(OH)_2$	7.1 7.5 5.2	5.0 5.3 3.7	168	.75	4.25	166	.....	71.0	Shives only slightly digested.
A-5	Dusted. Dusting loss 16 percent, not cut	NaOH Na_2S $Ca(OH)_2$	9.7 4.0 3.8	6.8 2.8 2.8	171	.75	4.25	166	92.0	57.0	Slightly better digested than A-4.
A-7	Dusted, not cut	NaOH Na_2S $Ca(OH)_2$	14.0 4.0 3.8	9.8 2.8 2.8	171	1.00	7.00	148	67.0	57.0	Pulp similar to that from cook A-6.
A-8	do	NaOH Na_2S $Ca(OH)_2$	9.7 4.0 3.8	6.8 2.8 2.8	171	1.50	6.50	148	85.0	66.0	Pulp not so well digested as that of cook A-5, of which it is a duplicate except for time and temperature.
A-14	Not cut or dusted	NaOH Na_2S $Ca(OH)_2$	9.7 4.0 3.8	6.8 2.8 2.8	170	1.75	3.75	166	.....	60.0	A duplicate of cook A-5, except for previous treatment of the tow. Results same as for A-5.
A-18	Cut, not dusted	NaOH Na_2S $Ca(OH)_2$	9.7 4.0 3.8	6.8 2.8 2.8	170	1.25	3.75	174	.....	57.0	A duplicate of A-5, except for temperature and time schedule. Pulp of about same quality as A-5.
D-34	Not cut or dusted	NaOH Na_2S $Ca(OH)_2$	9.7 4.0 3.8	16.8 6.5 6.2	74	2.00	4.00	166	.....	.....	A semicommercial duplication of A-5, 25 percent of bleaching powder was insufficient to bleach the shives. (See table 11 for strength of paper.)
A-19	Cut, not dusted	NaOH Na_2S $Ca(OH)_2$	11.0 4.0 5.0	7.8 2.8 3.5	170	.75	4.25	174	.....	40.0	Lower yield but quality about the same as A-5.
D-20	do	NaOH Na_2S $Ca(OH)_2$	10.2 4.2 5.0	8.7 5.0 6.2	96	8.00	1.50	166	.....	.....	A semicommercial digestion, 25 percent of bleaching powder was insufficient to bleach the pulp to a white color.
A-21	do	NaOH Na_2S $Ca(OH)_2$	11.0 4.0 5.0	7.8 2.8 3.5	170	.75	4.25	166	.....	56.0	Quality of pulp about same as A-5.
A-22	do	NaOH Na_2S $Ca(OH)_2$	11.0 4.0 5.0	7.8 2.8 3.5	170	1.00	5.00	166	.....	77.0	Shives only partially digested.
A-23	do	NaOH Na_2S $Ca(OH)_2$	11.0 4.4 4.2	7.8 3.1 2.9	170	2.00	3.00	174	.....	55.0	No advantage gained by lime impregnation.
A-28	do	NaOH	25.0	17.6	170	.75	5.50	166	.....	.....	Shives well digested.
A-29	do	NaOH $Ca(OH)_2$	25.0 8.0	17.6 5.6	170	1.00	5.00	166	.....	.....	Shives not so well digested as in A-28.
A-30	do	NaOH $Ca(OH)_2$ Na_2S	25.0 8.4 8.0	17.7 6.0 5.7	170	.75	5.25	166	.....	.....	Pulp softer than either A-28 or A-29. Probably overcooked.
A-31	do	NaOH Na_2S $Ca(OH)_2$	20.0 8.4 8.0	14.2 6.0 5.7	170	.50	5.50	166	.....	.....	Shives well digested. Fiber seemed overcooked. See also cook A-33, table 7.
A-32	do	NaOH Na_2S $Ca(OH)_2$	15.0 8.4 8.0	10.6 6.0 5.7	170	.50	5.50	166	.....	.....	Shives not so well digested as in A-31. See also cook A-33, table 7.
D-35	Not cut or dusted	NaOH Na_2S $Ca(OH)_2$	20.0 8.4 8.0	31.0 13.0 12.4	78	3.00	3.75	166	73.0	43.0	A semicommercial duplication of A-31. Shives well digested and bleachable with 25 percent of bleaching powder. (See table 11 for strength of paper.)

[1] See page 26 for definitions of terms and units of measurements used in column headings.

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Table 6.--Digestion of medium flax tow with mixtures of sodium hydroxide, sodium sulphide, and calcium hydroxide[1, 2]

Cook number	Previous treatment	Chemicals charged: Kind	Chemicals charged: Amount	Chemicals charged: Concentration	Volume of cooking liquor	Duration of cooking[3]: To maximum temperature	Duration of cooking[3]: At maximum temperature	Maximum temperature[3]	Total chemicals consumed	Yield of crude pulp	Remarks
			Pounds	G. per l.	Gallons	Hours	Hours	°C.	Percent	Percent	
D-36	Not cut or dusted	NaOH Na_2S $Ca(OH)_2$	20.0 8.4 8.0	30.9 12.9 12.4	80	2.50	4.50	166	79.0	40.0	A duplication of D-35, (see table 5) except for raw material. Pulp of about same quality. Pulp given an acid wash and bleached with 25 percent of bleaching powder.
D-38	Cut, not dusted	NaOH Na_2S $Ca(OH)_2$	20.0 8.4 8.0	16.0 6.2 6.0	98	2.25	4.50	166	70.0	47.5	Not so well digested as D-36. Shives bleached with an acid wash and 35 percent of bleaching powder.
D-39	..........do..........	NaOH Na_2S $Ca(OH)_2$	20.0 8.4 8.0	30.0 12.9 12.0	80	2.50	4.00	166	....	....	Pulp similar to that of D-36, which is practically a duplicate.
D-40	..........do..........	NaOH Na_2S $Ca(OH)_2$	20.0 8.4 8.0	30.0 12.6 12.0	80	2.25	4.00	166	60.0	31.0	A duplicate of cook D-39.
D-41	..........do..........	NaOH Na_2S $Ca(OH)_2$	20.0 7.0 8.0	43.5 18.2 17.4	55	(2.50 (1.00	1.50 3.00	100) 166)	65.0	42.0	Not so well digested as cooks D-36 to D-40; believed due principally to poor circulation caused by packing digester too tightly. Pulp given an acid wash and bleached with 14.5 percent of bleaching powder.
D-42	..........do..........	NaOH Na_2S $Ca(OH)_2$	20.0 8.4 8.0	42.3 17.7 16.8	51	(1.00 (1.00	2.00 3.00	100) 166)	59.0	45.0	Results similar to cook D-41. Digester packed too tightly. Pulp given an acid wash and bleached with 12.5 percent of bleaching powder.
D-43	..........do..........	NaOH Na_2S $Ca(OH)_2$	20.0 8.4 8.0	27.9 11.6 11.1	60	(1.75 (.50	3.00 3.00	120) 166)	65.0	33.0	Digester not packed so tightly as cooks D-41 and D-42. Pulp similar to that of cook D-36. Given an acid wash and bleached with 11 percent of bleaching powder.
D-44	Cut, dusted, cut again. Dusting loss: 25 percent.	NaOH Na_2S	13.0 4.0	24.7 7.4	65	6.50	6.00	148	92.0	52.0	Twenty-five percent of bleaching powder was insufficient to bleach all the shives.
D-45	Cut, not dusted	NaOH Na_2S $Ca(OH)_2$	14.1 5.5 5.3	26.5 11.0 10.5	60	12.00	11.50	148	71.0	51.0	Shives only partially digested. Thirty percent of bleaching powder was insufficient to bleach all shives.
D-46	..........do..........	NaOH Na_2S $Ca(OH)_2$	14.1 5.5 5.3	26.5 11.0 10.5	60	3.50	8.00	166	82.0	33.0	Shives digested more than in cook D-45 because of higher temperature. After an acid wash, shives bleached with 30 percent of bleaching powder.
D-53	Cut twice, not dusted	NaOH Na_2S $Ca(OH)_2$	14.0 5.6 5.8	27.4 11.2 10.9	60	1.75	6.25	170	96.0	51.0	Pulp of about same quality as cook D-45. No acid wash. Pulp bleached to a light brown with 38 percent of bleaching powder.
A-85	..........do..........	NaOH Na_2S	12.0 7.31	12.3 9.5	86	....	....	166	93.0	45.0	Cooked in 3 stages using one-third of the chemical for each. Total time 10-1/2 hours. No special benefit was noted. Shives were only partially digested.

[1] See page 26 for definitions of terms and units of measurements used in column headings.

[2] See table 11 for the strength of the paper made from these pulps. Paper not made from the pulp of A-85.

[3] Where two values are given the first represents the maximum temperature of the first stage, and the other the maximum temperature of the final stage.

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Table 7.--Digestion of fine and medium flax tow with various mixtures of chemicals[1]

Cook number	Previous treatment	Chemicals charged			Volume of cooking liquor	Duration of cooking[2]		Maximum temperature[2]	Yield of crude pulps	Remarks
		Kind	Amount	Concentration		To maximum temperature	At maximum temperature			
			Pounds	G. per l.	Gallons	Hours	Hours	°C.	Percent	
A-24	Fine tow, cut, not dusted	$NaOH$ Na_2SO_3 $Ca(OH)_2$	20.9 6.0 3.8	14.1 4.2 2.8	170	1.00	4.00	166	52.0	Pulp well digested. Shives bleachable with 20 percent of bleaching powder.
D-27	..........do..........	$NaOH$ Na_2SO_3 $Ca(OH)_2$	10.4 1.6 6.1	17.3 2.3 10.2	72	2.00	4.75	166	....	Shives only partially digested.
A-15	Fine tow, not cut or dusted	$NaOH$ Na_2SO_3	14.0 6.0	9.8 4.2	170	1.00	4.00	166	59.0	..........do..........
A-26	Fine tow, cut, not dusted	$NaOH$ $Na_2S_2O_4$ $Ca(OH)_2$	20.9 2.8 3.8	14.7 2.0 2.8	170	1.00	4.00	166	56.0	Not quite so well digested as cook A-24.
A-17	..........do..........	$NaOH$ $Na_2S_2O_4$	14.0 2.0	9.8 1.4	170	.75	4.50	166	51.0	Shives only partially digested.
A-25	..........do..........	$NaOH$ Zn $Ca(OH)_2$	20.9 .3 3.6	14.7 .2 2.8	170	.75	4.25	166	54.0	About equal to the pulp of cook A-20.
A-16	..........do..........	$NaOH$ $CaSO_3$	14.0 6.0	9.8 4.2	170	1.00	4.00	166	64.0	Shives less digested than in cooks A-15 and A-17.
A-47	Medium tow, cut, not dusted	$NaOH$ Na_2O_2	14.0 2.0	9.8 1.3	170	1.00	5.00	166	....	Shives only partially digested. Fiber tender.
A-48	..........do..........	$NaOH$ Na_2O_2	14.0 5.0	9.9 3.5	170	1.00	5.00	166	....	Pulp of same quality as that of cook A-47
A-9	Fine tow, dusted	Na_2S $Ca(OH)_2$	4.0 12.9	6.0 19.4	80	.75	7.25	146	66.0	Shives only partly digested.
A-10	A-9 recooked	$NaOH$ Na_2S	8.0 2.0	9.6 2.4	100	3.00	3.00 2.00	146 150	79.0	Shives fairly soft.
A-11	Fine tow, dusted, cut	Na_2S $Ca(OH)_2$	6.3 10.8	7.5 12.8	100	1.00	4.50 2.50	140 160	78.0	Shives only slightly digested.
A-33	Fine tow, cut, not dusted	Na_2S $Ca(OH)_2$	8.4 8.0	5.9 5.6	170	.50	5.00	166	....	Shives only slightly digested. This cook is a duplicate of A-31 and A-32, table 5, except for omission of sodium hydroxide.
A-12	Fine tow, dusted, cut	$Ca(OH)_2$ Na_2CO_3	12.9 5.4	15.5 6.5	100	.50	3.50 4.00	140 160	85.0	Pulp of same quality as cook A-11.

[1] See page 26 for definitions of terms and units of measurement used in column headings.

[2] Where two values are given, the first represents the maximum temperature of the first stage, and the other the maximum temperature of the final stage.

