A STUDY OF PULPING PROCESSES IN THE UNITED STATES WITH POSSIBILITIES OF APPLICATION TO INDIAN WOODS

by

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India is one of the oldest civilized countries of the world. Her old histories and religious books were written on palm leaves and barks of trees in very early times. Some of these ancient scriptures and writings are still available in various museums in India.

Manufacture of hand-made paper was known to the people from early times. The first paper-making machine in India was installed by an English missionary named Dr. William Carey at Serampore in the province of Bengal, in the year 1867. A regular paper mill with the name of the Royal Paper Mill was established in 1882 at Bally near Serampore. Subsequently in Bengal, as well as in other provinces, other paper mills were started. By about 1900, the production of paper was approximately 20,000 tons per year.

The early paper mills of India used mostly rags and waste paper for their raw materials. Two mills used Moonj (Sacharum Loonja) and Sabai (Ischaenum Augustifolium), plant fibers similar to esparto grass. Subsequently, however, these were put out of business by the competition of wood pulp. Bamboos, for instance, have become a new raw material rich in long and strong fibers for some Indian
mills. In 1947, sixteen paper mills operating thirty-two machines produced nearly 100,000 tons of paper from bamboo pulp (5, p830). In 1949, paper production reached 109,900 tons and consumption was 226,000 tons in the same year (13).

India has to import a large amount of paper from other countries, especially newsprint, from Canada and the United States. During World War II, there was a great scarcity of paper. Most of the paper produced in the country was used for the Government and for military purposes. Only small percentages were released from time to time for civilian use. The students were the greatest sufferers as they had to purchase paper from the black market at exhorbitant prices. For want of paper, important textbooks could not be printed.

The province of Assam although rich in raw materials, does not have a single paper mill. Many years ago, an Assamese gentleman attempted to organize a company for starting a paper mill in the province of Assam. Unfortunately his attempt did not succeed.

It is now realized that paper, like food and medicine, is a vital important material for humanity. In order to develop the country and educate the masses, paper is essential. The following figures of annual per capita consumption of paper and wood pulp during 1950 will show how greatly deficient India is in paper and wood pulp (13).
<table>
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<th>Country</th>
<th>Annual Per Capita Consumption</th>
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<td>Paper in lb</td>
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<tr>
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<td>226</td>
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<tr>
<td>Canada</td>
<td>256</td>
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<td>Less than 1</td>
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The percentage of illiteracy in India is as high as 80 per cent. Illiterate masses are a great handicap to democracy as they can be led astray by any false and clever propaganda.

In order to be self-sufficient, a country must develop both agriculture and industry. Assam produces tea, oil, and coal. It has the necessary raw materials for starting pulp and paper mills, cotton mills, and factories for the manufacture of cement, chemicals, and wood products. Until now, however, there has been no genuine attempt either by the Government or by private companies to develop these industries.
INTRODUCTION

The writer of this thesis does not claim to have a clear knowledge of the chemistry involved in pulp and paper manufacture. Nor has he had any experience in this line in his own country. Having become interested in the pulp and paper industry after coming to the United States, he studied the subject and visited some of the important mills of the states of Oregon and Washington, with the idea that the knowledge and information he might gather here might be useful to his State Government, which has sponsored his studies in the United States.

It is not possible in a treatise of this kind to deal in detail with the pulping processes prevalent in this country. The aim is, therefore, to summarize the basic principles and requirements of the various processes.

In Chapter II are given the properties of some of the abundantly available soft and medium-soft species of broad-leaved woods. In the Assam forests there are many more varieties of woods, mostly broad-leaved, of which some are real hardwoods. Of the coniferous woods, various kinds of pines are available in the Assam hills, but their supply would not be sufficient to feed constantly a pulp and paper mill in Assam. Information regarding the properties and fiber qualities of different kinds of bamboos which are recommended as an important raw material, is not available
Information about the various pulping processes and types of equipment used for pulping is given in Chapters IV and V. A brief discussion of the treatment and bleaching of pulp is given in Chapters VI and VII.

In the last chapter, the author has discussed the feasibility and advantages of locating a pulp and paper mill in Assam. Cheap and abundant raw materials, cheap labor, process water, adequate transportation, and a vast market are favorable points for consideration.
CHAPTER I
RAW MATERIALS FOR PAPER-PULP

The basic material of paper-pulp is plant fiber, composed of cellulose. It is obtained in the following different varieties:

(a) Seed-hair fiber  eg cotton, bombax wool
(b) Stem fiber  eg hemp, jute, bamboo, esparto, straw
(c) Leaf fiber  eg palm, manila hemp, pineapple-leaf fiber
(d) Fruit fiber  eg coconut fiber
(e) Wood fiber  eg spruce, hemlock, fir

The principal factors that determine whether a particular plant shall or shall not be used in manufacture of paper are suitability of paper, dependability of supply, cost of collection, transportation, and preparation, and tendency to deteriorate in storage. At present, considering all these factors, wood is the most important and the most widely used material for paper-pulp. For tropical countries, like India, Burma, and the Philippines, bamboos, available in great abundance, are the most important raw materials for paper-pulp. Consequently, the writer will restrict his discussion to woods and bamboos.

Wood is composed of cellulose, lignin, and other extraneous components such as resins and fats, tannins, volatile constituents, and coloring matter. Of these,
cellulose in the form of fibers is the most essential component of paper, the rest being extracted as far as practicable depending upon the type of paper to be made out of the resulting pulp.

It is beyond the scope of this treatise to deal in detail with the anatomical structure of wood. The properties of a wood depend largely upon its fibers, which are hollow tubular cells. Given similar operating conditions, the characteristic qualities of the paper produced depend on the color, length, diameters, flexibility, strength, and other related properties of the fibers used. If the diameter of these cells of a wood is large and the walls are thin, the wood is of low density. Such wood yields little pulp. Paper made from pulp wood of long fibers is generally strong, because the greater length of fibers permits more felting and interlocking of the individual strands than is possible with short fibers.

So-called soft woods (Conifers) have longer fibers than those of the hard woods (Broad-leaved). Average length of fibers of soft woods, like spruce, hemlock, and Douglas fir, is 3,000 to 3,500 microns, which is equivalent to 3 mm or 3-1/2 mm (1 micron = \( \frac{1}{1000} \) mm) or nearly 1/8 inch; whereas the average length of broad-leaved woods (hardwoods) is a little more than 1 mm or 1/25 inch. Generally speaking, the fibers of all kinds of wood are
roughly about 100 times as long as they are wide. In the same tree, fibers near the pith are shorter than those in the sapwood. In most trees the largest fibers are available in the section from 10 to 20 feet above the ground; above or below that section, the fibers become progressively shorter.

In order to make pulp for excellent paper with sufficient strength, soft wood having long fibers, with the smallest percentage of heartwood, is generally used. Debarkation of the wood should be complete. Any decayed wood found in a log should be removed.

Lignin is intermingled with the fibers in the cell walls and surrounds the cells, thus binding them together. Lignin as it exists in wood, usually called protolignin, is an amorphous, somewhat aromatic compound which surrounds the fibers and impregnates the whole wood structure. To isolate the fibers, the lignin must be removed. Removal is done to a large extent in the chemical pulping process by bringing much lignin into solution with acid or alkaline cooking liquors and removing the remainder during the bleaching process. However, in the mechanical process, most of the lignin remains with the pulp, except for a small percentage which goes into solution in the wash-water. Coniferous woods generally contain 28 per cent, and hardwoods about 24 per cent lignin.
Resins and fats are troublesome components of wood so far as paper-pulping is concerned. The resins and fats, especially in unseasoned wood, are tacky and cause pitch trouble. They are not soluble in sulphite cooking liquor, and therefore woods with high resin and fat content are unsuitable for sulphite pulping. However, they dissolve in the alkaline cooking liquors and can be recovered from the waste cooking liquor to form an important by-product in the form of tall oil. Spruce, hemlock, and Douglas fir, and some American hardwoods, contain almost negligible (less than 1 per cent) amounts of resins and fats; whereas pine contains about 2 to 6 per cent. The woods with high resins and fats can be pulped either in soda or by the kraft process.

Nearly all soft woods contain volatile materials which may be removed by steam. These volatile materials cause no trouble in the pulping process and can be recovered as an important by-product (viz turpentine) by condensing the relief gases from sulphite or sulphate digestion.

Tannins are chemical materials found mostly in barks; they are present in some woods, however. When present in a small per cent, they do not cause much trouble as they are soluble in water and therefore are largely removed during the cooking process. Small amounts of tannin generally remain in the pulps, imparting a brownish
color to the liquid. Woods containing high amounts of tannin are difficult to pulp and to bleach, even by the alkaline process.

Phenolic compounds are objectionable components of wood found mostly in the heartwoods of various species of pine. They hinder the delignification of wood by sulphite cooking liquor. However, woods containing phenolics are pulped by the alkaline process without difficulty.

Besides lignin and tannin, certain species of woods contain coloring materials which are undesirable, as they cannot be easily removed during the cooking and bleaching process. Wood-pulps made from such woods are not suitable for printing and writing papers.

Starch and other water-soluble carbohydrates are often found in wood. They cause no trouble during the pulping process. However, woods containing starch are likely to be attacked by insects and fungi, and therefore it is not possible to preserve them for any great length of time.

Some woods also contain small amounts of mineral matter and on combustion usually yield from 0.2 to 1 percent ash. The chief metallic constituents of wood ash are calcium, potassium, and magnesium. Often traces of aluminum, iron, and manganese are present.
CHAPTEII
CHARACTERISTICS OF SOME ABUNDANTLY AVAILABLE
WOODS IN ASSAM (INDIA)

Satiana (Alstonia scholaris) is a large tree, up to
8 feet in girth and over, with a 40-foot straight, but
often buttressed, stem. It is available in considerable
quantity all over the province of Assam. It grows rapidly
and can be planted on a large scale. Satiana is uniformly
white when first exposed, turning yellowish-white to pale
brown with age; quite lustrous, working smooth without
characteristic odor; very light to light (specific gravity
0.47); very straight-grained; and medium fine and even-
textured. Vessels are medium-sized to small, thin-walled,
with occasional yellow gummy deposits. Fibers are non-
libriform, medium coarse with abruptly pointed ends and
frequently contiguous to the vessels. Weight of the wood
at 12 per cent moisture content is 26 to 36 lb per cu ft.
It is a soft, light wood of low strength. It can be
easily peeled.

