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A STUDY OF A METHOD OF MANUFACTURING DISSOLVER PULP FROM INDIAN BAMBOO

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Abstract

This report presents the results of a study to determine the design of a rayon-grade pulp plant using bamboo as a raw material.

The study consisted of preliminary investigations based on available information. Various process variables are defined, and a process to manufacture 50 tons of pulp per day is evolved.

Preliminary estimates show that such a plant would cost about $4,200,000. The high break-even point of 11,200 tons of pulp per year necessitates consideration of a plant with higher capacity or modifications in the process.

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I. INTRODUCTION

The factor that mostly controls the development of the rayon industry in India is that vital raw materials such as rayon-grade pulp, caustic soda, and sulfur must be imported. Vast forest areas of India are, however, a great source of cellulose for the paper and pulp industries; and, furthermore, vigorous studies are being made to find means of harnessing this natural potential at the pilot plant level, and, to some extent, at a full-scale industrial level.

One of the great sources of cellulose that India can offer to the paper and pulp industries is bamboo. The suitable climate and soil in India engenders a prolific growth of bamboo there, and, because bamboos grow rapidly and plentifully and yield good pulp, they are a potential source of dissolver pulp.

With these factors in mind, the study presented in this paper is an attempt to define the process variables that must be considered in making rayon-grade pulp out of bamboo, to evolve such a process, and to investigate the economic feasibility of such a process.

A. Availability and Pulp Quality of Bamboo Species in India

The high potential of pulp production in India may easily be seen from Table I which shows the availability and pulp quality of some important bamboo species in India.

B. Cultivation of Bamboo

There are essentially two classes of bamboo: the clump-forming and the running. Since the clump-forming class is most common in India, the study applies to this variety.

1. Propagation

Clump-forming bamboos are propagated by cutting clumps into divisions containing one or two nodes each. Some clump-forming species respond well to propagation by culm cuttings in which single node sections are planted.

2. Soil

For the cultivation of bamboo, a tropical or warm temperate climate is preferable. The most desirable soil for most species is fertile friable soil with good drainage.

3. Harvesting methods

The following are the three common methods of harvesting bamboo.

a. Selective cutting. Every culm is marked with its year of emergence. Culms of proper age are selected and cut with axe or saw, annually or biennially.

b. Strip cutting. A portion of the grove is cut away be machine. This method is cheaper.

c. Clear or total harvesting. Each grove is completely cut off. It is inefficient as it takes long for the grove to recover.

Selective cutting is cumbersome and expensive while clear harvesting is obviously inefficient. Therefore, the strip cutting method is preferred as the best method.

4. Yield

Harvest varies from four to eight tons per acre per year in India.[9]

TABLE I

BAMBOO SPECIES IN INDIA

Species (with references)	Availability	Pulp Quality
Bambusa Polymorph (Bhargava, Chemical Abstracts 42, 4746 Pearson, C. A. 8, 246 Raitt, C. A. 6, 2527)	Most suitable species both in terms of location and quantity	Good bleachable pulp
Bambusa Tulda	Plentiful	Difficult to bleach
Cephlostachyum Pergracile (Bhargava, Pearson & Raitt. loc. cit.)	Plentiful, promising source of pulp manufacture	Good, α-cellulose content
Deudrocalamus longispathies (Bhargava loc. cit.)	Plentiful	Yield of α-cellulose as high as 62%
Dendrocalamus Strictus (Ahmed & Karnik C. A. 39, 184) Bhargava, Singh Biol. Abs. 18, 2405 Karnik & Sen C. A. 43, 2768)	Enormous reserves	Difficult to bleach
Melocanna Bambusoides (Bhargava, Pearson, Raitt. loc. cit.)	Plentiful, promising for location and pulping	Good, α-cellulose content
Ochlandra Brandisi Ochlandra nigrociliata Ochlandra Travencorica	Plentiful. (One of the principal sources used in Rayon manufacture)	Good, α-cellulose content

C. Properties of Bamboo

Table II gives average properties of bamboo.[1,2]

TABLE II

Chemical Properties

Total cellulose	42-55%
Pentosans	20-27%
Lignins	20-30%
Ash	3-4.75%
Total N_2	1.93-5.73%
Soluble matter	10%
Alcohol extract	2.39-6.31%
Benzene-alcohol extract	4.49%
Cold water extract	2.12%
Hot water extract	6.32%
1% NaOH extract	20.0%
Normal moisture	9-10%

Physical Properties

Density between nodes	35-45 lbs./ft.^{3}
Density at nodes	47 lbs./ft.^{3}
fiber length	1.6 to 3.8 mm.
width	0.009 to 0.036 mm.
(length/width) ratio	100 to 193