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Table 8.—Digestion of medium flax tow with mixtures of sodium hydroxide, sulphur, with and without calcium hydroxide[1,2]

Cook number	Chemicals charged: Kind	Chemicals charged: Amount	Chemicals charged: Concentration	Chemicals available for cooking[3]: NaOH	Chemicals available for cooking[3]: Na_2S	Chemicals available for cooking[3]: Total alkali[4]	Volume of cooking liquor	Duration of cooking: To maximum temperature	Duration of cooking: At maximum temperature	Maximum temperature	Total alkali consumed	Yield of crude pulp	Bleaching powder	Remarks
		Pounds	G. per l.	Pounds	Pounds	Pounds	Gallons	Hours	Hours	°C.	Percent	Percent	Percent	
A-49	NaOH S	24.0 6.4	28.8 7.7	8.0	11.7	14.0	100	0.50	4.50	168	....	....	....	Shives fairly well digested.
A-51	NaOH S	24.0 6.4	28.8 7.7	8.0	11.7	14.0	100	.50	7.50	160	....	....	....	Pulp of same quality as cook A-49.
D-101	NaOH S	24.0 6.4	47.0 12.4	8.0	11.7	14.0	61.5	2.00	4.00	168	92.0	36.0	29.0	Bleached to a light buff color. (See table 11, for strength of paper.)
A-58	NaOH S	24.0 6.4	27.4 7.3	8.0	11.7	14.0	105	.75	4.25	166	....	42.0	20.0	A duplicate of A-49, but not so well digested. Shives only partially bleached.
A-102	NaOH S	16.5 1.6	19.7 1.9	12.5	2.9	14.0	100	.50	4.50	166	84.0	50.0	70.0	Shives only partially cooked. Did not bleach.
A-103	NaOH S	20.3 4.0	24.3 4.8	10.3	7.3	14.0	100	.50	4.50	166	69.0	50.0	53.0	Pulp of same quality as cook A-102.
A-104	NaOH S	27.8 8.8	33.3 10.5	5.7	16.1	14.0	100	.50	4.50	166	78.0	46.0	50.0	Shives digested more than in cooks A-102 and A-103. Bleached fairly well.
A-105	NaOH S	16.5 1.6	19.7 1.9	12.5	2.9	14.0	100	.50	4.50	166	84.0	55.0	70.0	Duplication of A-102, except NaOH and S heated together at 160°C. before adding tow. Shives only partially bleached.
A-106	NaOH S	20.3 4.0	24.3 4.8	10.3	7.3	14.0	100	.50	4.50	166	67.0	49.0	65.0	Duplicate of A-103, except as indicated for cook A-105 above. Shives bleached fairly well.
A-107	NaOH S	27.8 8.8	33.3 10.5	5.7	16.1	14.0	100	.50	4.50	166	53.0	47.0	68.0	Duplicate of A-104, except as indicated for cook A-105 above. Shives bleached fairly well.
A-69	NaOH S $Ca(OH)_2$	24.0 6.4 6.1	26.7 7.1 6.7	14.6	5.4 [5]5.9	17.3	108	.50	4.50	166	74.0	50.0	21.0	Shives not so well digested as in cook A-70, below.
A-70	NaOH S $Ca(OH)_2$	24.0 6.4 3.1	26.7 7.1 3.4	11.3	8.5 [5]2.9	15.7	108	.50	4.50	166	87.0	46.0	20.0	Bleached to a light buff.
A-71	NaOH S $Ca(OH)_2$	24.0 6.4 9.5	26.7 7.1 10.5	8.0	11.7 [5]9.2	14.0	108	.50	4.50	166	79.0	52.0	23.0	Shives only partially digested.
A-63	NaOH S	24.0 6.4	26.7 7.1	8.0	11.7	14.0	108	.50	4.50	166	97.0	41.0	16.0	Duplicate of A-49. Shives bleachable.
A-64	NaOH S	19.7 4.0	21.9 4.5	9.7	7.3	13.4	108	.50	4.50	166	97.0	44.0	24.0	Not so well digested as cook A-63.
A-57	NaOH S	18.3 6.5	20.2 7.2	2.1	11.9	8.1	109	.75	4.25	166	....	....	30.0	Shives only partially bleached.
A-65	NaOH S	18.2 3.0	20.3 3.3	10.7	5.5	13.5	108	.50	4.50	166	96.0	44.0	23.0	Pulp about same quality as cooks A-57 and A-64.
A-66	NaOH S	22.0 6.4	24.5 7.1	6.0	11.7	12.0	108	.25	6.50	166	100.0	50.0	23.0	Shives only partially digested.
A-67	NaOH S	24.0 4.0	26.7 4.5	14.0	7.3	17.7	108	.25	4.50	166	90.0	40.0	14.0	Shives fairly well digested and bleachable.
A-68	NaOH S	24.0 8.0	26.7 8.9	4.0	14.6	11.7	108	.25	4.50	166	100.0	45.0	21.0	Shives only partially digested.
A-50	NaOH S	22.0 4.0	26.4 4.8	12.0	7.3	15.7	100	.50	4.50	168	....	....	....	Pulp similar to A-49 in quality. Shives fairly well digested.
A-59	NaOH S	22.0 4.0	25.1 4.6	12.0	7.3	15.7	105	.75	4.25	166	....	39.0	22.0	Duplicate of cook A-50. Shives well digested and bleachable.
A-60	NaOH S	22.0 4.0	25.1 4.6	12.0	7.3	15.7	105	.75	6.25	166	....	39.0	17.0	Duplicates of cooks A-50 and A-59.[6]
A-72	NaOH S	22.0 4.0	24.9 4.5	12.0	7.3	15.7	106	.50	10.50	148	93.0	43.0	32.0	Shives not so well digested as in cook A-60.[7]
A-73	NaOH S	22.0 4.0	24.9 4.5	12.0	7.3	15.7	106	.50	9.50	154	93.0	42.0	32.0	Shives slightly more digested than in cook A-72.[7]
A-74	NaOH S	22.0 4.0	24.9 4.5	12.0	7.3	15.7	106	.50	8.50	160	95.0	43.0	32.0	Shives only partially digested and not bleachable.[7]
A-75	NaOH S	23.2 6.6	27.9 7.9	6.8	12.0	13.0	100	.50	4.50	166	100.0	50.0	30.0	Shives only partially digested and not bleachable.
A-76	NaOH S	26.7 8.8	32.0 10.5	4.8	16.0	13.0	100	.50	4.50	166	100.0	47.0	30.0	Pulp similar to that of cook A-75.
A-52	NaOH S	30.0 8.0	36.0 9.6	10.0	14.6	17.5	100	.50	7.50	160	....	....	....	Shives only partially digested.
A-77	NaOH S	30.2 11.0	36.2 13.2	2.8	20.0	13.0	100	.50	4.50	166	100.0	53.0	30.0	Pulp similar to those from cooks A-52 and A-75.
A-78	NaOH S	26.7 8.8	32.0 10.5	4.8	16.0	13.0	100	.50	4.50	166	98.0	43.0	30.0	Duplication of cook A-76. Shives more digested and more bleachable.
A-79	NaOH S	30.2 11.0	36.2 13.2	2.8	20.0	13.0	100	.50	4.50	166	98.0	41.0	30.0	Duplication of cook A-77. Pulp similar to that of cook A-78.
A-80	NaOH S	33.5 13.1	40.3 15.8	.7	24.0	12.9	100	.50	4.50	166	95.0	42.0	30.0	Shives well digested and bleachable. Pulp probably over cooked.

[1]See page 26 for definitions of terms and units of measurements used in column headings.

[2]The material was cut but not dusted before cooking.

[3]Calculated from the probable reaction. $8\ NaOH + 4\ S = Na_2SO_4 + 3\ Na_2S + 4\ H_2O$.

[4]Total available alkali is calculated as the sum of the excess sodium hydroxide, and that produced by the hydrolysis of the sodium sulphide in water according to the reaction, $Na_2S + H_2O = NaOH + NaSH$.

[5]Calcium sulphide.

[6]See table 9 for semicommercial duplication of these autoclave cooks.

[7]See table 9 for autoclave and semicommercial digestions showing affect of longer duration of cooking at lower temperature.

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Table 9.—Digestion of medium flax tow with mixtures of sodium hydroxide and sulphur showing effect of increased duration of cooking at lower temperatures[1]

Cook number[1]	Preliminary treatment	Cooking conditions: Chemical charged: Kind	Amount	Concentration	Duration of cooking: To maximum temperature	At maximum temperature	Maximum temperature	Alkali consumed	Yield of crude pulp	Bleaching powder	Properties of paper: Weight per ream	Average thickness	Bursting strength	Tearing strength	Tensile strength	Stretch at rupture	Folding strength	Whiteness of paper
			Pounds	G. per l.	Hours	Hours	°C.	Percent	Percent	Percent	Pounds	Inches	Points	Grams	Meters	Percent	Double folds	Percent
D-61	Cut, not dusted	(NaOH (S	22.0 4.0	44.0) 8.0)	2.0	6.0	166	77.0	42.0	15.0	[2]54.7	0.0045	0.70	0.97	6565	5.2	695	....
D-62	..........do..........	(NaOH (S	22.0 4.0	41.6) 7.6)	1.75	6.0	166	87.0	39.0	15.0	[3]61.3	.0050	.68	1.35	4745	6.2	205	....
A-180-1	Dusted and cut	(NaOH (S	22.0 4.0	44.0) 8.0)	6.0	8.0	155	....	46.0	25.0	....	....	....	....	....	....	....	59
A-180-2	..........do..........	(NaOH (S	22.0 4.0	44.0) 8.0)	5.0	15.0	145	....	53.0	20.0	....	....	....	....	....	....	....	59
B-186	Dusted but not cut	(NaOH (S	22.0 4.0	88.0) 16.0)	5.0	15.0	145	89.0	....	25.0	39.5	.0025	.64	.66	4594	4.2	109	....
B-184	..........do..........	(NaOH (S	22.0 4.0	44.0) 8.0)	5.0	25.0	140	80.0	....	20.0	{[4]38.0 {[5]27.4	.0028 .0020	.68 .78	.47 .78	4934 5771	5.9 2.8	370 } 327 }	42

[1]See page 26 for definition of terms and units of measurements used in column headings.

[2]Cooks D-61 and D-62 were combined for four machine runs. Results in this line are for machine run 2.

See table 11 for all machine runs.

[3]See footnote 2. Results in this line are for machine run 4.

[4]Machine run 1.

[5]Machine run 2.

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Table 10.--Digestion of medium flax tow with sodium sulphite[1]

Cook number	Dusting loss[2]	Na_2SO_3 charged		Volume of cooking liquor	Duration of cooking--		Maximum temperature	Na_2SO_3 consumed	Yield of crude pulp	Bleaching powder	Remarks
		Amount	Concentration		To maximum temperature	At maximum temperature					
	Percent	Pounds	G. per l.	Gallons	Hours	Hours	°C.	Percent	Percent	Percent	
A-111	....	20.0	24.0	100	1.0	10.0	130	89.0	68.0	18.0	Shives digested fairly well but fiber appeared weakened. Paper hydrated. Color a light buff.
A-112	33.0	20.0	24.0	100	1.0	10.0	170	77.0	44.0	24.0	Pulp similar to cook A-111, but bleached to a lighter color. Paper hydrated.
A-114	33.0	20.0	24.0	100	1.25	23.50	124	39.0	58.0	32.0	Shives practically undigested. Bleached pulp hydrated and of a light brown color.
A-115	33.0	20.0	24.0	100	1.25	15.75	153	56.0	51.0	37.0	Pulp about same quality as in cook A-114 but bleached to a slightly lighter color.
A-116	33.0	20.0	24.0	100	1.25	12.75	162	60.0	52.0	31.0	Pulp of slightly better quality than A-115.
D-117	43.0	17.0	25.5	80	2.50	17.50	158	87.0	57.0	15.0	Semicommercial digestion. Paper of a light brown color and hydrated. (See table 11 for paper tests.[3])
D-118	40.0	17.0	25.5	80	2.50	17.50	158	80.0	59.0	12.0	Duplication of cook D-117. (See table 11 for paper tests.[3])
D-119	39.0	17.0	25.5	80	2.50	17.50	158	85.0	59.0	(4)	Duplication of cook D-117. (See table 11 for paper tests.)
D-120	39.0	17.0	25.5	80	2.50	17.50	158	83.0	59.0	(4)	Duplication of cook D-117. (See table 11 for paper tests.)

[1]See page 26 for definitions of terms and units of measurement used in column headings.

[2]The medium tow was cut and dusted before cooking in all cooks except A-111. In A-111 the tow was extracted with a 4 percent solution of sodium hydroxide, washed and treated for fifteen minutes with chlorine water before cooking.

[3]The hydrated condition of these papers indicates their possible use for glassine or greaseproof. (See also table 27 for other greaseproof papers.)

[4]Pulps not bleached but treated with chlorine water. The resulting papers were of a lighter color than those of cooks D-117 and D-118 and not so hydrated.