Gomari (Gmelina arborea) is a medium-sized tree with
6 to 7 feet girth, a clear bole of 30 to 40 feet, and a
height of about 80 feet. It is available in considerable
quantity in Upper Assam. It is yellowish-white when first
exposed, aging to light russet or yellowish-brown; heart-
wood not distinct; lustrous, with a smooth somewhat oily
feel, without characteristic odor or taste; very light to
light (specific gravity approximately 0.47), straight or more or less irregular and interlocked-grained, medium-coarse-textured. Growth rings are distinct and fairly conspicuous. Vessels are very large to medium-sized and very small, occluded with tyloses. Yellow gummy infiltration is sparse in all types of parenchyma; starch deposits are occasional in the outer rings. Fibers are non-libriform, coarse, strongly angled in the transverse section and not arranged in definite radial rows, seldom contiguous to the vessels, non-gelatinous. Weight at 12 per cent moisture content is 30 lb per cu ft. The wood is moderately hard, but is strong and elastic.

Pitali (Trewia nudiflora) is a moderate- to large-sized tree with 6 to 10 feet girth. It is an extremely light, straight-grained, medium-fine and even-textured, white or pale brownish-grey wood. Weight at 12 per cent moisture content is 22 lb per cu ft. This tree is quite common all over the state of Assam. If planted on a large scale, it will be an excellent source of paper pulp. It is now used mostly for packing cases.

Hollong (Dipterocarpus pilosus) is an extremely large tree, with 15 to 23 feet girth, a clear bole of 100 feet, and a height of 150 feet and up. This wood is available in considerable quantity in Upper Assam. The sapwood is grayish or brownish-white; heartwood is light red to uniform
reddish-brown. The wood is dull with rather rough feel, without characteristic odor or taste, moderately heavy (specific gravity approximately 0.71), fairly straight or somewhat interlocked-grained, even coarse-textured. Fibers are libriform, rather coarse, angled in the transverse section and arranged in radial rows, forming extensive, almost solid tracts between the vessels and the rays, non-gelatinous, non-septate, 640 to 2,280 micron long, 30 to 37 micron wide; walls are 7 to 11 micron thick, and inter-fiber pits are most numerous on the tangential walls. Weight of the wood at 12 per cent moisture content is 45 lb per cu ft.

Semul (Bombax malabriocum) is a very large, straight, cylindrical-stemmed tree 6 to 10 feet in girth. It sometimes attains very large dimensions -- 160 to 180 feet high. It grows almost wild in the Assam Valley where the tree is not planted systematically. It is marked by its very rapid growth. The wood is very light (specific gravity approximately 0.39) and soft, straight-grained, even- and coarse-textured. It appears white when first cut and turns yellowish-brown on exposure; it is without heartwood and without characteristic odor and taste. Fibers of semul are non-libriform, 650 to 3,000 micron long, 30 to 36 micron in diameter, and the walls are 3 to 6 micron thick. Weight at 12 per cent moisture content is
25 lb per cu ft, and it can be easily sawed. It is used mostly for making packing boxes, matches, river boats, etc.

Salua (Sterculia villosa) is a moderately large-sized tree with 5 to 6 feet girth and about 30 feet clear bole; it is available in considerable quantity in the Assam Valley. The wood is white and lustrous when first exposed, soon turning to grayish-brown. It is without characteristic odor or taste, extremely light (specific gravity approximately 0.11), even- and straight-grained, and coarse-textured. Fibers are non-libriform, 550 to 2,150 micron long, 30 to 35 micron diameter, and the walls are 5 to 7 micron thick. Weight at 12 per cent moisture content is 17 lb per cu ft. It is very soft but weak and is therefore unsuitable for products requiring strength.

Hollock (Terminalia myricarpa) is a large tree that grows to 20 feet girth and great height. It is found in large quantity in the Northern and Upper Assam. The wood is light brown, turning darker with age. It is without characteristic odor and taste, moderately heavy (specific gravity 0.70), straight-grained and coarse-textured. Fibers are 325 to 1,600 micron long, 28 to 32 micron in diameter, and the walls are 3 to 5 micron thick. Weight at 12 per cent moisture content is 39 lb per cu ft. Some of the timber is sawed into scantlings, rafters, and planking in Assam, and a large quantity is used for plywood.
Amara (*Spondias mangifera*) is a medium-sized tree, attaining 7 feet and over in girth and having a clear stem of 40 to 50 feet. It is a common tree, often found scattered in Assam forests. It is a light, coarse-textured, perishable, gray wood. The fibers are 365 to 1,525 micron long, 36 to 42 micron in diameter, and the walls are 2 to 4 micron thick. Weight with 12 per cent moisture content is 23 lb per cu ft. It is liable to stain and must be peeled very soon after felling. The wood has been tried in India and was found to yield a fairly good unbleached wood-pulp (9).

Apart from these eight varieties of wood, there are a large number of other woods which are sawed into planks, and timbers in the lumber mills of Assam. Particulars of all these woods are not available for mention here. An Assam forest does not consist of one type of trees alone but of many different kinds of trees, mostly growing wild.

As they age, most of the woods change from white to dark brown or yellow. Seldom is any wood like spruce, which remains almost white at all times, available in Assam. Consequently, there is little prospect for manufacturing mechanical pulp unless spruce, balsam fir, and poplar are cultivated in the state.

It has been mentioned previously that bamboo is a good source of paper pulp. There are many varieties of
bamboo, which are available extensively in Assam. Some varieties are soft and make excellent paper pulp. Bamboo fibers vary from short to very long.
CHAPTER III
PREPARATION OF PULPWOOD

Pulpwoods are generally transported from forests in one of several ways: 1. Floating down streams. 2. Towing in booms in the comparatively still water of lakes or rivers. 3. Carriage by rail. 4. Carriage by motor trucks. The first method is the cheapest and generally adopted by several mills in the state of Oregon.

The woods received at the mills normally have bark intact. Woods cut during the spring and summer seasons are sometimes supplied with bark removed in the field, as debarking can be easily done during the growing season. Bare wood dries out more readily and is suitable for manufacture of chemical pulp.

If wood is received faster than used, it should be stored after removing the bark; otherwise, insects and fungi may destroy the wood.

The sequence of operations of pulpwood is: 1. Logs are hauled up to the slasher where they are cut into blocks of convenient length, from 24 to 48 inches.

2. Blocks are carried by conveyors to the barker where bark is removed. In a stationary barker, the full-length logs are transported to the barker, and the logs after barking are piled up by special hoists. All sawdust and bark go to the refuse conveyor. Blocks and logs are
washed thoroughly by a strong shower of water after bark-
ing.

3. The required quantity of clean barked blocks is conveyed to the grinders to be converted into ground wood or mechanical pulp.

4. For chemical pulp, the required quantity of clean barked blocks or logs is conveyed to the chipper, where they are chipped into required sizes.

5. Chips are then passed through chip-screens where they are classified. The fine chips are rejected to the refuse conveyor, and oversize ones are crushed and re-screened.

6. The chips are then dried in driers to eliminate their natural moisture, which may dilute the cooking liquor.

7. The chips are then stored in bins, usually over the digester into which the chips are fed by gravity.

A wood-preparing plant generally includes a log haul-up, a slasher, one or more barking drums or some other bark-removal devices, and a conveyor system for handling both wood and bark. Wood splitters are necessary to split up blocks too large in diameter to enter the chipper spout or grinder magazine.

For preparation of wood for chemical pulp, the plant should have wood chippers, chip screens, chip crushers, chip conveyors and bins, etc.
The purpose of the haul-up is to convey the logs from the water to the slasher mechanically. The most economical and common method of reclaiming logs from the river or log pond for slashing into blocks suitable for mill use is by means of a parallel log haul-up. With the endless chains driven by electric motors, the logs are carried up from water to the slasher deck.

A slasher is a machine assembly with circular saws used to cut logs into blocks of any desired length. The logs are picked up by endless feed chains that run at 40 to 60 feet per minute and form a cradle for holding the logs. The chains carry logs up an inclined plane and against circular saws driven at 700 to 800 rpm. After the logs are cut into several pieces or blocks of desired length, they are automatically discharged onto conveyor that runs at right angles to the direction of the slasher chains and are conveyed to the barker or to the storage.

The barking operation is performed mechanically by two principal methods.

1. By means of friction through tumbling or rotating action in a moving mass of pulpwood sticks. In the application of the friction method, there are two types of equipment:

   a. Rotating cylindrical drums.
   b. Stationary machines with agitating cam equipment.
2. By mechanical friction or high pressure (1000 psi) water jets applied to individual logs.
   a. The Astrom barker is a Swedish machine, which works on the principle of mechanical friction. In this machine, barking is done by passing the log through a rotating ring of chain links held in close contact with the log.

   b. In the hydraulic barkers logs are barked by high pressure water jet or jets as the logs are passed separately through the machine.

Nowadays, multiknife chippers with eight to twelve sharp knives are generally used for making chips from logs. It is necessary to cut the chips with sharp knives so that the cooking liquor in the digester may penetrate the wood quickly, completely, and uniformly. Plate I shows a multiknife chipper. Clean barked wood blocks or logs are fed endwise from a conveyor C, by sliding them down the inclined chute E, and into the chipper spout A. The wood is supported by the bed knife and chipped off as it comes into contact with the knives K in the revolving disk F. The usual speed of a multiknife chipper is from 300 to 500 rpm. It is generally driven by belt drive or through a flexible coupling directly connected to a squirrel-cage
Carthage multiknife chipper.

Plate I
motor.

Three different kinds of screens are generally used for classifying the chips. They are: 1. Vibratory type; 2. Rotary type; and 3. Shaker type. Of these, the rotary screens are the most common and the simplest to operate.
CHAPTER IV
OUTLINE OF DIFFERENT PROCESSES
BY WHICH PULP IS PRODUCED

The basic raw material for the manufacture of paper is cellulose, obtained in the form of fibrous pulp by the mechanical and chemical treatment of certain of the many plant substances which contain it. The other substances like lignins, pectins, resins, and waxes, vegetable coloring matters and carbohydrate compounds, which are found along with cellulose fibers of a plant are impurities which must be extracted. All the processes used for making pulp may be regarded as methods of extraction of these impurities, leaving cellulose as an end product.