II. MANUFACTURING PROCESS

A. Considerations for a Manufacturing Process

The chemical characteristics of a suitable viscose pulp are:

α-cellulose	88%
Pentosans	5%
Lignins	. 0.15%
Ash	. 0.15%
Alcohol-Benzene Solubility	0.5%
Viscosity - Tappi	1 to 25 C.P.
Brightness - Higgins	85%

There are two common processes of manufacturing pulp from wood, the Kraft process and the Soda process.[5] Low lignin and ash content and good bleachability characterize a good pulp. In these terms, the pulp produced from bamboo by the Kraft process has been found superior to that produced by the soda process. This can be seen from the following table of average compositions given by Jogleker[6].

TABLE III

Average Composition

	Soda Pulp	Kraft Pulp
Active Na_2O	16-20%	16-20%
Total yield	37-41%	38-6%
Screened yield	36-39%	32.7-37.8%
Ash	1.4-1.6%	1.3-1.4%
Alcohol-Benzene Solubility	0.0%	0.0-0.4%
1% NaOH Solubility	4.6-5%	4.9-5.4%
Pentosans	16%	17.6-16.5%
Lignins	3.5-4.5%	2.84-2.24%
α-cellulose	85%	80-78%
Viscosity [$Cu(En)_2$]- C.P.	392-640	967-575
Ash in α-cellulose	0.6-0.8%	0.46-0.48
Brightness (Higgins)		
10% consumption of Cl_2	66-68.1	78-82

Jogleker[6] notes that the high pentosan content of bamboo was a prohibitive factor in converting bamboo into dissolver pulp. The pentosan content in the Kraft pulp could not be reduced below 7% even with drastic purification treatments. However, better results were obtained by prehydrolysing the bamboo chips using 2% sulfuric acid at 110° C for 2½ hours. Pulp produced by this method required no more purification than that normally required.

According to Raitt[7] the plant substance of bamboo falls into four different chemical groups. Each group has one substantially basic substance which manifests individual color reactions and reacts in a distinct special manner to the action of the solvents and temperature. The four groups are:

1. Starch, sugars, tannins, gums, earth salts, coloring matter, and secondary starches and sugars soluble in water. This group includes all neutral substances which are soluble in water at 100° C.

2. All acid bodies soluble in 1% NaOH at 100° C.

3. Lignins and acid bodies soluble in 4% NaOH at 130° C.

4. α-, β-, and γ-cellulose as insoluble residue from the action of the solvents above.

Raitt[8] suggested that during digestion, groups 1 and 2 produce a dye that is not entirely discharged. To obviate this difficulty, Raitt developed a fractional digestion method in which the components of groups 1 and 2 are removed by treating the bamboo with the spent liquor from a previous cook, and the bamboo residue is then treated with a stronger caustic solution. When these starches and pectins are removed prior to delignification, the pulping action takes place in a non-staining medium, producing an easy-to-bleach pulp.

Joglekar[6], Bhargava and Singh[3] concluded that adequate purification of the prehydrolysed bamboo pulp could be secured through a 3-stage bleach consisting of chlorination, alkaline extraction and a NaOCl bleach. Hence, a conventional 3-stage bleach was found to be satisfactory for purification of Kraft pulp from prehydrolysed bamboo. For all multi-stage treatments, the total consumption of chlorine in bleaching was found to remain constant.

B. Process for Manufacturing 50 Tons/day of Dissolver Pulp from Bamboo

Because of the rapid market growth for rayon in India which has a low per capita rayon consumption, it is anticipated that the production of rayon will be increased from about 35 tons/day at present to about 100 tons/day in the next ten years. Pulp requirements on the basis of the rayon production will increase from about 40 tons/day to about 110 tons/day. Two pulp plants of about 50 tons per day capacity would satisfy the needs of the rayon industry in India. In the present study, therefore, a 50 tons/day pulp plant is considered. Likewise, in view of the peculiar chemical characteristics of bamboo, the process considered here is a modified Kraft process. The process, beginning with the cultivation of bamboo in the forest to the final stage of lapping the pulp in a wet machine would consist of six main stages of operations. In the following pages a complete description of each of these processes is given, and Figures 1, 2, 3, and 4 on pages 13, 14, 15, and 16 represent the process flowsheets.

1. Cultivating, Harvesting, Seasoning, and Storing of Bamboo.

The average yield of bamboo is 6 tons per acre. On an average, therefore, on a six-year harvesting cycle, about 700 acres of land would be required per 1000 tons of pulp per year. For a 50 tons/day plant the land required would be 10,900 acres.

The partial harvesting method, i.e., the partial cutting of the grove, is advisable for better control of the cultivation cycle.