Table 11.--Properties of some machine made flax papers[1]

Cook number	Material	For pulping data see table	Grade of paper obtained	Machine run number	Weight per ream	Thickness	Bursting strength	Tearing strength	Tensile strength	Stretch at rupture	Folding	Remarks
					Pounds	Inches	Points	Grams	Meters	Percent	Double folds	
D-34	Fine tow	5	....	1	38.5	0.0033	0.63	1.90	4,650	2.4	550	Paper full of undigested shives; not comparable with commercial paper.
D-35	.....do.....	5	Medium grade bond	1	50.0	.0057	.68	1.36	4,820	3.4	143	Paper of cream-white color.
			............do............	2	57.5	.0048	.97	1.36	6,545	4.8	295	Tub sized.
D-36	Medium tow	6	............do............	1	54.7	.0049	.81	.78	5,950	4.0	447	Paper of cream-white color.
			............do............	2	58.5	.0047	1.09	1.33	7,015	4.0	487	Tub sized.
D-38	.....do.....	6	............do............	1	56.6	.0041	.72	1.31	5,910	4.0	837	Paper of cream-white color.
D-39	.....do.....	6	............do............	1	39.5	.0031	.61	1.14	5,315	3.3	98	......................do......................
D-40	.....do.....	6	............do............	1	39.5	.0032	.73	1.38	5,930	3.2	231	......................do......................
D-41	.....do.....	6	....	1	44.5	.0030	.84	1.30	6,015	7.8	963	Paper similar to D-38 to D-40 inclusive, but of light-buff color.
D-42	.....do.....	6	....	1	42.5	.0032	.82	1.39	6,375	4.8	585	Paper full of undigested shives; not comparable with commercial paper.
D-43	.....do.....	6	............do............	1	40.5	.0043	.83	1.68	5,615	3.3	156	Paper similar to D-41, but of a slightly lighter color.
D-44	.....do.....	6	Tough wrapper	1	38.0	.0029	.63	1.29	4,700	2.9	641	A brown hydrated paper containing some undigested shives.
D-45	.....do.....	6	Glassine grease proof	1	38.0	.0029	.73	1.08	5,485	3.2	688	A light-brown colored, hydrated paper.
			............do............	2	32.0	.0028	.87	1.19	5,450	3.2	774	......................do......................
			Tough wrapper	3	38.0	.0030	.51	.90	4,175	2.1	122	A light-brown hydrated paper full of undigested shives.
D-46	.....do.....	6	Medium grade bond	1	38.5	.0031	.87	1.51	6,545	4.1	369	Paper of cream white color.
			............do............	2	45.5	.0039	.82	1.47	6,360	4.3	226	......................do......................
D-53	.....do.....	6	Wrapper	1	47.0	.0040	.59	1.85	2,625	3.9	393	Pulp not bleached. Paper of dark-brown color containing many undigested shives.
			............do............	2	38.0	.0040	.74	2.24	5,030	3.2	278	......................do......................
			............do............	3	51.0	.0040	.88	1.22	4,760	4.0	216	Pulp bleached to a light buff color with 30 percent of bleaching powder. Paper contained many undigested shives.
			............do............	4	38.0	.0032	.97	1.37	4,555	1.8	185	Pulp bleached to a light buff color with an acid wash and 30 percent of bleaching powder. Paper contained many undigested shives.
D-54	New unbleached linen rags	32	Linen bond	1	43.5	.0031	.82	1.93	5,510	5.7	2,846	A tough hydrated cream-white colored paper.
			............do............	2	38.0	.0035	.86	2.32	4,600	3.4	2,356	......................do......................
			............do............	3	38.0	.0034	.62	1.91	6,020	5.9	2,397	......................do......................
			............do............	4	44.5	.0035	.83	1.90	5,302	7.1	2.985	Similar to machine runs 1, 2, 3, but not hydrated.
D-61,D-62	Medium tow	9	Medium grade bond	1	38.5	.0029	.65	.92	6,010	3.2	507	Paper of light-buff color.
			............do............	2	54.7	.0045	.70	.98	6,565	5.2	695	Paper of slightly lighter color than machine run 1.
			............do............	3	51.0	.0045	.69	1.07	7,295	5.2	613	Paper of cream-white color.
			............do............	4	61.3	.0050	.68	1.35	4,745	6.2	205	......................do......................
D-101	.....do.....	8	Tough wrapper	1	52.9	.0040	.60	.99	4,430	3.4	584	A light-gray colored hydrated paper.
D-117	.....do.....	10	Glassine, grease proof	1	33.0	.0030	.68	1.05	4,617	3.3	635	A light-brown colored hydrated paper containing some undigested shives.
D-118	.....do.....	10	............do............	1	38.0	.0030	.82	.97	2,052	4.2	905	......................do......................
D-119	.....do.....	10	Tough wrapper	1	50.0	.0040	.59	.86	6,920	2.4	42	A light-buff colored paper not so hydrated as D-117.
D-120	.....do.....	10	Wrapper	1	63.2	.0055	.48	.58	2,370	2.4	7	Pulp bleached in chlorine water. Paper not so light colored or as hydrated as D-117.
....	Linen rags	10	High grade bond	....	50.0	.0035	1.04	....	6,360	7.4	3,563	A commercial paper of high-white color.

[1] See page 26 for definitions of terms and units of measurement used in column headings.

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Table 12.--Digestion of medium flax tow with mixtures of sodium hydroxide, sodium bisulphite, and sodium sulphide[1,2]

Cook number	Chemicals charged			Chemicals available for cooking[3]		Volume of cooking liquor	Duration of cooking		Maximum temperature	Chemicals consumed			Yield of crude pulp	Bleaching powder	Remarks
	NaOH	$NaHSO_3$	Na_2S	NaOH	Na_2SO_3		To maximum temperature	At maximum temperature		NaOH	$NaHSO_3$	Na_2S			
	Pounds	Pounds	Pounds	Pounds	Pounds	Gallons	Hours	Hours	C.	Percent	Percent	Percent	Percent	Percent	
A-86	15.4	0.2	....	15.4	0.3	102	0.5	4.5	166	97.0	73.0	....	46.7	....	Shives only partially digested. Pulp slimy.
A-87	16.9	.5	....	16.7	.6	102	.5	4.5	166	93.	94.	....	39.3	50.4	Shives only partially digested and not bleachable.
A-88	16.9	4.9	....	15.0	6.0	100	.5	4.5	166	93.	99.	....	51.2	70.5	Shives more digested than cook A-87, but not entirely bleached with the amount of bleaching powder used.
A-89	15.4	2.4	....	14.5	3.0	100	.5	4.5	166	94.	99.	....	48.4	70.8	Pulp quality similar to that of A-88, but not so well bleached.
A-90	9.9	4.9	....	8.0	5.8	100	.5	4.5	166	100.	99.	....	53.3	61.3	Shives only partially digested and not bleachable.
A-91	17.6	5.6	5.4	15.4	6.8	100	.5	4.5	166	84.	71.	32.0	42.6	13.0	Pulp of quality similar to cook A-88. The low amount of bleaching powder required indicates probable overcooking.
A-92	14.1	12.1	....	9.5	14.8	100	.5	4.5	166	100.	72.	....	51.0	32.5	Pulp of a quality similar to cook A-90.
A-94	16.7	17.8	6.3	13.1	21.5	117	.5	4.5	166	97.	56.	34.	45.3	10.8	Pulp of a quality similar to A-91. Probably overcooked.
A-95	16.7	17.8	6.3	13.1	21.5	117	.5	4.5	166	97.	62.	34.	46.0	17.5	A duplicate of cook A-94, except cooking liquor diluted with black liquor from a previous cook instead of with water. Amount of bleaching powder used was not sufficient to bleach the shives. Pulp of a buff color.
A-96	7.7	17.8	13.3	.9	21.5	117	.5	4.5	166	....	65.	44.	41.2	24.9	Shives fairly well digested but not entirely bleached with the amount of bleaching powder used.
A-97	5.5	14.0	10.5	.1	17.0	100	.5	4.5	166	98.	66.	41.	56.0	34.0	Pulp of a quality similar to that of cook A-96.
A-98	5.5	14.0	10.5	.1	17.0	100	4.0	3.0	166	93.	66.	46.	46.5	45.5	A duplicate of cook A-97, except for time schedule. Not so well digested as cook A-97.
A-99	5.5	14.0	10.5	.1	17.0	100	{ 4.0 (.5	4.0 1.5	148 } 166 }	94.	69.	42.	43.0	45.0	A duplicate of cook A-97, except for time schedule. Pulp similar to that of cook A-98.
A-113	....	16.5	12.4	....	....	100	1.0	10.0	170	....	46.	51.	48.7	....	Shives only slightly digested and not bleachable.

[1]See page 26 for definitions of terms and units of measurement used in column headings.

[2]The tow was cut but not dusted in each cook except A-113, in which the tow was dusted with a loss of 33 percent.

[3]The excess amount of sodium hydroxide and the amount of sodium sulphite available for the digestion of the tow were calculated from the reaction: $NaOH+NaHSO_3=Na_2SO_3+H_2O$. The amount of sodium sulphide charged was considered as unchanged by reaction with the other chemicals and, therefore, available for the digestion, although it is known that sodium sulphite and sodium sulphide react in a complicated way.

Table 13.--Digestion of medium flax tow with mixtures of sodium hydroxide, sodium sulphite, and sodium sulphide[1]

Cook number	Cooking data: Chemical charged: Kind	Amount	Concentration	Duration of cooking: To maximum temperature	At maximum temperature	Maximum temperature	Yield of crude pulp	Bleaching powder[2]	Properties of the papers: Weight per ream	Thickness	Bursting strength	Tearing strength	Tensile strength breaking length	Folding strength
		Pounds	G. per l.	Hours	Hours	°C.	Percent	Percent	Pounds	Inches	Points	Grams	Meters	Double folds
D-100	Na_2S Na_2SO_3	13.3 21.5	26.6 43.0	2.00	3.25	166	42.0	45.0	51.9	0.0033	0.77	1.46	5,760	2,013
B-171	Na_2S Na_2SO_3	13.3 21.5	28.0 45.3	2.75	2.75	166	....	25.0	47.0	.0032	.93	1.19	5,435	1,344
D-156	$NaOH$ Na_2S Na_2SO_3	4.0 6.5 21.5	8.0 13.0 43.0	2.50	3.50	166	49.0	25.0	28.0	.0025	.74	1.54	5,720	285
B-172	$NaOH$ Na_2S Na_2SO_3	2.7 8.0 21.5	7.2 21.3 57.0	2.75	2.75	166	....	25.0	34.0	.0022	.88	1.20	5,719	1,639

[1]See page 26 for definitions of terms and units of measurement used in column headings.

[2]These pulps were exceedingly difficult to bleach. The amounts of bleaching powder used had only a slight effect.

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Table 14.--Digestion of medium flax tow with calcium sulfhydrate and sodium sulfydrate[1]

Cook number	Chemicals charged: Kind	Chemicals charged: Amount	Chemicals charged: Concentration	Duration of cooking: To maximum temperature	Duration of cooking: At maximum temperature	Maximum temperature	Yield of crude pulp	Bleaching powder	Degree of whiteness of pulp test sheet[2]	Remarks
		Pounds	G. per l.	Hours	Hours	°C.	Percent	Percent	Percent	
A-175	[3] $Ca(SH)_2$	15.0	30.0	3.0	6.5	166	74.0	50.0	44.0	Pulp unbleachable, shives brittle and fiber weakened.
A-179a	([4] NaSH	10.0	20.0)	3.0	3.0	166	70.0	25.0	14.0	Pulp similar to cook A-175.
	(NaCl	10.3	20.6)							
A-179B	([5] NaSH	10.0	20.0)	3.0	3.0	166	76.0	50.0	19.0	Pulp similar to cook A-175.
	(Na_2SO_4	12.7	25.4)							

[1]See page 26 for definitions of terms and units of measurement used in column headings.

[2]Color after bleaching treatment.

[3]Prepared by passing hydrogen sulphide gas into milk of lime.

[4]Prepared by adding hydrochloric acid to a solution of sodium sulphide.

[5]Prepared by adding sulphuric acid to a solution of sodium sulphide.

Table 15.--Digestion of flax straw with mixtures of sodium hydroxide and sodium phosphate and the strength of new linen cloth digested therewith[1]

Cook number	Chemical charged[2] NaOH		Na_3PO_4		Yield of pulp	Bleaching powder	Degree of whiteness of pulp test sheet[3]	Loss in tensile strength of linen cloth	Remarks
	Percent	G. per l.	Percent	G. per l.	Percent	Percent	Percent	Percent	
A-173-6	....	....	40.0	96.0	64.0	22.5	19.0	7.5	Shives undigested and black in color. Did not bleach.
A-173-7	4.0	9.6	40.0	96.0	50.5	25.0	27.0	18.8	...........do.............
A-173-8	8.0	19.2	40.0	96.0	61.5	25.0	25.0	21.3	...........do.............
A-173-12	13.0	42.3	40.0	96.0	46.7	25.0	32.0	36.2	Shives only slightly digested. Brown in color and did not bleach.
A-173-11	17.6	42.3	40.0	96.0	41.8	25.0	38.0	51.3	Shives partially digested and difficult to bleach.
A-173-9	19.3	46.3	6.8	16.3	38.5	20.0	60.0	38.8	Pulp fairly well cooked.
A-173-1	22.0	52.8	1.3	3.1	39.1	15.0	46.0	46.3	Pulped overcooked.
A-173-5	22.0	52.8	3.0	7.2	52.4	12.5	65.0	56.3	...........do.............

[1]See page 26 for definitions of terms and units of measurement used in column headings.

[2]The cooking schedule was 2 hours to the maximum temperature of 160° C., and 8 hours at the maximum temperature.

[3]Color after bleaching treatment.