There are mainly two forms of wood pulp which are further classified as:

1. Mechanical pulp
   a. Ordinary mechanical pulp
   b. Semi-chemical pulp

2. Chemical pulp
   a. Sulphite pulp
   b. Soda pulp
   c. Sulphate pulp

MECHANICAL PULP

This pulp is commonly known as ground wood as it is obtained by grinding wood into fibrous condition. The
basic operation consists of forcing a block of wood against a grindstone in the presence of water. The block is held against the abrasive surface of the revolving stone by such force that the wood is reduced to a fibrous condition; while the water keeps the stone cool, cleans and lubricates its surface, and carries away the pulp.

The process of making ordinary mechanical pulp is very simple, as it merely involves the wet grinding of wood blocks. The composition of the mechanical pulp is practically identical with that of the wood itself as no processing is done to the impurities. The equipment used is shown in Plates II and III. The former plate shows a three-pocket grinder. It is efficient but requires an attendant to feed the grinder constantly with wood. The latter plate shows an automatic magazine grinder, which is very economical, has greater capacity, and does not require frequent attention.

The process for semi-chemical pulp differs from the ordinary mechanical process only in that the wood is steamed before being ground. As a result of steaming, the pulp loses some of the resinous impurities of the fiber and assumes certain characteristics, such as greater strength and flexibility, that make the pulp more suitable for some finished products. The action of steam on wood results in the fiber's becoming brown which limits the application of
Three-pocket Grinder. Plate II
Automatic magazine grinder.

Plate III
this kind of pulp to uses such as making of brown boards and wrapping paper where color is not objectionable.

In order to use mechanical pulp for manufacture of printing paper, newsprint, toilet tissues, toweling, etc, it has been found necessary to bleach the pulp with zinc hydrosulphite to obtain the desired color and brightness.

The most important advantage of mechanical pulp over sulphite, kraft and soda pulps is its low cost. This is due chiefly to the fact that the yield of mechanical pulp is double that of chemical wood pulps and to the lower cost of production achieved by the use of power instead of chemicals and steam. The use of mechanical pulp of proper quality in printing paper has been found to improve printing results. For newsprint, mechanical pulp is added with advantage to chemical wood pulps. It has been found by experience that the printing quality of newsprint is improved in direct proportion to its content of mechanical pulp.

The chief disadvantage of paper containing mechanical pulp is its lack of permanence which is due to the reactivity of the noncellulose matter to the oxygen of the air and other gases as well as to sunlight and heat. Sunlight, air, and heat have an adverse effect on the color, strength, and durability of paper containing ground wood. Ground papers are characterized by low strength properties,
low brightness, and poor color when compared with papers made from chemical pulp.

Wood suitable for mechanical pulp are woods of uniform structure, white in color, of greater fiber content, and having long fibers. The woods should be free from tannic acid and resins and should contain the least possible amount of heartwood. In the United States, the woods generally used for mechanical pulp are poplar, spruce, hemlock, and balsam fir. In eastern Canada jack pine is sometimes mixed with the spruce. However, jack pine is not entirely satisfactory because of the high heartwood and resin content and the dark color of the pulp.

Information received from the Forest Research Institute, Dehra Dun, India, indicates that mechanical pulp is made from semul (Bombax malabricum), which is abundantly available in Assam. Such pulps are now being used as fillers in manufacturing Triplex boards.

Assam forests do not have woods like spruce, hemlock, or balsam fir. In other provinces of India, mechanical pulp of newsprint grade is being made on a limited scale from Broussonetia papyrifera, Kydia calicina, and Excucario agallocha.
CHEMICAL PULP

In the sulphite process, pulp is obtained by digesting wood chips with the bisulphite liquor at high temperature and pressure. The acid liquor dissolves all the undesirable constituents of the wood chips except the cellulose, which when separated, constitutes the unbleached sulphite pulp. When bleached, this pulp consists of practically pure cellulose and is white in color.

The process has two systems known as (a) tower system and (b) milk of lime system. The essential difference between the two is in the process of making the acid liquor. In the tower system, limestone is used in the absorption tower, and the sulphur dioxide gas is brought in contact with limestone in the presence of water. In the milk of lime system, the gas is brought into contact with water containing lime in suspension.

The sequence of operations in the sulphite process is as follows:

1. Sulphur dioxide gas is produced by burning either sulphur or iron pyrites (FeS₂) in air under controlled conditions.

2. The resulting sulphur dioxide gas is freed from dust and cooled.

3. It is then absorbed in absorption towers containing limestone, magnesium carbonate, or milk of lime. The
acid liquor or cooking liquors are then passed to storage tanks ready for use.

4. The cooking liquor and the wood chips are charged in the digester where they are mixed and heated under pressure by introducing steam.

5. When digestion is completed, the pressure is relieved, the excess of sulphur dioxide gas evolved at this stage being recovered for strengthening weak liquor in the absorption tower.

6. The pulp and waste liquor are then blown into the blow pit. The waste liquor is drained off and the pulp is washed thoroughly with warm water.

7. The pulp mixed with water then goes forward for screening and bleaching.

The woods containing high percentages of resins and fats are not suitable for sulphite pulp. The sulphite cooking liquor does not dissolve the fats and resins to any extent, and these materials which are left in the pulp are responsible for pitch trouble. The presence of even small amounts of phenolic compounds, generally found in the heartwood of various species of pine, hinders the delignification of wood by sulphite cooking liquor (12).

The woods generally used in the United States for sulphite pulp are spruce, hemlock, balsam, and fir. The spruce is generally used for all chemical pulps because of
its desirable properties, such as low resin content, high percentage of cellulose, and long, flexible, strong fibers.

Sulphite pulp costs considerably more to make than mechanical pulp for the following reasons:

1. The yield of pulp is low because of elimination; about 50 per cent of the raw material is retained in the finished product.

2. Much labor and power must be spent on preparation of the wood before it reaches the digesting process proper.

3. The process involves the upkeep of a large chemical plant for making the acid liquor.

4. The machinery is expensive both as to first cost and maintenance; the upkeep is high because the acid nature of the process makes for rapid deterioration.

The sulphite process requires about 1,300 to 1,500 lb of coal, 232 lb of sulphur, and 300 lb of limestone per ton of pulp. However, the greater length and higher pliability and strength of sulphite fibers, together with the freedom from deterioration, cause it to be used instead of mechanical pulp for all except the cheapest grades of paper, in spite of its higher costs.

In the soda process the cooking liquor is the caustic soda (NaOH) solution. The alkaline solution at high temperatures dissolves all other constituents of wood except the cellulose. The soda process is simpler than the
sulphite process, but in order to operate it at a profit, it is necessary to recover the soda from the residual liquor.

The residual liquor is evaporated and the residue burned, resulting in the formation of sodium carbonate. When lime is added to a solution of sodium carbonate, sodium hydroxide is regenerated, and is used in subsequent digestion. During the recovery operation, some sodium compounds are lost in washing, and therefore it is necessary to add a little sodium hydroxide or sodium carbonate to each batch in order to maintain strength for the subsequent digestion.

In this process it is not necessary to take extreme care in preparing the wood, as it is in the sulphite process. The bark is removed, but small particles of bark or decayed wood do not create the difficulty that they do in the sulphite process. The more drastic solvent power of the soda lye readily reduces even knots, bark, and decayed wood.

Almost all kinds of woods may be converted into pulp by the soda process. Woods with high resins and fat contents can be used in this process. The deciduous or broad-leaf types of woods have been found particularly suitable for the soda process. In the United States and Canada, woods used for soda pulp are poplar, aspen, chestnut,
hemlock, maple, balsam, birch, and some spruce and pine.

Assam (India) woods such as semul, pine, hollock, hollong, poma, and various other broad-leaf woods which are available in rather large quantities can be used for soda pulp. The state of Assam in India has large forests of bamboo of different varieties. The bamboos with long fibers are particularly suitable for soda-pulp. The growth of bamboo is very rapid, and it is estimated that an area of 16 square miles of bamboo plantation can feed a paper mill of a 100-ton capacity indefinitely (18, p42). Paper made from bamboo is excellent for books and for writing purposes.

The sulphate or kraft process is similar to the soda process except that, for the preparation of the cooking liquor, sodium sulphate (Na$_2$SO$_4$) or salt cake is used in place of caustic soda or soda ash. The process was developed some time after the sulphite and the soda processes.

Sulphate and soda pulps are much darker in color before being bleached than is unbleached sulphite pulp. They are used in the unbleached state for manufacturing coarse wrappings, packaging, and for industrial papers and container boards, where low color is not objectionable.

Salt cake (Na$_2$SO$_4$) is cheaper than caustic soda, but the recovery system in the sulphate process costs more than in the soda process. With the advent of multi-stage
bleaching, the kraft pulp can be satisfactorily bleached. Also the recovery of the sodium compounds from the digester liquor serves the double purpose of economy and elimination of the disposal of an objectionable effluent. For these reasons, the kraft process is becoming more and more popular.

As in the soda process, all kinds of resinous and non-resinous woods and bamboos can be used for making kraft pulp. The kraft process is especially adaptable to the pulping of long fibered woods. In this process, greater yield is obtained than in the sulphite process as no elimination is necessary. In addition, kraft pulp is ideal for certain much-used kinds of paper.