Table 16.--Digestion of flax straw with sodium sulphite--effect of cooking conditions on yield and chemical properties of the pulps[1]

Series and sample number		Pulping conditions: Duration of cooking[2]	Na_2SO_3 charged: Per 100 grams of straw	Na_2SO_3 charged: Concentration	Na_2SO_3 consumed	Yield of crude pulp	Lignin[3]	Cellulose[3]: Total	Cellulose[3]: Pentosan-free	Pentosans[3]: Total	Pentosans[3]: In cellulose	Pentosans[3]: Not in cellulose	Sum of pentosan-free cellulose, lignin, and total pentosans	Copper number	Soluble in 1 percent NaOH
		Hours	Grams	G. per l.	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
SERIES I	371	0.0	.....	......	....	100.00	23.28	53.80	46.75	17.10	7.05	10.05	87.13	7.97	33.73
	388	1.0	20	40	56.9	68.36	13.75	51.15	44.30	10.32	6.84	3.48	99.98	5.17	10.45
	386	3.0	20	40	61.0	[4]65.59	11.70	51.15	43.60	10.23	7.58	2.65	99.84	3.64	7.75
	384	6.0	20	40	84.9	[4]64.36	11.10	50.15	43.35	10.11	6.78	3.33	100.21	5.10	10.52
	383	8.0	20	40	82.1	62.97	10.45	50.80	43.40	9.50	7.40	2.10	100.50	4.36	8.17
	382	10.0	20	40	78.0	61.95	9.45	50.40	43.00	9.57	7.44	2.13	100.05	4.62	8.23
	385	12.0	20	40	82.1	61.37	9.80	49.50	42.50	9.45	6.97	2.48	100.54	3.99	8.72
SERIES II	393	1.5	40	40	29.9	62.26	12.10	51.00	43.60	9.87	7.43	2.44	105.32	3.00	7.29
	392	3.0	40	40	28.4	64.19	11.81	50.00	42.83	10.02	7.12	2.90	100.75	3.35	8.13
	394	6.0	40	40	26.9	62.01	10.16	49.15	42.38	9.58	6.73	2.85	100.20	3.68	9.81
SERIES III	391	1.5	40	80	30.1	[4]67.74	13.16	51.80	43.95	11.00	7.85	3.15	100.51	3.31	8.56
	389	3.0	40	80	35.5	[4]64.79	11.50	49.60	42.75	10.45	6.87	3.58	99.80	4.94	11.29
	390	6.0	40	80	43.7	[4]61.94	9.95	48.85	42.15	9.90	6.73	3.17	100.02	5.38	11.75

[1]See page 26 for definitions of terms and units of measurement used in column headings.

[2]Of this time 20 minutes was consumed in reaching the maximum temperature of 155° C.

[3]Based on the original straw. All other chemical constituents are based on the sample analyzed.

[4]Pulp was gelatinous and difficult to wash free of spent cooking liquors and to filter in the subsequent chemical analyses.

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Table 17.--Digestion of flax straw with sodium hydroxide and chlorine[1, 2]

Cook number	Soda cooking: NaOH charged: Amount	Soda cooking: NaOH charged: Concentration	Soda cooking: Duration of cooking at maximum temperature[3]	Soda cooking: Yield of crude pulp	Soda cooking: Chemical consumed: Based on amount charged	Soda cooking: Chemical consumed: Based on 100 pounds of straw	Chlorination by a modified Roe method[4]: Yield of residue: Based on crude soda pulp	Chlorination by a modified Roe method[4]: Yield of residue: Based on straw	Chlorination by a modified Roe method[4]: Chlorine consumed: Based on crude soda pulp	Chlorination by a modified Roe method[4]: Chlorine consumed: Based on straw	Chlorination by a modified Roe method[4]: Chlorine consumed: Based on total loss in weight of straw	Chlorination by chlorine water method: Yield of residue: Based on crude soda pulp	Chlorination by chlorine water method: Yield of residue: Based on straw	Chlorination by chlorine water method: Chlorine consumed: Based on crude soda pulp	Chlorination by chlorine water method: Chlorine consumed: Based on straw	Chlorination by chlorine water method: Chlorine consumed: Based on total loss in weight of straw
	Pounds	G. per l.	Hours	Percent	Percent	Pounds	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
[5]355	......	....	....	....	....	....	54.3	54.3	38.6	38.6	82.5	....	....	....	....	....
A-192-4	2.0	4.0	2.0	76.8	100.0	2.0	66.1	50.8	[6]31.1	[6]23.9	[6]50.6	44.0	33.8	28.8	22.1	33.4
A-192-5	5.0	10.0	2.0	72.5	100.0	5.0	69.3	50.3	39.6	28.7	57.8	42.7	30.9	29.7	21.5	31.1
A-192-6	10.0	20.0	4.5	70.5	99.4	9.9	68.7	48.5	26.3	18.6	36.1	47.3	33.4	23.3	16.4	24.6
A-192-1	15.0	30.0	7.0	55.6	89.0	13.4	77.5	43.1	25.3	14.1	24.8	[7]32.9	[7]18.3	23.6	13.2	15.7
A-192-2	20.0	40.0	9.5	51.4	81.5	16.3	88.6	45.6	9.8	5.0	9.2	58.4	30.0	12.0	6.2	8.9
A-192-3	25.0	50.0	12.0	43.8	74.5	18.7	93.0	40.8	6.1	2.7	4.6	71.3	31.3	7.4	3.2	4.7

[1]See page 26 for definitions of terms and units of measurements used in column headings.

[2]See tables 18 and 19, for the chemical analysis of the pulps.

[3]The period of rising temperature was 2 hours, and the maximum temperature was 155° C.

[4]Chlorine gas method.

[5]Sample 355 was untreated, dusted, and cut straw, ground to pass a 40 mesh sieve.

[6]These values are low because of a gas leak in the apparatus.

[7]These values are low. The finished pulp appeared to be over-chlorinated, although the amount of chlorine consumed was apparently not excessive.

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Table 18.--Chemical properties of pulp from flax straw digested with sodium hydroxide[1,2]

Cook number	Yield of crude pulp	Lignin[3]	Cellulose[3]		Pentosans[3]			Cellulose	Sum of pentosan-free cellulose, lignin, and total pentosans	Copper number	Soluble in 1 percent NaOH solution
			Total	Pentosan free	Total	In cellulose	Not in cellulose				
	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent		Percent
[4]355	100.0	24.7	52.3	45.4	16.3	6.9	9.4	52.3	86.4	......	33.5
A-192-4	76.8	22.6	51.1	43.3	10.9	7.8	3.1	66.5	100.1	6.2	13.6
A-192-5	72.5	19.9	50.3	42.1	10.5	8.2	2.3	69.4	100.0	4.3	11.8
A-192-6	70.5	19.2	48.8	40.9	10.1	7.9	2.2	69.2	99.6	4.2	9.8
A-192-1	55.6	11.3	41.8	35.3	8.0	6.5	1.5	75.2	98.2	4.0	10.6
A-192-2	51.4	6.2	44.2	37.4	7.4	6.8	.6	86.0	99.4	3.7	8.6
A-192-3	43.8	2.4	39.6	34.6	5.5	5.0	.5	90.3	97.0	2.4	7.9

[1]See page 26 for definitions of terms and units of measurement used in column headings.

[2]See table 17 for the pulping conditions.

[3]Based on original straw. All other chemical constituents are based on sample analyzed.

[4]See footnote 5, table 17.

Table 19.--Chemical properties of flax straw soda pulps chlorinated with chlorine water[1,2]

Cook number	Yield of residue	Lignin[3]	Cellulose[3]		Pentosans[3]			Cellulose	Copper number	Soluble in 1 percent NaOH solution
			Total	Pentosan-free	Total	In cellulose	Not in cellulose			
	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent		Percent
A-192-4	33.8	0.8	32.8	29.5	3.7	3.3	0.4	97.0	4.0	12.7
A-192-5	30.9	.9	29.8	27.3	3.1	2.5	.6	96.2	4.3	15.1
A-192-6	33.4	.7	32.4	28.8	4.4	3.6	.8	97.0	2.4	9.6
A-192-1	18.3	.3	15.7	15.1	1.1	.6	.5	85.7	19.3	33.2
A-192-2	30.0	.4	29.5	25.7	4.0	3.8	.2	98.5	2.3	8.5
A-192-3	31.3	.9	30.6	27.2	3.7	3.4	.3	97.7	3.9	11.3

[1]See page 26 for definitions of terms and units of measurement used in column headings.

[2]See table 17 for the pulping conditions.

[3]Based on original straw. All other chemical constituents are based on sample analyzed.

Table 20.--The digestion of flax straw with mixtures of sodium hydroxide and sodium sulphide and chlorination of the crude pulps[1]

Series number	Digestion number	Alkaline digestion: Duration of cooking[2]: At maximum temperature	Alkaline digestion: Duration of cooking[2]: Total time	Alkaline digestion: Chemicals charged[3]: NaOH	Alkaline digestion: Chemicals charged[3]: Na_2S	Alkaline digestion: Chemicals charged[3]: Total alkali as NaOH[6]	Alkaline digestion: Yield of crude pulp	Lignin in crude pulp[4]: In the sample analyzed	Lignin in crude pulp[4]: Per 100 pounds of straw	Chlorination by modified Roe method[4]: Chlorine consumed: In the sample treated	Chlorination by modified Roe method[4]: Chlorine consumed: Per 100 pounds of straw	Chlorination by modified Roe method[4]: Yield of residue: In the sample treated	Chlorination by modified Roe method[4]: Yield of residue: Per 100 pounds of straw	Loss of material other than lignin per 100 pounds of straw[5]: By digestion	Loss of material other than lignin per 100 pounds of straw[5]: By chlorination
		Hours	Hours	Pounds	Pounds	Pounds	Percent	Percent	Pounds	Percent	Pounds	Percent	Pounds	Pounds	Pounds
Uncooked straw[7]	.....	.....	.....	.....	.....	.....	.....	27.0	27.0	29.9	29.9	49.0	49.0	.....	22.0
[8]A-211	5	0	2	16.5	0.2	16.6	50.8	15.8	8.1	16.8	8.5	78.2	39.7	30.2	3.0
	4	1	3	14.1	.8	14.5	45.7	11.7	5.4	12.0	5.5	84.9	38.8	32.7	1.5
	1	3	5	17.0	1.3	17.7	43.7	6.4	2.8	6.2	2.7	88.8	38.8	32.5	2.1
	2	4	6	17.3	1.5	18.1	41.7	6.3	2.6	4.4	1.8	88.7	37.0	33.6	2.1
	3	5	7	17.6	1.7	18.5	42.5	6.4	2.7	5.1	2.2	89.2	37.9	32.9	1.9
[9]A-212	3	0	2	14.4	.2	14.5	52.2	18.7	9.7	16.6	8.7	76.2	39.8	30.6	2.7
	4	1	3	15.9	.6	16.2	48.8	14.9	7.3	11.2	5.5	79.4	38.8	31.5	2.7
	1	5	7	14.9	1.9	15.9	43.3	8.5	3.7	7.1	3.1	83.0	36.0	33.6	3.6
	2	7	9	15.2	1.5	16.0	42.6	7.8	3.3	6.3	2.7	85.0	36.2	34.2	3.1

[1]See page 26 for definitions of terms and units of measurement used in column headings.

[2]The period of rising temperature was 0.5 hour from the initial temperature to 100° C. and 1.5 hours for the additional increase to 155° C. at which point the temperature was held constant for the time indicated.

[3]The volume of cooking liquor in all cooks was in the ratio of 60 gallons to 100 pounds of straw (oven-dry basis).

[4]The samples of pulps and of uncooked straw were ground to pass a 40-mesh sieve before the determinations of lignin and the chlorine requirement.

[5]The chlorination method is considered as removing all the remaining lignin.

[6]Total available alkali is calculated as the sum of the excess sodium hydroxide and that produced by the hydrolysis of the sodium sulphide in water according to the reaction, $Na_2S + H_2O = NaOH = NaSH$.

[7]The threshed straw was cut by means of a rag cutter without preliminary dusting.

[8]In series A-211 the straw was digested with 22.5 pounds of sodium hydroxide and 5.5 pounds of sodium sulphide per 100 pounds of straw. The total available alkali was equivalent to approximately 25 pounds of sodium hydroxide.

[9]In series A-212 the straw was digested with 17.4 pounds of sodium hydroxide and 4.3 pounds of sodium sulphide to 100 pounds of straw. The total available alkali was equivalent to approximately 20 pounds of sodium hydroxide.

Table 21.--The digestion of flax straw with sodium hydroxide alone and with a mixture of sodium hydroxide and sodium sulphide[1, 2]

Sample number[3]	Cook number	Duration of cooking[4]: To maximum temperature	Duration of cooking[4]: At maximum temperature	Duration of cooking[4]: Total	Total available NaOH per 100 g. of straw[5]	Chemicals charged: NaOH: Per 100 g. of straw	Chemicals charged: NaOH: Concentration	Chemicals charged: Na_2S: Per 100 g. of straw	Chemicals charged: Na_2S: Concentration	Chemicals consumed: NaOH	Chemicals consumed: Na_2S	Yield of pulp
		Minutes	Hr. Min.	Hours	Grams	Grams	G. per l.	Grams	G. per l.	Percent	Percent	Percent
372	202	21	0:39	1	15	15	30	....	....	11.7	....	59.20
	203	20	:40	1	15	15	30	....	....	12.8	....	59.14
373	204	21	2:39	3	15	15	30	....	....	13.2	....	57.08
	205	23	2:37	3	15	15	30	....	....	13.8	....	57.08
374	206	22	6:38	7	15	15	30	....	....	14.8	....	55.87
	207	21	6:39	7	15	15	30	....	....	14.6	....	55.63
375	208	120	7:00	9	15	15	30	....	....	14.6	....	56.09
	209	120	7:00	9	15	15	30	....	....	14.5	....	55.95
376	210	120	7:00	9	15	15	30	....	....	14.2	....	[6]58.04
	211	120	7:00	9	15	15	30	....	....	14.2	....	[6]58.36
377	[7]212	22	3:38	4	10	10	20	....	....	10.0	....	67.07
379	[7]216	20	3:40	4	10	8.8	17.6	2.2	4.4	8.8	1.6	61.69
	[7]217	20	3:40	4	10	8.8	17.6	2.2	4.4	8.8	1.8	63.04
380	[7]218	21	6:39	7	15	13.4	26.8	3.3	6.6	12.9	2.6	50.65
	[7]219	21	6:39	7	15	13.3	26.7	3.3	6.6	12.6	1.8	49.68
378	214	20	9:40	10	20	20.0	40.0	....	....	14.4	....	48.64
	215	20	9:40	10	20	20.0	40.0	....	....	14.7	....	48.89
381	[7]220	20	9:40	10	20	17.4	34.8	4.3	8.6	15.2	2.5	45.09
	221	20	9:40	10	20	17.4	34.7	4.3	8.6	14.8	2.2	44.98

[1]See page 26 for definitions of terms and units of measurement used in column headings.

[2]See table 22 for chemical analysis of the pulps.

[3]The pulps from two practically identical digestions were combined to form the sample for chemical analysis.

[4]The maximum temperature was 155° C.

[5]Total available alkali is calculated as the sum of the excess sodium hydroxide and that produced by the hydrolysis of the sodium sulphide in water according to the reaction, $Na_2S + H_2O = NaOH + NaSH$.

[6]The ground straw was extracted with a mixture of alcohol and benzene (33 percent and 67 percent, respectively) previous to pulping. These yield figures are based on extracted straw. The average yield calculated similarly for unextracted straw is 56.26 percent, which is only slightly higher than the yield when the straw is not extracted with organic solvents.

[7]The resulting pulp was washed free of spent cooking liquors with difficulty.

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Table 22.--Chemical properties of pulps from flax straw digested with sodium hydroxide and with a mixture of sodium hydroxide and sodium sulphide[1]

Series and sample number		Total cooking time[2]	Alkalinity calculated as NaOH	Average yield of pulp[3]	Lignin[4]	Cellulose[4]		Pentosans[4]			Sum of pentosan-free cellulose, lignin, and total pentosans	Copper number	Quantity soluble in 1 percent NaOH solution
						Total	Pentosan-free	Total	In cellulose	Not in cellulose			
		Hours	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent		Percent
	[5]371	0	....	100.00	23.3	53.8	46.8	17.0	7.0	10.0	87.1	8.0	33.7
	372	1	15	59.17	13.5	46.4	39.9	8.1	6.4	1.6	103.98	3.7	5.5
	373	3	15	57.08	11.2	45.5	39.0	8.1	6.6	1.5	101.93	4.7	4.7
SERIES I	374	7	15	55.75	10.7	44.8	38.1	7.9	6.8	1.1	101.6	5.2	5.0
	375	9	15	56.02	11.2	45.0	38.3	7.9	6.7	1.2	102.4	6.5	6.7
	376	9	15	56.26	10.5	45.6	38.8	7.9	6.8	1.1	101.6	5.7	5.0
	377	4	10	67.07	18.9	46.9	39.9	9.2	6.9	2.3	101.4	7.4	....
	379	4	10	62.37	15.3	46.2	39.8	8.6	6.5	2.2	102.1	7.7	8.9
	374	7	15	55.75	10.7	44.8	38.1	7.9	6.8	1.1	101.6	5.2	5.0
SERIES II	380	7	15	50.17	5.3	44.3	38.2	7.2	6.2	1.0	101.0	3.8	4.7
	378	10	20	48.77	5.7	43.7	37.3	6.8	6.4	.4	102.1	5.2	4.9
	381	10	20	45.04	2.2	42.2	36.6	6.4	5.6	.8	100.6	2.3	3.8

[1]See page 26 for definitions of terms and units of measurement used in column headings.

[2]See table 21 for other pulping conditions.

[3]The pulps from two practically identical digestions were combined to form the sample for chemical analysis.

[4]Based on original straw. All other chemical constituents are based on the sample analyzed.

[5]Sample 371 was untreated, dusted and cut straw, ground to pass a 40 mesh sieve.

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Table 23.--Digestion of flax straw (in series A-215) with sodium hydroxide and with sodium sulphite, both individually and in various mixtures, some of which included sodium sulphide[1]

Digestion number[2]	Material	Chemical charged: Kind	Chemical charged: Amount per 100 pounds[3] of--: Material cooked	Chemical charged: Amount per 100 pounds[3] of--: Straw	Duration of cooking at maximum temperature[4]	Amount of chemical consumed per 100 pounds of--: Material cooked	Amount of chemical consumed per 100 pounds of--: Straw	Yield of crude pulp per 100 pounds of--: Material cooked	Yield of crude pulp per 100 pounds of--: Straw	Lignin in crude pulp[5]: In the sample analyzed	Lignin in crude pulp[5]: Per 100 pounds of straw	Chlorination by a modified Roe method[6]: Chlorine consumed: In the sample treated	Chlorination by a modified Roe method[6]: Chlorine consumed: Per 100 pounds of straw	Chlorination by a modified Roe method[6]: Yield of residue: In the sample treated	Chlorination by a modified Roe method[6]: Yield of residue: Per 100 pounds of straw	Loss of material other than lignin per 100 pounds of straw[6]
			Pounds	Pounds	Hours	Pounds	Pounds	Pounds	Pounds	Percent	Pounds	Percent	Pounds	Percent	Pounds	Pounds
	Uncooked straw									27.0	27.0	29.9	29.9	49.0	49.0	24.0
1	Straw[7]	NaOH	10.0	10.0	2	10.0	10.0	67.0	67.0	30.1	20.2	32.9	22.0	64.8	43.5	3.3
25[8]	...do...	Na_2SO_3	20.0	20.0	6	18.3	18.3	59.2	59.2	20.4	12.1	17.1	10.1	77.1	45.7	1.4
3	...do...	($NaOH$ / (Na_2SO_3	10.0 / 20.0	10.0) / 20.0)	2	(9.8 / (13.6	9.8) / 13.6)	54.5	54.5	21.8	11.9	17.6	9.6	73.7	40.2	2.4
1R	Pulp from digestion 1	Na_2SO_3	20.0	13.4	6	9.0	6.0	89.3	59.8	26.5	15.9	23.6	14.1	67.6	40.4	3.5
2R	Pulp from digestion 25	NaOH	10.0	5.9	2	8.7	5.1	73.6	43.6	11.9	5.2	9.7	4.2	84.6	36.9	1.5
4	Straw[7]	($NaOH$ / (Na_2S	8.8 / 2.2	8.8) / 2.2)	2	(8.8) / (0.4)	65.5	65.5	65.5	29.3	19.2	28.2	18.5	68.2	44.7	1.6
4R	Pulp from digestion 4	Na_2SO_3	20.0	13.1	6	9.7	6.3	84.0	55.0	22.5	12.4	17.8	9.8	73.5	40.4	2.2
5R	Pulp from digestion 25	($NaOH$ / (Na_2S	8.8 / 2.2	5.2) / 1.3)	2	(7.2 / (1.4	4.3) / 0.8)	73.4	43.4	14.0	6.3	12.3	5.3	83.0	36.0	1.0

[1]See page 26 for definitions of terms and units of measurement used in column headings.

[2]"R" indicates a redigestion.

[3]The volume of cooking liquor in all cooks was in the ratio of 60 gallons to 100 pounds of straw (oven-dry basis).

[4]The period of rising temperature was 0.5 hour from the initial temperature to 100° C. and 1.5 hours for the additional increase to 155° C. at which point the temperature was held constant for the time indicated.

[5]The samples of pulps and of uncooked straw were ground to pass a 40-mesh sieve before the determinations of lignin and the chlorine requirement.

[6]The chlorination method is considered as removing all the remaining lignin.

[7]The threshed straw was cut by means of a rag cutter without preliminary dusting.

[8]Pulp 25 was divided for redigestions 2R and 5R.

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Table 24.--Total loss of lignin and of material other than lignin in various alkaline digestions (in series A-215) of flax straw

Digestion number	1	[1]25	3	[2]1R	[2]2R	4	[2]4R	[2]5R
Chemicals used and sequence of treatments	NaOH	Na_2SO_3	NaOH and Na_2SO_3 together	NaOH followed by Na_2SO_3	Na_2SO_3 followed by NaOH	NaOH and Na_2S together	NaOH and Na_2S together followed by Na_2SO_3	Na_2SO_3 followed by NaOH and Na_2S together
Loss of lignin in percent..	6.8	14.9	15.1	11.1	21.8	7.8	14.6	20.7
Loss of material other than lignin in percent........	26.2	25.9	30.4	29.1	34.6	26.7	30.4	35.9
Total loss of constituents in percent..............	33.0	40.8	45.5	40.2	56.4	34.5	45.0	56.6

[1]Pulp 25 was divided for redigestions 2R and 5R.

[2]Values in these columns are the combined losses caused by the two treatments.

Table 25.--Pulping of flax straw by the chlorine process[1]

Digestion number	Alkaline digestion[2]: Chemical charged[3]: Kind	Chemical charged[3]: Amount	Chemical charged[3]: Total available alkali[4]	Duration of cooking[5]	Total available NaOH consumed per 100 pounds straw	Yield of crude pulp	Rod milling: Run number[6]	Consistence	Rods: Kind	Rods: Per pound of pulp	Rate of milling	Chlorination: Run number[6]	Number of chlorinations	Total chlorine consumed per 100 pounds of crude pulp	Chemical used in alkaline boiling treatment	Bleaching powder	Yield of bleached pulp	Remarks[7]
		Pounds	Pounds	Hours	Pounds	Percent		Percent		Pounds	Pounds per hour			Pounds		Pounds	Percent	
B-205-1	NaOH	15.0	15.0	9	14.2	52.8	1, 2	9.3	Steel	133	48	(1	2	21.8	Na_2SO_3	16.1	43.5	
												(2	2	18.7	Na_2SO_3	16.1	...	
B-205-2	NaOH	15.1	15.1	9	13.5	52.4	1, 2	3.0	Bronze	349	18	1	2	29.4	NaOH	1.5	...	
							3	9.0	do.	179	19	2	2	24.9	do.	5.0	...	
							4	9.0	do.	133	32	3	2	22.5	do.	2.0	32.5	
B-208-1	(NaOH	13.4)	15.1	9	14.6	49.3	2	9.0	do.	127	23	1	2	17.6	do.	4.0	...	
	(Na_2S	3.3)					1	6.5	do.	127	22	2	2	15.1	do.	11.0	...	
B-208-2	(NaOH	13.4)	15.1	9	...	48.8	1	9.0	do.	127	19	1	2	15.6	do.	5.0	...	
	(Na_2S	3.3)					2	9.0	do.	117	21	2	2	15.1	do.	2.0	...	Sodium bicarbonate added during chlorination treatments.
B-214-1	(NaOH	17.4)	19.6	3	16.8	54.2	1	9.5	Steel	128	23	1	2	12.2	do.	5.0	[illegible]	Treated with hydrochloric acid and washed before bleaching.
	(Na_2S	4.3)					2	9.5	do.	130	19	2	1	12.3	do.	...	...	
B-214-2	(NaOH	17.4)	19.6	3	17.3	50.4	1	9.0	Bronze	130	16	1, 2	1	11.1	do.	10.0	...	
	(Na_2S	4.3)					2	5.2	do.	223	9	3	1	11.4	do.	10.0	35.3	
							3	5.5	do.	213	10	4	1	10.8	do.	...	...	
							4	5.9	do.	199	10	5	1	11.2	do.	7.5	...	
							5	7.0	do.	206	12	6	1	11.7	do.	...	...	
B-214-3	(NaOH	17.4)	19.6	3	13.5	47.6	1	9.0	do.	130	15	1, 2	1	10.4	do.	6.0	...	
	(Na_2S	4.3)					...	3.3	...	...	3	...	1	12.3	do.	8.0	...	Beater run number 1, digestion B-214-3.
B-217-1	(NaOH	17.4)	19.6	7	16.5	42.6	1	9.0	do.	130	28	1, 2	1	7.5	do.	5.0	...	
	(Na_2S	4.3)					2	6.0	do.	199	36	3	...	...	...	32.0	...	Pulp not chlorinated; bleached only.
							3	6.0	do.	167	26							
B-221-1	(NaOH	8.8)	9.9	4	...	70.0	1	14.3	do.	82	15	...	...	...	...	...	...	Pulp not chlorinated or bleached.
	(Na_2S	2.2)					2	13.0	do.	82	18	1, 2	2	21.4	do.	3.0	...	
B-222-1	Na_2SO_3	20.0	...	8	...	62.0	1	6.0	do.	208	31	1	1	18.9	...	11.0	...	No alkaline boiling treatment.
							2	6.0	do.	208	31	2	1	16.6	Na_2SO_3	5.5	...	
							...	4.0	...	...	6	3, 4	1	16.0	NaOH	9.0	...	Beater run number 1, digestion B-222-1.
							3	13.0	do.	82	15	5	1	17.4	...	12.0	...	No alkaline boiling treatment.
												6	1	15.8	...	...	...	
												7	1	16.2	do.	12.0	...	
							4	9.0	do.	130	27	8	1	8.1	do.	22.0	...	
B-224-1	(NaOH	10.0)	...	8	...	53.4	...	...	...	...	...	1, 2	1	14.5	do.	18.0	...	Beater run number 1, digestion B-224-1.
	(Na_2SO_3	20.0)					1	8.0	do.	200	29	3, 4	1	19.0	do.	8.5	...	
							2	6.0	do.	206	22	5	1	23.5	do.	6.0	...	
							3	9.0	do.	130	19	6	1	18.1	do.	8.5	...	

[1] See page 26 for definitions of terms and units of measurement used in column headings.

[2] The straw without preliminary dusting was cut before pulping by means of a rag cutter.

[3] The volume of cooking liquor was in the ratio of 60 gallons to 100 pounds of straw (oven-dry basis).

[4] Total available alkali is calculated as the sum of the excess sodium hydroxide and that produced by the hydrolysis of the sodium sulphide in water according to the reaction, $Na_2S + H_2O = NaOH + NaSH$.