In the kraft process several valuable by-products such as methyl alcohol, oil of turpentine, and various resins are obtained. These products have considerable commercial value and make the kraft process quite economical.
CHAPTER V
FLOW PROCESS AND EQUIPMENT FOR MANUFACTURE
OF CHEMICAL PULPS

SULPHITE PROCESS

As mentioned in the process outline, the cooking liquor is prepared by absorbing sulphur dioxide gas in a solution of lime water or on limestone. The first stage is therefore the preparation of the sulphur dioxide gas. This is done by burning sulphur or iron pyrites in controlled air according to the following equation:

\[ S + O_2 = SO_2 \]

\[ 2FeS_2 + \frac{5}{2} O_2 \rightarrow Fe_2O_3 + 4SO_2 \]

In this process, the object of burning sulphur is to form as much sulphur dioxide as possible and to avoid formation of other combinations of sulphur and oxygen. In excess air, sulphur dioxide is readily oxidized into trioxide, which should be always avoided, since it combines with calcium in the absorption system, forming practically insoluble calcium sulphate (CaSO₄). It may also combine with water that might leak into or condense in the system to form sulphuric acid. The presence of sulphuric acid in the digester is detrimental to the fiber in the cooking process; also, it represents a direct loss of sulphur. On the other hand, an insufficient supply of air results in incomplete combustion of the sulphur, and this causes
sublimation or the deposit of unburned sulphur throughout the system. This leads to serious difficulties in clogging the pipe lines, or it may reach the acid system and seriously interfere with the cooking process, owing to the formation of complex sulphur compounds. It is very important, therefore, that the air supply into the burner be correctly regulated.

The formation of sulphur trioxide \((SO_3)\) also depends upon the temperatures. It is found that with the possible catalytic effect of metals in the system, the maximum of sulphur trioxide is produced between 600 \(\text{C}\) and 900 \(\text{C}\). Practically no sulphur trioxide is formed at temperatures below 400 \(\text{C}\) and above 1000 \(\text{C}\) \((12)\). It is therefore important to keep the temperature in the combustion chamber higher than 1000 \(\text{C}\) and to cool the gases as quickly as possible after they leave the combustion chamber, in order to avoid the formation of sulphur trioxide.

Several different types of sulphur burners are in use. The oldest type, the flat burner, is now almost obsolete. Of the modern sulphur burners, the rotary type and the spray type are widely used in this country.

The rotary-type burner consists of a cast iron or welded steel cylinder with a steel cone on each end. The rear cone is connected to a steel box lined with fire brick, called the combustion chamber, in which the sulphur gases
are mixed with air and any vaporized unburned sulphur is consumed before the gases go to the cooler. In the older type of rotary burner, powdered sulphur is fed to the burner by a worm from a small bin placed directly above the front cone. In the modern type, the sulphur is melted with steam coils from which the liquid sulphur is fed to the burner. Different sizes of this type of burner are available. A 100-ton sulphite mill can be efficiently served with two rotary burners 15 feet long and 4 feet in diameter.

The spray-type sulphur burner shown on Plate IV consists of a cylindrical steel combustion chamber lined with firebricks. The chamber is equipped with over- and under-pass baffles, located at regular intervals over its entire length, and with a burner gas outlet at the back end. The combustion chamber is stationary. Molten sulphur from the melting tank is pumped by means of a metering pump into an atomizing spray nozzle connected with a compressed air line. The nozzle is located in one end of the combustion chamber. The sulphur in a fine state of subdivision due to the atomizing nozzle, burns in suspension in the air as it passes through the combustion chamber.

The spray-type burner can be started up and shut down very quickly. Complete elimination of sulphur trioxide formation and production of a high concentration of
Sulphur melting, pumping, spraying and burning equipment of Texas Gulf Sulphur Co.

1. Sulphur buggy.
2. Sulphur scale.
3. Sulphur melting pit.
4. Melting coils.
5. Sulphur pump.
7. Compressed air pipe.
8. Sulphur burner.
10. Refractory brick.
12. Sulphur spray nozzle.
13. Air intake.
15. Heat-exchanger and boiler.
16. Steam connection.

Plate IV
sulphur dioxide are possible in this type of burner.

It has been mentioned previously that the sulphur dioxide gas must be cooled rapidly to prevent formation of trioxide. It is necessary to cool the gas to about 25 C before it enters the towers for absorption.

There are several different types of coolers. The Jenssen cooler is efficient and widely used in the United States. It consists of a submerged, horizontal pond cooler of 6-inch lead pipes arranged parallel to one another and a vertical cooler consisting of vertical lead pipes connected at the top by U bends. Water is sprayed onto the pipes at the top, and flows down along the pipes. With this cooler, the gas can be cooled nearly to the temperature of the water. The connection between the sulphur burner and the gas cooler should be as short as possible to permit rapid cooling of the gas.

The absorption of the SO₂ gas takes place in two different systems: in the tower system and in the milk-of-lime system. Of these, the tower system is the more modern and economical. The flow sheets of both the systems are shown on Plate V.

The most efficient tower system is the Jenssen, the towers of which are constructed of reinforced concrete lined with acid-resistant tile. They are slightly conical in form in order to prevent packing of the limestone. The
SULPHITE PULPING FLOW SHEETS

Direct or Indirect Cooking—with or without Forced Liquor Circulation

**A - TOWER SYSTEM**

- Sulphur or Pyrites
- Sulphur Burner or Pyrites Furnace
- Combustion Chamber or Scrubber
- Water
- Weak Tower
- Gas Coolers
- Limestone
- Strong Tower
- Gas Fan
- Steam
- Reclaiming or Absorption Tower
- Relief or Absorption Tower
- Relief or Absorption Tower
- Acid Storage Tanks
- Accumulator
- Relief (a)
- Relief (b)
- Digesters
- Pulp to Screens
- Blowpit
- Gas to Recovery
- Waste Liquor to Sewer or Recovery

**B - MILK-OF-LIME SYSTEM**

- Sulphur or Pyrites
- Sulphur Burner or Pyrites Furnace
- Combustion Chamber or Scrubber
- Water
- Slaking Tower
- Gas Coolers
- Lime
- Absorption Tanks
- Exhauster
- Steam
- Reclaiming or Absorption Tower
- Relief or Absorption Tower
- Relief or Absorption Tower
- Acid Storage Tanks
- Accumulator
- Relief (a)
- Relief (b)
- Digesters
- Pulp to Screens
- Blowpit
- Gas to Recovery
- Waste Liquor to Sewer or Recovery

Flow sheets of sulphite process.

*Plate V*
towers are filled from the top with limestone or dolomite. The modern sulphite mills have two or more absorption towers. The figure on Plate VI shows the diagram of a Jenssen two-tower installation.

The cooled gas from the cooler is blown by the gas fan through the towers, which work in series. The gas is first forced into the bottom of one of the towers, called the strong-acid tower, where it comes in contact with a current of weak solution somewhat strengthened by the absorbed SO$_2$ gas. The unabsorbed weak gas leaves the first tower from the top and is conducted to the bottom of the second tower, now the weak-acid tower, which is identical in construction with the first tower. Water is sprayed at the top of the weak-acid tower, absorbing on its way the weak SO$_2$ gas, and forming sulphurous acid (H$_2$SO$_3$), which acts upon the limestone and forms a weak solution of calcium bisulphite. This weak acid is pumped from the bottom of this tower to the top of the strong-acid tower where it is strengthened by the fresh sulphur dioxide gas.

By using four-way cocks, the operation of the towers is made reversible in which case the weak-acid tower becomes the strong-acid tower and vice versa. In the three-tower system, two towers remain in operation while the third is shut down for washing and filling. In the four-tower system, two towers are used as strong-acid towers,
Diagram showing construction and operation of Jenssen tower system.

Plate VI
one as weak-acid tower, and the fourth is shut down for washing and filling. In all these systems, the towers are always reversible just as in the two-tower system.

The object of the absorption is to form the bisulphite liquor. Chemical reactions occurring in the absorption system include the following principally:

\[
\begin{align*}
\text{CaCO}_3 + \text{SO}_2 + \text{H}_2\text{O} & = \text{CaSO}_3 + \text{H}_2\text{O} + \text{CO}_2 \\
\text{CaSO}_3 + \text{SO}_2 + 2\text{H}_2\text{O} & = \text{Ca(HSO}_3)_2 + \text{H}_2\text{O}
\end{align*}
\]

Insoluble calcium sulphite is formed in the first reaction of sulphur dioxide gas with calcium carbonate and water. In excess sulphur dioxide gas, calcium sulphite turns into calcium bi-sulphite which is soluble in water. The bi-sulphite solution is the cooking liquor, which is usually stored in a series of large storage tanks, frequently made from long-leaf yellow pine, cypress, or Douglas fir.

Milk-of-lime is prepared by slaking burned lime, containing a high percentage of magnesia, with warm water. Insoluble hydroxides of lime and magnesia are formed according to the equations:

\[
\begin{align*}
\text{CaO} + \text{H}_2\text{O} & = \text{Ca(OH)}_2 \\
\text{MgO} + \text{H}_2\text{O} & = \text{Mg(OH)}_2
\end{align*}
\]

The hydroxides are screened into a wooden tank equipped with an agitator to keep them in suspension, and
sufficient water is added to give the milk-of-lime and magnesia a strength of 1 degree Bé. The solution is then ready for use in the absorption tower.

There are three different milk-of-lime systems, known as the Stebbins, the Burgess, and the Burker systems. Of these, the Burker system is the most generally used; the other two are gradually becoming obsolete.

The Burker system consists of a four-tank milk-of-lime system, with an absorption tower, all combined in one steel shell. The tanks are placed one above the other. These tanks are formed by partitions of perforated copper plates, through which the gas from the tower passes. The milk-of-lime is pumped into the top tank and overflows into the second, third, and fourth tanks in succession. The gas enters the bottom tank through the perforated plate, and the solution passes into the bottom of the second tank and, in the same manner, into the third and fourth tanks.

In this system, gas first dissolves in the water and the solution reacts with lime to form insoluble calcium monosulphite which separates from the solution. This reaction goes on until all the lime is precipitated in the form of monosulphite. The monosulphite then takes up more $SO_2$ gas, forming soluble bisulphite. However, in addition to the bisulphite, sulphuric acid and insoluble calcium sulphate are formed, causing considerable trouble in the
digester by clogging the openings of the perforated plates and also the pipe lines.

Lime with high magnesia content is advantageous in the milk-of-lime system; whereas in the tower system, limestone with low magnesia content is preferable for satisfactory operation. As a consequence, the acid made by the milk-of-lime system generally contains high magnesia, which yields a more pliable and whiter fiber during the cooking process than that resulting from pure calcium bisulphite liquor. The tower system is more popular in the United States, however, since it is simpler to use and requires less power and labor than does the milk-of-lime system.