[5] The period of rising temperature was 0.5 hour from the initial temperature to 100° C. and 1.5 hour for the additional increase to 155° C. at which point the temperature was held constant for the predetermined time.

[6] Where numbers are grouped (that is, 1 and 2), the runs indicated were duplicates within the practical limits of operation.

[7] See table 26 for the properties of papers made from these pulps.

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Table 26.—Summary of the processing and the properties of paper from flax straw pulp prepared by the chlorine process[1]

Digestion number	Digesting[2]: Type of digestion	Digesting[2]: Total available alkali charged	Digesting[2]: Duration of cooking	Rod milling[2]: Run number[3]	Rod milling[2]: Consistence	Rod milling[2]: Rate of milling	Chlorination[2]: Run number[3]	Chlorination[2]: Number of chlorinations	Chlorination[2]: Total chlorine consumed per 100 pounds crude pulp[4]	Refining and papermaking: Machine run number	Furnish: Flax pulp	Furnish: Soda pulp	Furnish: Dyestuff[5]	Jordan treatment	Form: Weight per ream	Form: Thickness	Strength: Bursting	Strength: Tearing	Strength: Tensile	Strength: Stretch at failure	Strength: Folding	Color: White	Primary hue: Tint	Primary hue: Luminosity	Secondary hue: Tint	Secondary hue: Luminosity	Remarks[6]
		Pounds	Hours		Percent	Pounds per hour			Pounds		Percent	Percent	Kind		Pounds	Inch	Points	Grams	Meters	Percent	Double fold	Percent		Percent		Percent	
B-205-1	Soda	15.0	9	1,2	9.3	46	....	....	None	1	100	....	None	None	51	0.0048	0.34	66	2,979	1.53	26	.....	....	......	....	....	Not chlorinated or bleached.
							1,2	2	25.9	2	100	....	..do..	None-beaten 1.5 hours	42	.0028	.81	50	5,425	1.54	392	48	Yellow	6.7	Orange	1.9	Insufficiently chlorinated, yellow from steel rods.
B-205-2	....do....	15.1	9	1,2	3.0	18	1	2	29.9	1	100	....	..do..	None	47	.0035	.79	90	5,046	2.84	116	62	Orange	2.6	None	....	
				5	9.0	19	2	2	26.7	2	100	....	..do..	.....do....	50	.0037	.90	62	5,478	3.95	537	65	....do..	3.2	Yellow	.5	
				4	9.0	32	3	2	23.2	3	100	....	..do..	Heavy	43	.0030	.75	117	4,870	3.10	101	61	Yellow	4.5	Green	1.4	
B-206-1	Sulphate	15.1	9	2	9.0	23	1	2	19.0	1	100	....	..do..	None	41	.0044	.60	138	3,869	1.65	234	73	....do..	4.1	Orange	1.9	Not screened, formation wild.
				1	6.5	22	2	2	19.0	2	100	....	..do..	Light[7]	51	.0033	.90	70	5,224	4.40	1,236	51	....do..	5.0	...do...	3.2	Insufficiently chlorinated.
														.....do[8]...	51	.0034	.92	86	6,260	4.49	750	.....	....	......	....	....	
B-206-2	....do....	15.1	9	1,2	9.0	20	1	2	17.4	1	100	....	..do..	None-in beater 5 minutes	48	.0032	.56	62	5,010	2.15	27	68	....do..	4.5	None	....	Run without screening.
							2	2	15.8	2	100	....	..do..	None	50	.0036	.60	67	4,164	2.22	20	67	Orange	2.6	Yellow	1.8	$NaHCO_3$ added to chlorine water.
B-214-1	....do....	19.6	3	1,2	9.5	21	1	2	14.0	1	100	....	..do..	.....do....	39	.0030	.90	72	5,987	3.43	672	46	....do..	5.1	...do...	2.7	Yellow from steel rods.
							....	1		2	85	15	..do..	.....do....	42	.0032	.88	70	5,906	3.95	738	51	....do..	3.8	...do...	3.6	
B-214-2	....do....	19.6	3	1	9.0	16	1,2	1	14.6	1	100	....	Blue	Light	61	.0040	.76	99	5,018	2.89	1,174	54	Red	1.5	Orange	1.3	
				2	5.2	9	3	1	14.9	2	100	....	..do..	None	57	.0038	.81	99	5,802	4.59	390	52	Orange	5.1	Yellow	3.6	
				3,4,5	6.5	10	4,5,6	1	12.1	3	79	21	None	.....do....	48	.0040	.67	62	5,273	3.84	182	72	....do..	3.2	...do...	1.4	
										4	86	14	..do..	.....do....	50	.0041	.81	65	5,319	4.20	204	72	Red	1.7	None	....	
B-214-3	....do....	19.6	3	1	9.0	15	[9]1,2	1	12.5	1	100	....	..do..	.....do....	49	.0035	.93	55	5,944	5.29	311	62	Orange	.6	Yellow	.5	
							3	1	15.1	2	100	....	..do..	.....do....	56	.0038	.80	51	5,748	4.37	395	67	Yellow	4.0	Orange	.6	
B-217-1	....do....	19.6	7	1	9.0	28	1;2	1	9.3	1	100	....	Blue	.....do....	49	.0036	.59	45	4,969	3.12	42	62	....do..	8.1	None	....	
														.....do....	68	.0050	.64	82	4,951	3.47	76	.....	....	......	....	....	
				2,3	6.0	31	3	....	11.2	2	85	15	..do..	.....do....	44	.0034	.54	45	4,199	2.48	40	68	Orange	1.3	Yellow	.9	Chlorine entirely as bleaching powder.
										3	100	....	..do..	.....do....	58	.0048	.65	74	4,622	3.01	85	60	....do..	2.6	Red	.2	
B-221-1	....do....	9.9	4	1	(14.3	15	....	....	None	2	100	....	None	.....do....	53	.0050	.37	62	2,499	1.26	19	18	....do..	5.8	Yellow	.5	Not chlorinated or bleached.
					(13.0	18	1,2	2	22.5	3	100	....	Blue	None-beaten lightly	60	.0039	.87	83	5,049	4.74	688	54	Yellow	1.8	Orange	1.3	
B-222-1	Sodium sulphite	....	8	1	6.0	31	1	1	22.8	1	100	....	..do..	Light[7]	55	.0038	.74	82	5,049	3.62	372	64	Blue	.3	None	....	No alkaline boiling treatment prior to bleaching.
														Heavy[8]	61	.0046	.72	98	5,198	3.95	1,362	.....	....	......	....	....	
				2	6.0	31	[9]2	1	18.5	2	100	....	..do..	None	52	.0038	.73	87	4,705	4.74	1,157	64	....do..	.1	None	....	
							3,4	1	19.1	3	100	....	..do..	.....do....	42	.0030	.66	39	4,731	2.23	83	58	....do..	.1	...do...	....	
				3	13.0	15	5,6,7	1	17.9	4	100	....	..do..	.....do....	53	.0037	.80	70	5,486	5.33	802	46	Orange	1.3	...do...	....	.........do.........
										5	100	....	..do..	.....do....													
				4	9.0	27	8	1	15.8	6	100	....	..do..	.....do....	69	.0050	.78	95	5,239	5.58	741	56	Purple-blue	.1	...do...	....	
										7	85	15	..do..	.....do....	55	.0040	.69	80	5,456	4.42	334	62	Orange	1.3	...do...	....	Of the chlorine 7.7 percent was bleaching powder.
															51	.0040	.71	86	5,016	4.27	382	67	Peacock-blue	.8	Purple-blue	.1	
B-224-1	Caustic soda and sodium sulphite	....	8	....	....	....	[9]1,2	1	20.8	1	100	....	None	.....do....	46	.0032	.61	60	4,360	3.45	542	57	Orange	1.3	Red	.6	Insufficiently chlorinated.
				1	8.0	19	3,4	1	22.0	2	100	....	..do..	.....do....	60	.0042	.74	81	4,760	4.20	784	50	Yellow	4.0	Orange	.6	Paper very dirty.
				2	6.0	22	5	1	25.6	3	100	....	..do..	.....do....	48	.0035	.69	78	4,275	3.61	216	66	....do..	3.2	...do...	.6	.......do.......
				3	9.0	19	6	1	21.1	4	100	....	..do..	.....do....	47	.0037	.74	78	4,935	5.21	452	57	Orange	1.3	None	....	.......do.......

[1]See page __ for definitions of terms and units of measurement used in column headings.

[2]For more detailed data see table 25.

[3]Where numbers are grouped average values from table 25 are tabulated.

[4]These values include the chlorine used as bleaching powder; all of it is expressed as Cl_2.

[5]When dye was added alum was always used to set the color.

[6]The best papers, as judged first by color, second by hydration and formation, and third by strength, were obtained in digestion B-214-2, machine runs 2, 3, and 4; digestion B-214-3, machine runs 1 and 2; digestion B-217-1, machines runs 1 and 2; and digestion B-222-1, machine runs 1, 2, 3, 5, and 7.

[7]First of the run.

[8]Last of the run.

[9]Beater run, see table 25.

Table 27.--Preparation of greaseproof and tissue papers from flax straw[1]

Cook number	Preliminary treatment losses: Dusting basis straw[2]	Preliminary treatment losses: Hot water extraction from straw	Chemicals: Kind	Chemicals: Amount per 100 pounds of dusted straw	Chemicals: Concentration	Cooking: Volume of cooking liquor per 100 pounds of dusted straw	Cooking: Duration of cooking: To maximum temperature	Cooking: Duration of cooking: At maximum temperature	Cooking: Maximum temperature	Cooking: Consumption of available alkali	Cooking: Yield of crude pulp based on dusted straw	Bleaching and beating: Bleaching powder[3]	Bleaching and beating: Capacity of beater used	Bleaching and beating: Duration of beating: Roll to reach bed-plate	Bleaching and beating: Duration of beating: Roll on bed-plate	Properties of machine made papers: Machine run number	Properties of machine made papers: Weight per ream	Properties of machine made papers: Thickness	Strength: Bursting	Strength: Tearing	Strength: Tension	Strength: Folding	Remarks
	Percent	Percent		Pounds	G. per l.	Gallons	Hours	Hours	°C.	Percent	Percent	Percent	Pounds	Hours	Hours		Pounds	Inches	Points	Grams	Meters	Double folds	
D-149	25.0	(4)	{NaOH {Na_2S	20.0 5.0	48.0} 12.0}	50	2.0	4.0	172	80	41	15	20	1.75	5.83	1	38.5	0.0033	0.82	1.14	4,390	57	Not greaseproof.
D-150	23.4	8.1	{NaOH {Na_2S	18.5 4.5	44.4} 10.8}	50	2.0	4.0	170	80	39	15	20	1.50	5.17	1	32.0	.0020	.69	1.80	4,632	89	More hydrated than D-149 but not greaseproof.
D-151	46.0	10.8	{NaOH {Na_2S	20.0 4.8	45.4} 10.9}	53	2.5	4.5	182	81	42	14	20	1.80	6.33	1	47.0	.0038	.43	1.42	4,480	375	More hydrated than D-149 or D-150 but not greaseproof.
D-152	34.5	6.1	{NaOH {Na_2S	17.6 4.4	42.3} 10.6}	50	2.5	5.5	160	77	45	18	{20 {5	2.00 2.25	17.60 8.25	1 2	27.5 28.0	.0015 .0020	.61 .73	.58 .61	4,860 5,635	251 276	Greaseproof. More greaseproof than machine run 1.
D-153	31.5	6.4	{NaOH {Na_2S	17.6 4.4	42.3} 10.6}	50	2.25	[5]12.5	150	78	37	14	{5 {5 {5	2.50 1.50 2.67	3.08 2.58 2.67	1 2 3	34.0 35.0 38.0	.0030 .0030 .0030	.81 .83 .82	.56 .66 .79	6,083 5,706 6,087	253 152 171	Greaseproof. ...do... More greaseproof than machine runs 1 and 2.
D-154a	(6)	(7)	{NaOH {Na_2S	19.1 4.4	43.3} 10.0}	53	2.0	8.0	160	91	46	10	[8]40	3.08	5.60	1	34.0	.0026	.74	.56	5,238	138	Greaseproof.
D-154b	(6)	7.5	{NaOH {Na_2S	17.6 4.4	42.3} 10.0}	50	2.0	8.0	160	91	50	11	...	...	...	...	...	...	...	...	...	...	
D-158a	(6)	6.7	{NaOH {Na_2S	17.6 4.4	42.3} 10.0}	50	2.0	8.0	160	74	33	13	[8]40	2.50	3.17	1	19.8	.0020	.79	1.52	6,013	85	Not so greaseproof as D-154 a,b.
D-158b	(6)	7.5	{NaOH {Na_2S	17.6 4.4	42.3} 10.0}	50	2.5	7.5	160	98	39	14	5	1.60	2.17	1	...	...	...	...	...	...	Too gelatinous to run on paper machine.
D-155a	(6)	6.9	Na_2SO_3	30.0	47.0	77	2.75	7.25	170	...	52	13	9	1.40	2.58	1	...	...	...	...	...	...	...do...
D-155b	(6)	10.3	Na_2SO_3	30.0	21.2	53	2.5	7.5	170	...	51	17	50	.60	1.50	1	...	...	...	...	...	...	Paper of poor formation and not greaseproof.

[1]See page 26 for definitions of terms and units of measurement used in column headings.

[2]After dusting, the straw was cut to from 1 to 3 inches in length.

[3]The amount of bleaching powder used was only sufficient to bleach the pulp to a light brownish yellow.

[4]Not extracted.

[5]Digester contents cooled an additional 9.25 hours from 150° to 110° C.

[6]Dusted but loss not determined.

[7]Extracted but loss not determined.

[8]Pulp from cooks D-158a and D-158b were combined for this beater run.

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Table 28.--Preparation of strawboard from flax towing mill waste, flax straw, and oat straw alone and in various mixtures[1]

Series number	Cook number	Machine run	Material cooked[2]: Kind	Material cooked[2]: Amount based on total charge	Method of refining[3]	Properties of machine-made papers: Weight per ream	Thickness	Bursting strength	Tearing strength
				Percent		Pounds	Inches	Points	Grams
B-201	1	2	Towing waste	100	Rod mill	208	0.020	0.20	1.11
		1	....	......	Beater	132	.014	.20	1.23
	5	2	Towing waste	75	Rod mill	165	.017	.25	.64
		1	Oat straw	25	Beater	157	.016	.25	.62
	4	2	Towing waste	50	Rod mill	146	.015	.34	.58
		1	Oat straw	50	Beater	152	.015	.30	.61
	3	2	Towing waste	25	Rod mill	132	.013	.39	.64
		1	Oat straw	75	Beater	118	.013	.40	.78
	2	2	Oat straw	100	Rod mill	118	.012	.47	.90
		1	....	......	Beater	127	.014	.38	2.43
B-202	4	2	Flax straw	25	Rod mill	94	.010	.35	.84
		1	Oat straw	75	Beater	104	.012	.34	.97
	3	2	Flax straw	50	Rod mill	85	.010	.29	.77
		1	Oat straw	50	Beater	94	.010	.32	.61
	2	2	Flax straw	75	Rod mill	85	.009	.39	.64
		1	Oat straw	25	Beater	95	.009	.28	.68
	1	2	Flax straw	100	Rod mill	96	.009	.29	.92
		1	....	......	Beater	96	.009	.26	.63

[1]See page 26 for definitions of terms and units of measurement used in column headings.

[2]The cooking conditions were 10.4 pounds of lime (96 percent $Ca(OH)_2$) and 16 gallons of liquor per 100 pounds of raw material (dry basis), 3 hours to maximum temperature, 5 hours at maximum temperature, and an average maximum temperature of 137° C. for all cooks except B-201-1 in which 12 pounds of lime and 19.5 gallons of liquor per 100 pounds of dry material were used, 3 hours to maximum temperature 7 hours at maximum temperature, and an average maximum temperature of 137° C.

[3]The rod mill contained approximately 3,700 pounds of solid steel rods and was operated continuously at 27 r.p.m. The beater was of 40 pounds capacity.

Table 29.--Pulping flax straw for strawboard[1]

Series and cook number	Cooking: Chemicals charged: Kind	Cooking: Chemicals charged: Amount	Cooking: Chemicals charged: Concentration	Cooking: Duration of cooking: To maximum temperature	Cooking: Duration of cooking: At maximum temperature	Cooking: Average maximum temperature	Cooking: Pulp yield	Rod milling[2]: Rod mill run number	Rod milling: Rods: Kind	Rod milling: Rods: Number	Rod milling: Rods: Weight: Total	Rod milling: Rods: Weight: Per pound of oven-dry pulp	Rod milling: Consistence	Rod milling: Duration of milling	Rod milling: Rate of milling	Rod milling: Power consumption actual[3]	Properties of machine made papers: Machine run number	Properties of machine made papers: Weight per ream	Properties of machine made papers: Thickness	Properties of machine made papers: Bursting strength	Properties of machine made papers: Tearing strength	Properties of machine made papers: Folding strength
		Percent	G. per L.	Hours	Hours	C.	Percent				Pounds	Pounds	Percent	Minutes	Tons per 24 hours	Hp.-days per ton		Pounds	Inches	Points	Grams	Double folds
B-188	$Ca(OH)_2$	18.6	112.0	2.0	14.5	160	....	[4]1	Solid steel	52	3,720	....	....	....	....	....	1	74	0.008	0.29	0.83	7
B-189	$Ca(OH)_2$	10.0	60.0	1.0	11.0	130	....	[5]1	......do......	52	3,720	....	....	....	....	....	1	118	.010	.30	.77	3
B-206-1	Na_2CO_3	14.0	78.0	3.0	2.5	137	....	[6]1	Solid bronze	37	3,660	100	8.0	....	0.11	....	1	76	.009	.38	2.60	29
								([5])	....	....	....	....	....	....	....	....	3	66	.009	.28	2.14	10
B-210-1	Na_2CO_3	14.0	78.0	3.0	2.5	137	....	1	Solid steel	52	3,720	122	9.4	105	.21	....	1	80	.009	.38	1.48	9
								2	......do......	52	3,720	146	9.5	75	.24	....	2	78	.010	.52	1.80	42
B-210-2	Na_2CO_3	14.0	78.0	3.0	2.5	137	76	3	......do......	52	3,720	129	9.0	75	.28	45.0	3	89	.009	.32	.94	1
								2	......do......	52	3,720	152	9.1	75	.23	97.0	2	121	.010	.34	1.09	7
								1	......do......	52	3,720	136	8.5	105	.19	27.8	1	121	.010	.36	1.16	5
								4	......do......	52	3,720	127	5.8	70	.30	77.0	4	69	.007	.36	.90	3
								5	......do......	52	3,720	152	5.8	50	.35	34.6	5	83	.010	.33	1.11	3
B-216-1	Na_2CO_3	14.0	78.0	3.0	2.5	137	....	1	Iron pipe	45	1,090	114	3.0	110	.06	....	2	74	.008	.48	1.22	11
								5	......do......	45	1,090	114	8.5	90	.08	....	5	64	.006	.49	.83	11
								2	......do......	45	1,090	57	6.2	210	.07	99.0	1	67	.007	.39	1.34	11
								4	......do......	45	1,090	57	10.0	225	.06	....	4	91	.009	.37	1.15	4
								3	......do......	45	1,090	38	9.0	320	.06	....	3	75	.007	.41	.95	5
A-197-1	$NaHCO_3$	15.9	64.4	1.5	2.5	165	76	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
A-197-2	$NaHCO_3$	15.9	64.4	1.5	2.5	160	77	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
A-197-3	$NaHCO_3$	15.9	64.4	1.5	2.5	150	77	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
B-209-1	$NaHCO_3$	22.4	75.0	3.0	2.5	137	68	1	Solid bronze	37	3,660	100	9.5	120	.22	....	1	66	.007	.33	.87	4
								2	......do......	37	3,660	123	12.3	90	.23	....	2	66	.008	.32	1.28	13
B-213-1	Na_2CO_3	8.0	38.4	3.0	2.5	137	70	1	Solid steel	52	3,720	123	9.5	100	.22	....	1	85	.010	.32	1.40	23
	Na_2SO_3	2.0	9.6					2	......do......	52	3,720	145	9.5	75	.25	....	2	85	.011	.29	1.10	7
B-213-2	Na_2CO_3	12.0	60.0	3.0	2.5	137	71	1	......do......	52	3,720	123	9.5	100	.22	....	1	80	.010	.33	1.13	8
	Na_2SO_3	3.0	15.0					2	......do......	52	3,720	145	9.5	75	.25	....	2	90	.011	.33	1.28	16
B-221-1	$NaOH$	8.8	17.6	2.0	2.0	155	70	1	Solid bronze	38	3,750	82	14.3	180	.19	71.0	1	115	.009	.34	1.17	43
	Na_2S	2.2	4.4																			
B-223-1	Na_2CO_3	5.0	18.2	1.0	6.0	130	....	[7]2	Solid steel	50	3,475	116	8.7	30	.72	17.5	1	104	.011	.24	.90	3
	Sulphur	.5	1.8														[8]2	93	.011	.16	.84	2
B-223-2	Na_2CO_3	10.0	36.4	1.0	6.0	130	72	2	......do......	50	3,475	113	10.2	90	.25	54.0	1	82	.008	.33	.98	9
	Sulphur	1.0	3.6														[8]2	116	.011	.25	1.22	20
B-223-3	Na_2CO_3	15.0	54.5	1.0	6.0	130	70	2	......do......	50	3,475	145	13.0	65	.27	52.0	1	100	.011	.23	1.46	21
	Sulphur	1.5	5.5					3	......do......	50	3,475	137	12.4	90	.20	61.8	2	129	.010	.30	1.47	45
								4	......do......	50	3,475	139	8.3	45	.40	36.6	3	108	.011	.23	1.63	18
																	[8]4	90	.010	.19	1.15	7
B-225-1	Na_2CO_3	14.0	76.4	3.0	2.5	137	75	2	......do......	50	3,475	145	13.0	50	.35	37.6	1	106	.009	.37	1.62	82
	Sulphur	1.4	7.6					3	......do......	50	3,475	137	12.4	70	.26	55.7	2	106	.010	.36	1.36	37
								4	......do......	50	3,475	139	8.3	60	.30	46.5	3	97	.009	.33	1.33	30
																	[8]4	105	.010	.26	.97	7
	Commercial, lime-cooked wheat strawboard	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	109	.010	.21	.58	1

[1]See page 26 for definitions of terms and units of measurement used in column headings.

[2]Rod mill operated batchwise (unless otherwise noted) at 28 r.p.m.

[3]Does not include the stray power or transmission losses.

[4]Pulp run once through rod mill, screened on a gyratory riddle, and beaten in a beater of 5 pounds capacity.

[5]Pulp through rod mill once, finished in a beater of 20 pounds capacity.

[6]Pulp passed through rod mill twice.

[7]Pulp not washed before beating. Sufficient alum or sulphuric acid to turn Congo red indicator was added to the stock before running on the paper machine.

[8]Beater run.

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Table 30.--Chemical analysis of shaker tow and flax straw

Constituent	Shaker tow	Flax straw
	Percent	Percent
Soluble in hot water	10.3	9.9
Soluble in 1 percent sodium hydroxide solution (corrected for hot water soluble)	18.8	32.1
Soluble in alcohol-benzol	15.6	3.7
Cellulose (Cross and Bevan)	50.2	51.3
Pentosans in cellulose	3.8	4.2
Pentosans, total	10.3	19.4
Lignin	13.4	24.2

[1]See page 26 for definitions of terms and units of measurement used in column headings.

Table 31.--Digestion of shaker tow with mixtures of sodium hydroxide and sodium sulphide[1]

Cook number	Cooking data: Chemicals charged: Kind	Chemicals charged: Amount	Chemicals charged: Concentration	Duration of cooking: To maximum temperature	Duration of cooking: At maximum temperature	Maximum temperature	Alkali consumed	Yield crude pulp	Bleaching and beating data: Beater run number[2]	Bleaching powder	Consistence	Duration of beating: Roll to touch bed plate	Duration of beating: Roll on bed plate	Properties of machine-made papers: Machine run number	Weight per ream	Thickness	Bursting strength	Tearing strength	Folding strength	Tensile strength	Stretch at rupture
		Pounds	G. per l.	Hours	Hours	°C.	Percent	Percent		Percent	Percent	Hours	Hours		Pounds	Inches	Points	Grams	Double folds	Meters	Percent
D-161	($NaOH$ (Na_2S	13.2 4.0	19.5) 5.9)	3.00	4.00	160	82	59	1	15	....	1.50	1.25	1	43.5	0.0035	0.60	0.37	113	4,953	1.6
D-162	($NaOH$ (Na_2S	13.0 3.8	19.5) 5.7)	4.25	4.75	150	88	60	1	20	....	1.92	.16	1	41.5	.0030	.67	1.08	196	4,994	3.5
D-163	($NaOH$ (Na_2S	12.2 4.0	24.4) 7.7)	6.75	2.25	150	65	....	(1	15	3.3	2.67	(3)	1	48.1	.0040	.71	1.04	230	5,208	3.9
									(2	15	3.5	2.58	(3)	2	48.1	.0040	.65	1.04	187	5,276	2.2
									(3	15	3.0	4.50	(3)	3	41.5	.0030	.70	.89	143	5,730	3.8
									(4	15	3.0	6.33	(3)	4	45.5	.0035	.62	1.14	172	5,706	2.7
									(5	(3)	3.0	6.50	(3)	5	39.5	.0030	.56	1.16	772	5,337	3.1
D-164	($NaOH$ (Na_2S	20.1 8.0	30.1) 12.0)	5.00	0.	140	44	64	1	[4]15	3.5	7.50	(3)	1	41.5	.0030	1.03	1.13	581	5,485	3.4

[1] See page 26 for definitions of terms and units of measurement used in column headings.

[2] Beater of 50 pounds capacity.

[3] None.

[4] This pulp contained undigested shives that were not bleached white with the amount of bleaching powder used.

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Table 32.--Properties of papers produced from carded flax fiber compared with linen rag papers[1]

Cook number	Bleaching and beating: Bleaching powder	Duration of beating[2]: Roll to touch bed plate	Duration of beating[2]: Roll on bed plate	Weight per ream	Thickness	Bursting	Tearing strength	Folding strength	Tensile strength	Stretch at rupture
	Percent	Hours	Hours	Pounds	Inches	Points	Grams	Double folds	Meters	Percent
[3]D-220-1	8.1	5.60	0.67	43.5	0.0030	0.79	1.36	2,245	5,921	5.4
[4]D-220-2	12.1	7.00	.17	37.6	.0023	.83	1.94	2,667	5,987	5.6
[5]D-54	12.0	(6)	(6)	44.5	.0035	.83	1.90	2,985	5,302	7.1
(7)	....	......	......	50.0	.0035	1.04	......	3,563	6,360	7.4

[1]See page 26 for definitions of terms and units of measurement used in column headings.