Plate VII illustrates a digester used in a sulphite mill. It consists of a steel shell, constructed by riveting or welding together steel plates of 7/8 to 1-1/4 inch in thickness. The usual size of the digester is from 12 to 18 tons, but large-size digesters, up to 35 tons capacity, have been built. The digester has a conical bottom ending in a flange to which are connected flanges for the steam, acid, and drain lines and the blow-off valve for emptying the digester. The digester is lined with acid-resistant brick lining. The top arrangement is shown at R (Plate VII). For the protection of the cover a stainless steel or acid-resisting bronze plate P is fastened to the bottom side of the cast-steel cover C.
Sulphite digester.

Plate VII
indicates the thermometer-well, for indicating or recording thermometer; \( H \) is a sampling cork for drawing samples of liquor during the process of cooking; and \( L \) shows the acid and gas relief line at the top of the digester.

There are four different methods of sulphite cooking:
1. direct steaming with cold acid; 2. direct steaming with hot acid; 3. direct steaming with hot acid and liquor circulation; 4. indirect steaming with hot acid and liquor circulation. The last method seems to be the best for producing a high-quality product in a reasonable cooking time.

The digester is charged from the top. All the valves on the bottom are kept closed and the top cover \( C \) is removed. Wood chips are fed into the digester by opening the chip bin on top until the digester is full. When the digester is full, the top cover is replaced and bolted on. Keeping the top relief valve \( L \) open, cooking acid is pumped into the digester through a line connected at the bottom. The height of acid in the digester is observed through a vertical gage glass connected to the top pressure-measuring line and the side-relief fitting. As soon as the digester is full of acid, the top vent valve is closed, the steam valve is opened, and the digester is gradually brought to the desired temperature and pressure in accordance with a cooking schedule conforming to the pulp desired.
There is no standard method of cooking; the process depends too much upon the nature of the wood, the composition of the acid, the desired quality of the pulp and especially, on the practice followed at each plant, which is based upon specific experience.

When the cooking time is to be short, the heating must be rapid; whereas, in slower cooking the temperature is raised more gradually. In the case of easily bleached pulp which requires 10 to 11 hours' cooking, a temperature of 105 to 110 degrees C is usually reached after three hours and is gradually increased to 135 to 145 degrees C, depending upon the wood and the cooking acid.

The following table gives the average cooking conditions for different grades of paper (12, p324).

### AVERAGE COOKING CONDITIONS

<table>
<thead>
<tr>
<th>Grade</th>
<th>Time to 110 C, hr</th>
<th>Total time, hr</th>
<th>Maximum temp, C</th>
<th>Pressure lb gage</th>
</tr>
</thead>
<tbody>
<tr>
<td>News</td>
<td>2-3</td>
<td>8</td>
<td>140</td>
<td>70-75</td>
</tr>
<tr>
<td>Bond</td>
<td>3</td>
<td>9</td>
<td>136</td>
<td>70-80</td>
</tr>
<tr>
<td>Book</td>
<td>3</td>
<td>9-9½</td>
<td>140</td>
<td>70-80</td>
</tr>
<tr>
<td>Chemical conversion</td>
<td>3</td>
<td>9-10</td>
<td>145</td>
<td>70-80</td>
</tr>
<tr>
<td>Mitscherlich</td>
<td>5</td>
<td>16-20</td>
<td>130</td>
<td>65-70</td>
</tr>
</tbody>
</table>

Steam consumption per ton of sulphite pulp varies with the system of cooking. Cold-acid systems use the greatest quantity of steam. The hot-acid systems, with circulation and indirect heating, require the least steam per ton of pulp. Average steam consumption per ton of
sulphite pulp varies from 7,000 to 3,500 lb.

During the various stages of cooking, samples of digester liquor are taken for acid and color tests, giving some indication of the progress of the cooking operation.

Toward the end of the cooking cycle, the digester pressure is reduced by relieving it at the top until it is about 15 to 45 psi, at which time the blow-off valve is opened, and the charge is blown into the blow pit.

The blow pit is a vertical tank of wooden or concrete construction and has more than twice the capacity of the digester. The bottom of the blow pit is equipped with a false or second bottom which is approximately one foot above the actual tank bottom and provided with innumerable holes of about 1/8 inch diameter to drain out the digester liquor. After the charges are blown into the pit, steam and gases escape through a blow stack, and liquor is drained off into the sewer; soon washing of the stock begins. Warm water, which readily removes traces of liquor, is generally used for washing; the process takes several hours and lasts until the wash-water shows no color from the liquor.

The stock as it is left in the blow pit after washing is a consistency of about 12 to 15 per cent air dry; and in order to get it out, it is necessary to thin the stock down by adding fresh or white water. This is done by cutting it
with a high pressure hose line. After the stock has been sufficiently thinned down, it is pumped over for screening and further washings and for other pulp treatments.

The general flow process of a sulphite pulp mill is shown in Plate VIII. The stock from the digester is blown into the blow pit where traces of liquor are washed off. It then goes to the washers where it is washed thoroughly with fresh water. From the washer it goes to the brown stock chest. It is then passed through the screens to remove slivers and other foreign matter. The stock then goes to the thickener where the consistency is raised. It is then subjected to the bleaching processes which will be discussed later on.

ALKALINE PROCESS

The essential difference between the two alkaline processes, soda and sulphate, in the preparation of their cooking liquors has been mentioned in the previous chapter. The function of the two processes is similar: the removal of the non-fiberous constituents of the wood. These processes have this function in common with the sulphite process. The important feature of the alkaline process is the recovery of the chemicals from the used cooking liquors; otherwise, the cost of alkaline pulps would be prohibitive. The soda and the sulphate processes are very similar in
General arrangement of a sulphite pulp mill.

Plate VIII
the nature of their operation, in equipment required, and in chemical reactions. Therefore, it is worth while to consider the two processes together in order to avoid repetition.

In the soda process, the wood is cooked with liquors consisting essentially of sodium hydroxide (NaOH), but often carrying a sulphidity of the order of 5 per cent. In the sulphate process, the chief constituent of the liquor is also sodium hydroxide, but the sulphidity is somewhat higher, generally ranging from 20 to 30 per cent. The reactions which take place in the digesters of the alkaline process are essentially those of hydrolysis. This applies to all the principal constituents; namely, lignins, carbohydrates, resins, fats, and, to some extent, the cellulose itself. Thus, all constituents of the wood are simultaneously attacked to a differing degree in the digestion process. The reactions involve hydrolysis of lignin and hemicelluloses, resulting in the formation under the influence of sodium hydroxide of salts soluble in water or in excess alkaline. Simultaneously most of the extractives, fats, resins, etc., are saponified and dissolved in the cooking liquor.

In the sulphate process, the cooking liquor is a mixture of sodium hydroxide and sodium sulphide, the latter being produced in the furnace of the recovery process by
reduction of the sodium sulphate added. The carbon produced from burning organic matter in the cooking liquor causes reduction, according to formula:

\[ \text{Na}_2 \text{SO}_4 + 2\text{C} = \text{Na}_2\text{S} + 2\text{CO}_2 \]  

(1)

Although sodium sulphide is one of the main constituents of the sulphate cooking liquor, the reactions that take place in the digester are not very different from those of soda process, as sodium sulphide is hydrolized according to the equation:

\[ \text{Na}_2\text{S} + \text{H}_2\text{O} = \text{NaOH} + \text{Na SH} \]  

(2)

The sodium hydrosulphide thus formed contributes to the cooking power of the liquor in the same way as the sodium hydroxide. Thus both substances have the power to combine with the phenols and alcohols produced during the cooking process. The principal function of the sulphide is to provide a reserve of alkali which is utilized for digestion only as required. In the soda process, the total alkali requirement of the wood is added at an early stage so that, until most of it is used up, cooking takes place under severe conditions, resulting in pulps of low strength. In the sulphate process, on the other hand, sodium hydroxide is produced from the sodium sulphide only so fast as it is used by the cooking operation, so that severe conditions are avoided. The supply of alkali is therefore controlled by the reversible nature of the above chemical reactions.
The restrained cooking conditions in the sulphate process result in pulp of higher strength than those obtained by the ordinary soda process.

Plate IX shows the general flow process of a soda mill. Plate X shows the flow sheet of the sulphate mill of the Longlac Pulp and Paper Company at Terrace Bay, Ontario. It is one of the latest and most improved types of mill for producing bleached sulphate pulp for writing and printing and for various other papers. Washing is done in three stages and bleaching in five stages, with provision for the addition of more stages if necessary.

In the recovery processes, a major saving in cost is effected by recovering the digestion reagent from the spent liquor with a minimum of loss, and in producing steam for digestion and other operations, such as bleaching and drying.

The black wash liquors, after digestion, are subjected to the following stages of operation to recover the chemicals.

1. **Evaporation:** The black alkaline liquor is concentrated by evaporating the water content in a series of (Multiple effect) evaporations, heated either by direct fire or steam. The concentrated liquor after the operation contains about 50 per cent of solid, consisting of organic matter and chemicals.
Flow Sheet of Soda Process.

**Kraft (Sulphate) Process Note**

With almost no change this flow sheet may be taken for the Kraft process. The principal change is in the addition of $\text{Na}_2\text{SO}_4$ in the furnace at X where the sulphate is reduced to sulphide. Digester relief may be treated for turpentine recovery. Fumes are obnoxious.

<table>
<thead>
<tr>
<th>Per ton of dried soda pulp</th>
<th>Per ton of dried Pulp</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Wood</strong></td>
<td>15-2 tons</td>
</tr>
<tr>
<td><strong>New lime</strong></td>
<td>500 lb.</td>
</tr>
<tr>
<td><strong>Soda Ash</strong></td>
<td>250 lb.</td>
</tr>
<tr>
<td><strong>Steam</strong></td>
<td>13,000 lb.</td>
</tr>
<tr>
<td><strong>Electricity</strong></td>
<td>250 kw-hr.</td>
</tr>
</tbody>
</table>

Plate IX
Flow sheet, bleached-sulphate pulp mill.
2. **Incineration:** The hot concentrated liquors are then burned in a recovery furnace where the water is driven off in the form of steam; the organic solid constituents are burned and give out heat during the process. Alkali remains as sodium carbonate or sodium sulphide according to whether the liquor contains caustic soda or sodium sulphate.

The general reactions are as follows:

a. Conversion of carbon from the organic matter into carbon dioxide

\[ C + O_2 = CO_2 \]

b. Reaction of CO₂ with any free sodium hydroxide remaining in the liquor to form sodium carbonate

\[ 2NaOH + CO_2 = Na_2CO_3 + H_2O \]

c. In the sulphate process there occurs, in addition, reduction of sodium sulphate to sulphides

\[ Na_2SO_4 + 2C = Na_2S + 2 CO_2 \]

The solids thus obtained undergo further burning in an oil-fed high temperature smelter to get rid of the remaining carbon.

3. **Lixiviation, or leaching:** The burned residue, or the fused material from the smelter, is dropped into a tank of water, the contents of which are kept agitated. Most of the sodium compound goes into solution, and is removed for causticization. The silicate does not dissolve easily
unless lixiviation is carried out at a relatively high temperature.

4. Causticization: The sodium compounds in solution are again converted to sodium hydroxide by the action of calcium hydroxide produced by the slaking of lime. The principal reactions are therefore:

\[
\text{CaO} + \text{H}_2\text{O} = \text{Ca(OH)}_2
\]

\[
\text{Ca(OH)}_2 + \text{Na}_2\text{CO}_3 = 2\text{NaOH} + \text{CaCO}_3
\]

5. Sedimentation: In the above reactions, the caustic soda, since it is soluble in water, remains in solution and the insoluble calcium carbonate forms a muddy precipitate. Removal of the calcium carbonate is achieved by allowing it to settle out, the top liquor being drawn off and sent back to the digester liquor storage tanks. The sediment is then washed to recover the remaining alkali, and the sludge is rejected. Sometimes the sludge is dried and reconverted by heat into lime for reuse:

\[
\text{CaCO}_3 = \text{CaO} + \text{CO}_2
\]

The wood preparation equipment, mentioned in connection with the sulphite process, is adaptable to the alkaline process. Digesters differ, and several varieties are used for alkaline processes. They may be vertical, horizontal, or spherical; stationary or rotating. Digesters for alkaline processes do not have linings as do those for the sulphite process, because the alkaline cooking liquors
have relatively little action on the steel of which the digesters are constructed.

Two kinds of washers are generally used for washing sulphate pulps, viz, diffusers and rotary-drum vacuum filters. The latter has many distinct advantages over diffusers. The rotary-drum vacuum filter, arranged for multi-stage, counter-current washing, has become standard equipment in a majority of the pulp mills in the United States and Canada.

In the alkaline processes, a greater amount of recovery equipment is necessary than in a sulphite mill of the same capacity, making alkaline process mills more costly.

Great advancement in the design and manufacture of the chemical and heat recovery equipment has been made during the last 15 years for the black liquor. In a modern mill, the major portion of the evaporation is now accomplished in vertical long-tube, multiple-effect evaporators. The final evaporation of the liquor, prior to its injection into the furnace, is carried out in direct gas-contact evaporators using heat from the recovery flue gas not absorbed in the steam generating equipments. Cascade and Cyclone evaporators are found very satisfactory for this operation.

Stationary furnaces with water-cooled walls are found
more satisfactory for incineration of the liquor than the refractory-lined rotary furnaces previously used.

The Longlac Pulp and Paper Company in their new 300-ton bleached kraft pulp mill at Ontario, is using the following equipment.

1. **Wood preparation:** Three drum barkers; a single Waterous Carthage type 88 inch 10 knife chipper; Ty-Rock chip screens.

2. **Pulp manufacture:**
   a. Six 3,500 cu ft capacity digesters (manufactured by the Dominion Bridge Company) for a conventional direct-steam sulphate cooking.
   b. Six washers - three on each side for three-stage washing which is preceded by a knotter.
   c. Six secondary and four tertiary flat screens (Waterous make).
   d. Six Rotary vacuum washers (Oliver United make).

3. **Pulp bleaching:** Five-stage continuous system with equipment supplied by Sherbrook Machineries Ltd; washers in the bleaching plant are of 8 ft x 16 in. size.

4. **Pulp drying:** Two PML Kamyr wet machines and SF Flakt dryers 136 inches wide.

5. **Recovery system:** A streamlined Dorr Causticizing system with four clarifiers with storage tanks directly
opposite the recovery furnace; also two steam boilers (manufactured by Foster Wheeler Ltd) of 75,000 lb per hour capacity each.

The great popularity of the kraft process during the recent years from 1934 in the United States can be attributed to the following reasons:

1. Almost all kinds of wood can be used for pulping. Short-fibered hardwoods, woods with high resin content which are unsuitable for sulphite process, can be easily pulped by the kraft process. Bark, decayed woods, and lumber mill-waste can be utilized. Therefore, the present trend in the United States is to establish sulphate mills side by side with lumber mills. It is found most economical to use the good wood for planks and timber, the waste for pulp, and the bark and sawdust for fuel to produce steam.

2. The recent development of modern-type chemical recovery furnaces, the application of chemical engineering principles, and the use of unit equipment of a type adapted to continuous liquor processing has greatly lowered the cost of production of alkaline pulps. Thus a low-cost unbleached pulp has brought about a tremendous increase in the use of kraft papers and paper boards in the packaging field.
3. Now, due to the advent of multi-stage bleaching, the production of bleached sulphate pulps of high brightness suitable for making fine paper has become possible. Such pulps have higher strength but hydrate less readily than bleached sulphite pulp. Therefore, the kraft process, because of its great flexibility in producing various kinds of papers for different purposes, is becoming quite popular.

4. There is no problem of stream pollution in the alkaline processes as the digester liquor is all utilized for chemical and heat recovery.
CHAPTER VI
TREATMENT OF PULP

Chemical pulps coming out of blow pits, generally contain knots, incompletely cooked chips, and foreign matter and dirt, such as pieces of bark, digester brick, cement, etc. Mechanical pulp coming out of the grinding pits is generally found to contain wood slivers, sand, and particles from pulpstones and shims of wood that have escaped grinding. During the refining of pulp, all these objectionable impurities are removed. The pulp before screening remains in bundles with fibers sticking to each other forming lumps. The fibers should be well separated and homogeneous in the stock. This is accomplished by screening, riffling, and washing.

During the pulp purifying process, water acts as a conveyor for the fibers, holding them in suspension as the pulps are pumped from place to place while being sorted and treated. The consistency of the stock is very important for the successful operation of the process. It is generally between 2 and 4 per cent.

Screening is one of the most important operations in the treatment of pulp, for separation of coarser fibers from the fine and for the removal of dirt and foreign matter. The process also separates the fiber into classes according to their dimensions. For greater efficiency in screening, the pulp is first passed through one or more
sets of coarse screens for removal of the largest material, and finally fine screens are used to separate the fine dirt and to deliver a clean homogeneous pulp.

Usually, for screening groundwood, two types of sliver screens are used: flat and rotary. The grinder pit is usually fitted with a grating under the pulpstone to catch thin slabs of wood before they reach the sliver screen.

The sliver screens may have stationary, rotating, or oscillating frames. The strainer is a steel plate with round holes, usually from 3/4 to 5/32 inch in diameter. If the frame is stationary or oscillating, scrapers move over the surface of the plate, to remove slivers deposited by the stock as it passes through the holes in the plate. If the frame and screen plates rotate, the screen is so constructed that it discharges the slivers retained by the screen plate at one end of the rotating drum to which the screen is attached. The flow of stock is always from inside to outside. The slivers are freed by a shower of water from such fibers as cling to them and are usually returned to the groundwood-screenings refiner system for treatment and recovery.

The consistency of the stock going to the sliver screen is dependent upon the size of the perforations of the screen plate. With larger perforations, a thicker stock
may be used, but the screening is less satisfactory. With smaller perforations, a thinner stock must be used, but a more satisfactory screening is obtained.

The knotter or the revolving-screen-plate type is widely used for coarse screening of both groundwood and chemical pulp. It consists of a rotating cylinder divided into two sections mounted on a steel shaft running in lubricated bearings, the whole being enclosed in a metal casing. For all stock, mechanical and alkaline, the machine and screen plates are of iron and steel construction; whereas for sulphite stock, the plates and other parts are of bronze or other corrosion-resistant alloy.

The stock entering the cylinder is, for the most part, screened by the larger section of the revolving screen; the remaining stock is lifted up and diluted with more water and then discharged into a smaller conical section where the acceptable solution passes through the screen. Knots, slivers, and coarse fibers are disposed by the knotter; and they are then returned for additional processing.

The machine is very simple in operation and requires a small amount of power and no attention beyond periodic inspection and occasional cleaning of the parts of the screen plates.

The stock in passing from the knotter screen to the next set of fine screens, passes through the riffler, a
long trough with pockets in the bottom. These pockets are usually formed by placing shallow dams or baffles across the direction of the stock flow at intervals along the trough. The various heavy impurities, such as brick and dust from the digesters, that may be in the stock sink to the bottom and are held by the baffles. In order to get satisfactory results, the flow of the stock should be smooth and uniform; otherwise, fiber may settle down in the riffler.

The consistency of the stock in the riffler should preferably be the same as for the fine screens which is generally not above 0.8 per cent for chemical pulp and 1 per cent for ground wood.

As mentioned before, the purpose of fine screening in a pulp mill is to grade the fibers according to their dimensions. Different grades of paper require pulps of different quality. Fibers larger than the maximum size required for a particular grade of paper are separated out by the fine screens. This gradation of fibers is accomplished by controlling the following variables: the size and shape of perforations or slots in the screen plates; consistency of the stock; the force used in passing the fibers through them; and the manner in which the screen is operated.

In a paper mill where the stock goes to the paper
machine, the primary function of the screen is to keep the fibers well separated and homogeneous. Its function is also to remove all tailings as in the case of a pulp-mill screen.

Fine screens, like coarse screens, have a perforated or a slotted plate mounted on a frame, some apparatus for forcing the stock through the plate, and a housing for these parts. The finer elements in the stock pass easily through the small perforations. The stock is kept agitated to keep the fiber in suspension and to keep the perforations clean and from clogging with fibers.