[2]Beater of 50 pounds capacity. Consistence from 3.5 to 4.0 percent.

[3]Carded fiber cooked with 15 percent of calcium hydroxide based on carded fiber; 60 gallons of solution per 100 pounds of material; cooking schedule, 2 hours to 130° C., 10 hours at 130° C.

[4]Carded fiber cooked under conditions of cook D-220-1, except the time at 130° C. was 8 hours.

[5]Linen rags cooked with 4.0 percent of calcium hydroxide and 0.5 percent of sodium carbonate; 50 gallons of solution per 100 pounds of rags; cooking schedule, 1.75 hours to 130° C., 11.25 hours at 130° C.

[6]Not recorded. Four machine runs were made from this pulp, each under different beating conditions. The best paper made, machine run 4, is shown here for comparison with the carded fiber. See table 11, for all machine runs.

[7]A commercial linen rag paper of high white color.

Table 33.--Bursting strength of hand-formed test boards composed of flax towing mill waste and jack pine pulps[1]

Furnish		Properties of board		
Flax waste[2]	Jack pine	Weight per ream	Thickness	Bursting strength
Percent	Percent	Pounds	Inches	Points
10	90	254	0.038	0.16
25	75	190	.024	.23
50	50	162	.020	.29
75	25	208	.024	.31
90	10	144	.019	.27
100	0	149	.019	.17

[1] See page 26 for definitions of terms and units of measurement used in column headings.

[2] The towing waste was cooked with 10 percent of sodium hydroxide and 4 percent of sodium sulphide by weight of the waste for 8 hours at a maximum temperature of 148° C. The jack pine was half-cooked by the sulphate process (commonly termed the semikraft process). The two pulps were beaten together in a small experimental beater.

Table 34.--Digestion of towing mill waste with mixtures of sodium hydroxide and sodium sulphide for the production of a bleachable pulp[1]

Cook number	Chemicals[2] Kind	Chemicals[2] Amount	Chemicals[2] Concentration	Volume cooking liquor	Duration of cooking[3]	Maximum temperature	Total alkali consumed	Yield of crude pulp[2]	Bleaching powder	Color of the shives in the bleached pulp[4]
		Pounds	G. per l.	Gallons	Hours	°C.	Percent	Percent	Percent	
A-1	(NaOH (Na_2S	13.0 4.5	16.0) 5.5)	96	8	139	84	48.5	....	....
A-2	(NaOH (Na_2S	13.0 4.5	16.0) 5.5)	96	8	165	96	33.6	....	....
A-3	(NaOH (Na_2S	17.4 5.0	14.0) 4.0)	150	5	139	82	44.1	....	....
A-4	(NaOH (Na_2S	9.9 10.0	10.0) 10.3)	117	5	139	86	46.9	....	....
A-5	(NaOH (Na_2S	17.4 5.0	14.0) 4.0)	150	5	165	93	39.2	....	....
A-6	(NaOH (Na_2S	20.0 5.0	16.0) 4.0)	113	5	165	90	35.0	....	....
A-7	(NaOH (Na_2S	15.0 10.0	16.0) 10.6)	150	5	165	91	38.6	30.0	Yellow
A-8	(NaOH (Na_2S	20.0 10.0	16.0) 8.0)	112	5	165	81	32.0	30.0	.....do......
[5]A-9	(NaOH (Na_2S	15.0 10.0	16.0) 10.6)	112	5	165	83	35.0	25.0	.....do......
[6]A-10	(NaOH (Na_2S	15.0 10.0	16.0) 10.6)	112	5	165	96	37.9	30.0	Light brown
[5]A-11	(NaOH (Na_2S	15.0 10.0	16.0) 10.6)	112	5	165	90	42.8	45.0	.....do......
[5]A-12	(NaOH (Na_2S	20.0 15.0	16.0) 12.0)	148	5	165	76	29.6	[7]30.0	Light yellow
[5]A-13	(NaOH (Na_2S	25.0 15.0	16.0) 9.6)	180	5	165	68	31.8	[7]25.0	.....do......
[5]A-14	(NaOH (Na_2S	30.0 15.0	24.0) 12.0)	165	5	165	65	30.2	[7]22.5	.....do......

[1]See page 26 for definitions of terms and units of measurement used in column headings.

[2]With the exception of cooks 1 and 2, the material was screened before cooking, with a loss of about 20 percent of fine dust and dirt. The amounts of the chemicals and the yields are based on the screened material.

[3]The time to reach maximum temperature was 1.5 hours.

[4]The predominating color of the sheet was the light cream of the bast fiber. The sheets were sprinkled with the undisintegrated shives, whose color was as noted. Some of the sheets were also sprinkled with dirt introduced with the raw material.

[5]Material was boiled 4 hours with water and then washed with hot water before cooking.

[6]Material percolated with a cold 2 to 1 mixture (by volume) of ethyl alcohol and benzene until the solvent was no longer of a green color.

[7]Pulp bleached in two stages; about half of the bleaching chemical used in each stage.

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Table 35.--Estimated cost of production of representative types of flax pulps on basis of prices prevailing in 1935[1]

Cook number	Pulp suitable for --	Type of flax material used	Chemicals: Kinds	Chemicals: Amount	Yield of oven-dry unbleached pulp	Bleaching powder	Cost of 2,000 pounds air-dry unbleached pulp[2]: Flax[3]		Soda ash[4]		Lime[5]		Sulphur[6]		Salt cake[7]		Total[8]	Cost of 2,000 pounds air-dry bleached pulp[2]: Chlorine[9]		Lime[5, 9]		Unbleached pulp[10]	Total[11]
				Percent	Percent	Percent	Pounds	Dollars	Pounds	Dollars	Pounds	Dollars	Pounds	Dollars	Pounds	Dollars	Dollars	Pounds	Dollars	Pounds	Dollars	Dollars	Dollars
D-163	Medium grade type of rag bond	Shaker tow	NaOH Na_2S	12.5 4.0	60.0	15.0	3410	85.25	501	6.15	361	3.05	......	......	252	1.75	102.35	106	2.10	128	1.10	113.70	120.60
D-46	Wood-pulp type of bond........	Medium tow, not dusted	NaOH Na_2S $Ca(OH)_2$	14.1 5.5 5.3	33.0	35.0	6200	77.50	1032	12.70	1040	8.55	......	......	663	4.65	102.10	248	4.95	298	2.55	113.45	124.65
D-61-62	................do..............	.....do......	NaOH Sulphur	22.0 4.0	40.5	15.0	5050	63.10	1310	16.10	945	8.05	178	1.60	......	......	86.15	106	2.10	128	1.10	95.70	102.60
D-118	Semibleached greaseproof, glassine, and tissue........	.....do.....	Na_2SO_3	17.0	59.0	12.0	3470	43.40	441	5.40	......	......	132	1.20	......	......	58.40	85	1.70	102	.85	64.90	71.15
D-152 D-154 D-158	..............do..............	Dusted straw: dusting loss: 32 percent[12]	NaOH Na_2S	17.6 4.4	[12]28.5	13.0	7180	35.90	1490	18.30	1070	9.10	......	......	585	4.10	61.50	92	1.85	110	.95	68.35	74.15
B-217-1	Medium grade type of wood-pulp bond..................	Straw, not dusted	NaOH Na_2S	17.4 4.3	42.6	32.0	4800	24.00	985	12.10	710	6.05	......	......	383	2.70	45.30	227	4.55	272	2.30	50.35	60.90
B-210-2	Straw board....................	.....do.....	Na_2CO_3	14.0	76.0	......	2695	13.45	335	4.10	......	......	......	......	......	......	27.00	......	......	......	......	......	......
D-100	Dense, tough, dark-colored specialities...............	Medium tow, not dusted	Na_2SO_3 Na_2S	21.5 13.3	42.0	......	4870	60.85	782	9.60	......	......	234	2.10	1200	8.40	78.10	......	......	......	......	......	......

[1]See page 26 for definitions of terms and units of measurement used in column headings.

[2]Air-dry pulp is assumed to contain 10 percent moisture.

[3]Material on the basis of 12 percent moisture content. Straw at $10 per ton, medium tow at $25 per ton, and shaker tow at $50 per ton.

[4]Soda ash, light, 58 percent Na_2O at $1.23 per 100 pounds.

[5]Lime, hydrated, 96 percent $Ca(OH)_2$ at $0.85 per 100 pounds.

[6]Sulphur at $0.90 per 100 pounds.

[7]Salt cake, 96 percent Na_2SO_4 at $0.70 per 100 pounds. An efficiency of reduction of the sulphate to sulphide is taken as 90 percent.

[8]Total cost of unbleached air-dry pulp includes the cost of materials plus $12.80 pulp mill overhead and credited with the recovery of 87 percent of the sodium content of the spent cooking liquor in the form of soda ash.

[9]Chlorine at $2 per 100 pounds. The amounts of chlorine and lime required based on 0.354 pound of chlorine and 0.425 pound of lime for each pound of bleaching powder required.

[10]Based on the assumption of 10 percent loss of pulp by bleaching.

[11]Total cost of bleached air-dry pulp includes cost of materials plus $3.70 bleach mill overhead.

[12]Average for the three cooks.

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Table 36.---Chemical constants of the ethyl alcohol-benzene soluble material in seed flax straw[1]

Determination	Sample number 1	Sample number 2
Saponification value................number	147.6	125.6
Iodine value........................number	114.5	88.1
Unsaponifiable matter..............percent	42.8	37.2
Free fatty acids...................percent	3.5	8.4

[1]The solvent consisting of 2 parts by volume of ethyl alcohol and 1 part of benzene was evaporated from the residue before determination of the constants.

Table 37.--Outline of the fractionation of the crude extract[1] obtained by treating flax straw with cold ethyl alcohol-benzene mixture

A. Treated with hot water:
  Soluble--A dark brown viscous solid.[1] (10 percent)
  Insoluble--Treated with carbon tetrachloride:[2]
    Soluble--A dark green viscous solid.[1] (82 percent)
    Insoluble--A dark brown granular solid (8 percent)

B. Treated with carbon tetrachloride:[2]
  Soluble--A dark green viscous solid.[1] (87 percent)
  Insoluble--Treated with ethyl alcohol.[2]
    Soluble--A dark brown viscous solid.[1] (12 percent)
    Insoluble--A dark brown granular solid. (1 percent)

C. Treated with hot ethyl alcohol:
  Soluble--Allowed to cool:
    Soluble[2]--A dark green viscous solid.[1] (83 percent)
    Insoluble--A light green waxy solid. (10 percent)
  Insoluble--A dark brown waxy solid. (7 percent)

D. Treated with petroleum ether:[2]
  Soluble--A dark green soft wax[1] (65 percent). Treated with boiling ethyl alcohol:
    Soluble--Allowed to cool:
      Soluble[2]--A dark green viscous solid.[1] (71 percent)
      Insoluble[2]--A hard light green solid. (2 percent)
    Insoluble--A brownish green sticky resin. (27 percent)
  Insoluble--(35 percent). Treated with boiling petroleum ether:
    Soluble--A hard green wax.[1] (33 percent)
    Insoluble--(67 percent). Treated with ethyl ether:
      Soluble[2]--A green resinous solid.[1] (51 percent)
        Treated with boiling ethyl alcohol:
        Soluble--(94 percent) Allowed to cool:
          Soluble[2]--(83 percent)
          Insoluble--(17 percent)
        Insoluble--(6 percent)
      Insoluble--(49 percent) Treated with chloroform:
        Soluble--A brown powdery solid.[1] (100 percent)

E. Treated with alcoholic-potash, dried and extracted with petroleum ether:
  Soluble--Unsaponifiable matter, 18 percent, yellow curdy wax.[1]
    Treated with acetic anhydride:
    Precipitate--Hydrocarbons found to contain 1.2 percent of sterol, basis unsaponifiable matter.
  Insoluble--(82 percent) Treated with acetone:
    Soluble--Treated with sodium carbonate solution, dried and extracted with ethyl ether:
      Soluble--Hydrocarbons (not identified)
    Insoluble--Saponifiable matter. Extracted with water:
      Soluble--Acidified:
        Precipitate--Brown, sticky fatty acids.

[1]Residue obtained after evaporation of solvent. [2]At room temperature

Table 38.--Dielectric strength of flax papers compared with similar commercial materials[1]

Material		Thickness		Dielectric strength	
		As tested	As used in dynamo work	As tested	Per mil thickness
		Inches	Inches	Volts	Volts
Flax cook D-35	air-dry	0.0055		952	173
	oven-dry	.0055		949	173
	oiled	.0055		4,586	835
Flax cook D-36	air-dry	.0035		912	260
	oven-dry	.0035		930	260
	oiled	.0035		4,341	1,241
Asbestos paper			0.004-0.020		125
Cotton, double covering, shellacked			.015- .025		275
Cloth, oiled			.005- .030		500
Paper, oiled, double coat			.006- .010		700
Paper, paraffined			.002- .008		900
Paper, brown			.005- .010		175
Silk, single covering, shellacked			.001- .003		475

[1]Data for commercial materials taken from "Mechanical Engineers Handbook," Marks, second edition, 1924, page 1695.

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