Fine screen used in pulp mills are chiefly of two types: centrifugal and diaphragm screens. A third type, the rotary screen, both inward and outward flow, has been used to some extent, mostly in Europe. By far the most commonly used screens are of centrifugal type. Diaphragm screens are also extensively used in chemical pulp mills for the final classification of the fiber and the further removal of dirt, especially if it is to be bleached.

The consistency of the stock after the screening process is generally very low, between 0.25 and 0.60 per cent. In order to use the stock in paper machines, the consistency is raised from 3 to 6 per cent by dewatering the stock. This process of thickening is called dewatering, slushing, deckering, or concentrating.
The thickening of stock is usually done in an apparatus called a decker or gravity thickener. It consists of a cylindrical frame covered with a fine mesh wire cloth. This is rotated in a vat containing the thin stock as it comes from the screens. The pulp remains on the wire-cloth surface, while the water passes to the inside of the cylinder and then flows out through a connection in the cylinder and vat. The object of the decker is to remove a certain proportion of water from the pulp supplied to it thus increasing the consistency and thickening the pulp.

The vacuum filters, which are also used for dewatering, are modern and efficient and are used for all kinds of pulp. Besides thickening the stock, the vacuum filter is used as a white-water filter and save-all. It has many advantages over the gravity decker. They are: (a) reduction of floor space, (b) effluent water almost entirely free from fiber, (c) removal of soluble impurities, (d) clarification of all excess paper machine white-water, (e) no increase in operating cost, and (f) lower maintenance.

Several types of vacuum filters are used in the United States pulp and paper mills. They are: Sherbrooke, Feinc, Oliver-Young, and American vacuum filter.

Washing is an important operation for chemical pulps, to remove chemicals and other non-cellulose constituents from the pulp. It may be an intermediate step in a
multi-stage process or a final purification operation. Washing aids the recovery of the chemicals and produces cleaner and purer pulp.

In the sulphate mill of the Longlac Paper Mill, Ontario (Plate X), six washers, for three-stage washing, have been installed. Such three-stage washing can remove almost 99 per cent of non-cellulose material from the pulp. The economy of multi-stage washing is related to the use of the effluent from a previous unit by the counter-current principle. This results in a saving of fresh water and a final effluent carrying a maximum of non-cellulose material, which in sulphate and soda mills, means a more efficient recovery of chemical and heat values.

In a pulp mill, the unbleached or bleached stock of either mechanical or chemical pulp, is dewatered, and the pulp is collected, pressed, and dried into sheets. Then the sheets are folded and lapped into bundles for transportation. The machine used for making pulp sheets is called a wet-press. The different types of machines are all alike in principle; they all make use of a wire-cloth covered cylinder and vat, similar to that of a decker. They differ, however, in the arrangement of the part which presses the water from the sheet of pulp formed on the cylinder. The bundle of pulp is called a lap which contains 30 to 45 per cent by weight of air-dry pulp,
depending upon the type of machine used to extract the water. These pulp laps may either be stored or be transported to paper mills.

In a pulp and paper mill, however, this pressing and drying operation is not necessary. The stock can be directly utilized in paper machines.
CHAPTER VII
THE BLEACHING OF WOOD PULP

The object of bleaching wood pulp is to remove the coloring matter as well as the residual lignin and resins and other impurities, from the cellulose. The cellulose when free from impurities becomes white in color and suitable for making writing, printing, and other kinds of papers where whiteness is essential. The bleaching process also sterilizes the pulp, which is important for its use for making food wrappings, and for its storage under conditions which may lead to deterioration by decomposition. The bleaching agents generally destroy the coloring matters in the pulp, or convert them into substances which are easily removed by washing.

Bleaching materials are either oxidizers or reducers. Oxidizing agents are substances capable of adding oxygen or removing hydrogen from materials with which they are brought into contact; whereas reducing agents have the opposite effect. Oxidizing agents which may be used for bleaching pulp are hypochlorites, chlorites, elemental chlorine, chlorine dioxide, permanganates and peroxides. The reducing agents which generally are used include sodium sulphite, calcium and magnesium bi-sulphite, and zinc hydrosulphite. Zinc hydrosulphite \((\text{ZnS}_2\text{O}_4)\) is an active reducer and is used widely for bleaching ground wood. The
oxidizing agents are, however, of far greater importance so far as wood pulp is concerned. Chlorine and its compounds have been used extensively for many years by reason of their convenience and relatively low cost; peroxides have been used recently to bleach mechanical wood pulps.

Previously, bleaching powder (CaOCl₂), containing about 35 per cent chlorine, was largely used for bleaching purposes. Nowadays, liquefied chlorine is used most frequently in order to save cost of transportation. Most of the chlorine marketed today is prepared by the electrolysis of brine, the chief constituent of which is common salt (NaCl). The sodium, produced in the negative electrode, combines with the water in brine to form sodium hydroxide according to the chemical formulae:

\[ \text{NaCl} \rightarrow \text{Na} + \text{Cl} \]
\[ \text{Na} + \text{H}_2\text{O} \rightarrow \text{NaOH} + \text{H} \]

The chlorine gas, produced in the positive electrode, is collected and compressed until it is liquefied.

The most commonly used bleaching solution is calcium hypochlorite, which is obtained by absorbing chlorine in milk-of-lime according to the equation:

\[ 2\text{Ca(OH)}_2 + 2\text{Cl}_2 \rightarrow \text{Ca(OC1)}_2 + \text{CaCl}_2 + 2\text{H}_2\text{O} \]

This is done by delivering chlorine through a tube to the bottom of a narrow deep tank containing milk-of-lime and provided with an agitator. As the chlorine rises up
from the bottom, it will be absorbed. The course of the reaction is conveniently controlled by observing the gradual rise in temperature produced by the heat developed. The end of the reaction is indicated by the failure of the temperature to rise further. The residual lime is allowed to settle and is removed in the form of sludge; the bleach liquor is decanted off and is ready for use.

In actual practice, bleaching of the pulp is done in several stages. In the first stage, a portion of the bleach liquor is added, and the chlorine attacks the lignins not eliminated during the digestion of wood, forming chlorolignins which are removed by washing, after which the pulp is left in a purer state for the true bleaching operation. The subsequent bleaching stages require less bleach liquor.

Nowadays, chlorine is generally used for the chlorination of the lignins, instead of bleaching liquor, and no excess chlorine is used, as that will attack the cellulose. The reaction may be written as follows:

\[ \text{LigH} + \text{Cl}_2 = \text{Lig Cl} + \text{HCl} \]  (Where "Lig" represents the portion of the lignin molecule which does not participate in the reaction).

Also,

\[ \text{H}_2\text{O} + \text{Cl}_2 = \text{HCl} + \text{HClO}. \]
The hydrochloric and hypochlorous acids formed are both detrimental to the cellulose and are removed by an alkaline wash, which also removes the remaining chlorolignins. It has been found advantageous to wash the stock twice; first with water to remove most of the acid, and then with alkali to neutralize any remaining acid and to dissolve out the chlorolignins. In order to remove the coloring matter, the pulp is given two or three stages of hypochlorite bleaching with an intermediate washing with water. It is preferable to finish the bleaching process with a dilute acid wash to neutralize the alkali in the pulp.

The efficiency of the bleaching process depends to some extent on the consistency of the pulp and water emulsion; that is, the ratio of pulp to water. It has been found that the best results are obtained when the consistency is low in the first (low-density chlorination) stage and relatively high in the subsequent stages. In general 3 to 4 per cent for the first stage and 5 to 10 per cent for the other stages may be taken as average figures.

Sulphite pulps can usually be bleached in three stages, namely: (1) chlorination; (2) alkali extraction; (3) hypochlorite treatment; but to bleach sulphate pulps, at least five stages are necessary. To secure satisfactory results, the bleaching of sulphate pulp may be done in
seven stages, namely: (1) chlorination; (2) alkali extraction; (3) HD hypochlorite treatment; (4) alkali extraction; (5) high-density hypochlorite treatment; (6) chlorination; and (7) alkali extraction.

It is advisable to effect an acid after-treatment in order to stabilize the brightness of pulp and to prevent color reversion during drying or storage.

The bleaching sequence followed in the new bleached kraft pulp mill of the Longlac Pulp and Paper Company at Terrace Bay, Ontario, is as follows:

1st stage Low-density chlorination
2nd stage High-density caustic
3rd stage High-density hypochlorite
4th stage High-density caustic
5th stage High-density hypochlorite

There is also provision for introduction of additional stages if necessary.
CHAPTER VIII
FEASIBILITY OF ESTABLISHMENT OF A PAPER MILL
IN ASSAM

The abundance of raw materials, especially bamboos and pulpwoods, in the state of Assam, has been previously discussed. Since the bamboos have long and strong fibers, are prolific in growth, and are available in abundance in the state, naturally the bamboos would be the chief raw material for pulping. But woods and saw mill waste also can be utilized to make different grades of paper at low cost.

The author visited the Central Research Laboratory of Crown Zellerbach Corporation at Camas, Washington, with various samples of Assam woods, bamboos, and grasses, in order to evaluate the pulping quality of the samples. Dr. W. F. Holzer, Assistant Director of Research, and Dr. K. G. Booth, the Chief of experimental pulping, are both of the opinion that the following woods are suitable for kraft pulping:

1. Lali
2. Sam
3. Satiana
4. Champa
5. Gamai
6. Hollong
7. Hollock

Since Semul and Modar are very light, they will produce a very poor yield; whereas Kakua bamboo (soft) will be an excellent raw material for both soda and kraft pulps.
The sample of grass, in their opinion, will make very poor yield but may be utilized for making fiber boards.

The Government of India has recently started planting Spruce and Balsam fir on the Himalayan range of Northern India on an extensive scale, for the purpose of making groundwood for newsprint. The provincial government of Assam may likewise start plantations of Spruce and Balsam fir on the Naga and Garo Hills, where the climate is suitable for such plantations. At present, most of the newsprint has to be imported from Canada. Since there is a great demand for newsprint all over the world, India, sooner or later, will have to make newsprint for her own consumption. The state of Assam, with its suitable climate, its good soil, and its vast amount of available space on both mountainous and table land for forest cultivation, will be able to contribute a great deal in the future if proper steps for the cultivation of Spruce and Balsam fir are taken as early as possible.

Besides the raw materials, other woods indigenous to Assam, such as satiaha, gomari, pitali, hollong, salua, champa, and various other woods, may be used for pulping in the kraft process. On the whole, there will be no dearth of pulpwoods and bamboos for pulping.

Sufficient quantities of water of satisfactory quality must be available for the various operations of
pulp- and paper-making, as water plays a large part in the quality of the finished product. It should be clear and free from iron, manganese, and it should have a low calcium content. Its color must not exceed 20, and its pH value should be close to 7, and the content of dissolves material very low (12).

The state of Assam, throughout, has very high rainfall, as a rule, the highest being at Cherapunji, where the annual rainfall is between 400 and 500 inches. The mighty river Brahmaputra runs from east to west through the state. Brahmaputra and its many tributaries carry sufficient water for power as well as for industrial use, although none of them has yet been harnessed, either for irrigation or for power. The water is generally clear, except during the rainy season, which lasts from July to the end of September, when it becomes muddy.

For use in connection with paper mills, a water treatment plant will have to be set up for the removal of suspended as well as dissolved impurities. The latest improved method for manganese and iron removal, by free residual chlorination at normal pH value, may be applied (1).

India is self-sufficient in respect to salt (NaCl) because of her large salt deposits in the states of Bombay and Madras. The manufacture of salt cake (Na₂SO₄), caustic
soda (NaOH), sulphuric acid (H$_2$SO$_4$), and liquid chlorine are being carried out in the different states of India, and their production has greatly increased in recent years (8). As the demand for these important chemicals continues to increase, the production will no doubt be increased accordingly.

India has not produced any sulphur previously; it has to be imported from Japan and the United States. However, according to the news published by the Christian Science Monitor, Boston, Tuesday, November 13, 1951, deposits of pyrites have been discovered in India that will supply all the country's sulphur needs.

Limestone (CaCO$_3$) deposits, in the hills of Assam, have furnished an abundant supply of good quality limestone.

Although the state of Assam has great hydro-electric potentialities, unfortunately nothing has yet been done in that line. No major project has yet been undertaken, only a few small ones. The state government may harness some of the rivers for flood control and power. Until then all the power necessary for a pulp and paper mill will have to be generated within the mill. Steam boilers and steam turbines of adequate capacity will have to be installed along with alternators for generation of electricity. This will make the matter of establishing a paper mill a little
more complicated since the mill will have to be of small capacity to start with, but there should be provision for expansion and for increasing the capacity when necessary.

Approximate power consumption per ton of paper produced depends largely on the type of equipment used, as well as on the quality of paper. For making sulphite wrapping paper, approximately 63 hp per ton of paper per day is required (18, p663). For making good quality book and magazine paper by the kraft process, approximately 75 hp per ton of paper produced may be assumed for the purpose of designing the power house for the mill. For a 200-ton daily capacity, kraft pulp and paper mill, the approximate power requirement will be 1500 hp which may be obtained by installing alternators, steam turbines, and boilers for the purpose.

The fuel for the boilers will be natural coal which is available within the province. There are several coal fields in Assam, the largest being at Ledo, situated four miles east of Margherita and 13 miles east of Digboi.

The Assam Oil Company Ltd, at Digboi, operates an oil field of considerable size, with a refinery. Their oil production a few years ago was about 100,000 gallons per day. The production must have increased now, as the company has recently struck a new oil field close to the old one.
Dubb's coke, residuum oil, and natural gas may also be available for steam generation from this company if the mill is located at Margherita.

There is no dearth of unskilled labor anywhere in India at present. There may be considerable difficulty in starting work with unskilled labor at the beginning. However, the Indian mill worker has a reputation for great adaptability and for his interest in his profession. In a short time he can be trained to do any skilled work.

At present, wages are very low compared to those of American labor. The cost of living, at the same time, is much lower in India than in America. On the whole, it can be assumed that the cost of labor in paper production in India will be 20 per cent (or even less) of that in the United States.

In selecting a site for establishing a mill, due consideration should be given to its proximity to raw materials, to the facility of transportation, and discharge of waste liquid, to the availability of sufficient good water, labor, fuels and power, to the suitability of the land for construction, and to the erection of heavy factories and machinery and their expansion.

All the pulp and paper mills in the states of Oregon and Washington have been established by the side of rivers, facilitating the transportation of lumbers, the drainage of
waste liquor, and the supply of water.

There will be no dearth of suitable sites for paper mills in Assam, as it has many rivers and ample space lying unused. Other points of consideration in this respect are proximity to future hydroelectric power and the location of the land above flood level. Many apparently excellent sites may be inundated by high flood waters.

Suitable sites at Margherita on the banks of the river Buridihing, at Golaghat, beside the river Dhansiri, and Tezpur by the side of the river Brahmaputra will be available. These places are connected by railways, and they are close to Government forest reserves (see Plate XI).

The cost of establishing a kraft pulp and paper mill in the United States of America is about $65,000 per ton of daily paper production in connection with plants of 250 tons and larger. For a mill smaller than 250 tons, it is higher approximately $70,000 per ton. For a 200-ton daily capacity paper mill, the cost will be nearly $14,000,000. Considering the transport expenses and custom duties, it may be assumed that $16,000,000 will be required to establish a 200-ton pulp mill in Assam. The cheap labor and low cost of acquiring the site will go far toward lowering the total cost.

We shall have to purchase the latest type of kraft machineries from different companies of the United States.
(The names of the well-known companies are given in the Appendix.) The question will be how to provide the capital in American exchange. This will have to be arranged by the State Government with the Central Government. The enterprise may be financed either entirely by the State Government or by private companies with the government's support.
A pulp and paper mill in Assam is long overdue. It should be started with a 200-ton kraft mill located if possible in conjunction with a saw mill to utilize waste wood. There would have to be sufficient provision for expansion to double its capacity in future. Two medium-sized pocket grinders should also be installed for making mechanical pulp from semul, pine, and other soft woods, for use in triplex boards and wrapping paper. Also, such mechanical pulp might be used in experimental newsprint composed of Kraft and ground wood pulps. Recent developments in ground wood bleaching with peroxides and zinc hydrosulphite have opened many possibilities of using cheap, bleached ground wood in production of different kinds of papers and newsprints.

The raw material for pulping could be chiefly bamboo and saw-mill wastes. Semul, pine, amara, lali, salua, and other woods which are not used for timbers might also be used in large quantity.

All equipment should be of the latest improved types. Vast improvements have been made in recent years in all types of pulp and paper manufacturing equipment by the manufacturing companies of the United States. It would be advisable to have all or at least the major equipment from reliable companies of this country.
The chemicals like salt cake, chlorine, peroxides, zinc hydrosulphite, etc, would necessarily be brought from the other states of India, and large stockpiles maintained. There is no possibility at present to install plants in Assam for manufacturing these chemicals, especially salt cake and chlorine, without cheap electricity. There would be additional initial costs for installation of the power plant including boilers, turbines, and generators at the mill site. In spite of the above handicaps, it is expected that a pulp and paper mill would make large profit, as there is a ready market with a great demand for paper. The expected installation of hydro-electric power in Assam within a decade will make future paper mill installations more favorable.

It would be economically wise to have the entire pulp plant designed and installed by experienced personnel. In the United States, there are experienced personnel who would be available to come to India to assist in the establishment and initial operation of the new pulp plant provided that sufficient compensation is furnished.
BIBLIOGRAPHY


APPENDIX
## APPENDIX

<table>
<thead>
<tr>
<th>Name of Company</th>
<th>Equipment Manufactured</th>
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<tbody>
<tr>
<td>1. Allis-Chalmers Mfg Co</td>
<td>Chip screens and other pulp and paper machinery.</td>
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<tr>
<td>Milwaukee, Wisconsin</td>
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<tr>
<td>2. Appleton Machine Co</td>
<td>Winders, finishing rolls, rewinders, other pulp and paper mill machines.</td>
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<td>Appleton, Wisconsin</td>
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<td>Watertown, New York</td>
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<td>Philadelphia 42, Pa.</td>
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<tr>
<td>5. Bird Machine Co</td>
<td>All kinds of screens, savealls, other pulp and paper manufacturing machinery.</td>
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<td>South Walpole, Mass.</td>
<td></td>
</tr>
<tr>
<td>6. Combustion Engineering-</td>
<td>Heat recovery, steam generating and related equipment; also superheaters and pressure vessels.</td>
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<tr>
<td>Superheater, Inc</td>
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<td>New York 16, N. Y.</td>
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<td>Montreal, Canada</td>
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<td>Pittsfield, Mass.</td>
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<tr>
<td>9. Foster Wheeler Corp</td>
<td>Digesters, boilers, absorption towers, etc.</td>
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<tr>
<td>New York, N. Y.</td>
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<tr>
<td>10. Foxboro Co</td>
<td>All kinds of automatic controls.</td>
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<td>Foxboro, Mass.</td>
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<tr>
<td>New York, N. Y.</td>
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<tr>
<td>12. Link-Belt Co</td>
<td>All kinds of conveyor equipment.</td>
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<tr>
<td>Chicago, Illinois</td>
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<tr>
<td>New York, N. Y.</td>
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14. Pusey & Jones Corp  
Wilmington, Delaware  
All kinds of paper machines.

15. R. P. Adams Co, Inc  
Buffalo, N. Y.  
Water filtration equipment.

16. Rice Barton Corp  
All kinds of paper manufacturing equipment.

17. Sandy Hill Iron & Brass Works  
Hudson Falls, N. Y.  
Pulp grinders, paper machines bleaching equipment, screens, thickers.

18. Smith & Winchester Manufacturing Co  
South Windham, Conn  
Paper mill and paper bag machinery.

Refiners.

20. Sumner Iron Works  
Everett, Wash.  
Hydraulic barkers, chippers, and other wood-room machinery.

21. Sutherland Refiner Corp  
Trenton, New Jersey  
Beaters.

22. Swenson Evaporator Co  
Harvey, Illinois  
Evaporators, pulp-washers, deckers, filters, condensers, causticizers.

23. Washington Iron Works  
Seattle, Wash.  
Barkers, dryers, pulp-balers, hot presses, logging equipment.