Raitt[7] has suggested that a seasoning period of not less than three months should elapse before the culms are used. Likewise, to avoid any contingency arising out of transportation difficulties, six months' requirements of bamboo should always be stocked. This stock should be piled in heaps 50' square by 60' high. These piles should be set 100 ft apart as a precaution against fire. For the 50 tons/day pulp plant, about 27,000 tons of dry bamboo would be stored, requiring about half an acre of land for storage near the plant.

2. Preparation of Bamboo Chips

Seasoned bamboo is conveyed to crushing rolls by a sluice conveyer, soaking the bamboo before crushing and thus reducing fines. A closed cycle water system is used in the sluice conveyer. The soaked bamboo is fed to the roll crusher through the feed chute. The fibrous structure of the wood is loosened by crushing. The crushed bamboo on the way out of the rolls is fed to a multi-knife chipper giving chips 1-3 mm. thick and about ½ in. long. Average composition of chips is as follows:[2,6]

Moisture	8.5 to 9.5%
Lignin	26.25%
Pentosans	19.75%
Total cellulose	52.84% (α-cellulose 76.65% of total)
Ash	3.0%
N_2	0.26%

Chips leaving the chipper are conveyed to a screen. The undersize chips are fed by a conveyer to the boiler, and the oversize chips are returned by a conveyer to the crusher. The screened chips are conveyed to a storage silo, by a redler conveyer, where three days' requirements of chips are stored. The chips are fed from the silo discharge to chip bins situated above the hydrolyser feed system by bucket elevators.

3. Prehydrolysis of Bamboo Chips

The prehydrolysis of chips consists of treating the chips with 2% H_2SO_4 at a pressure of 70 psi and at 120° C for two hours with liquor-to-chips ratio of 4:1, thus ensuring better penetration of the liquor, in a hydrolyzer which is a large pressure vessel with a recirculating system for process liquor.

Dilute acid solution is fed to the chip feed system, thus flushing the feeder and ensuring uniform distribution of chips in the hydrolyzer. The liquor is recirculated by a pump through a two-tube-pass heat exchanger to maintain the reaction temperature. At the end of the reaction period, the liquor is drained off to a storage tank for recycle. While draining, the liquor is passed through the heat exchanger to heat up cold water which is then passed on the shell side instead of steam. Hot water is stored in a presurge tank.

The chips in the hydrolyser are washed for one hour with hot water at 100° C. The wash water is drained to the liquor-storage tank.

A relief valve on the hydrolyser maintains a constant pressure, letting off air and steam during the operation. The excess dilute acid solution which is not recycled is pumped over to a yeast-recovery plant for the recovery of the yeast, Terula Utilis.

The prehydrolysed chips are then screw-conveyed to a digester feed system in the digester room.

4. Fractional Digestion of Bamboo Chips

The fractional digestion is a batch process consisting of treating the chips with a dilute caustic soda solution and then with an alkaline solution of 33% sulfidity.

Five digesters are estimated to be required for the plant. Each digester consists of a stainless steel-lined pressure vessel with a recirculating system. In the first stage of digestion the chips are treated with an alkaline solution of 8.63% Na_2O content at a temperature of 120° C and with a liquor ratio of 5:1 for 3 hours, to ensure uniform digestion of chips.

Caustic soda is dissolved and stored as a 30% solution and mixed with white liquor obtained from the recovery section to give required alkali concentration. The liquor is pumped to the digester feed system consisting of screw conveyers and flushing boxes. The liquor carries chips with it so that a uniform distribution of chips is achieved. A strainer at the bottom of the digester ensures that only the liquor passes to the recirculating system, comprised of a circulating pump and a heat exchanger. The recirculated liquor is sprayed in the digester through a sprayer so as to form a 60° solid angle. The heat exchanger maintains the reaction temperature during the reaction period, using steam on the shell-side, and heats water which is passed on the shell-side, instead of steam, when the liquor is drained. The drained liquor is stored in an alkaline-liquor-storage tank. The chips are now ready for the second digestion. A constant pressure and relief valve is employed to let out air and steam during reaction and the blow-off steam at the end of reaction period. The steam is condensed in a jet type of condenser.

Part of the alkaline liquor in the storage tank is recycled, and part of it is pumped over to the recovery system from which the white liquor, used as working liquor in the process, is obtained. In the second stage of digestion, an alkaline liquor of 15.6% Na_2O and 33% sulfidity[6,7] is fed to the digester. The liquor is made up of white liquor from the recovery system and recycled black liquor from the previous batch. The temperature of digestion is maintained at 170° C. The liquor-to-chip ratio is 3:1 and the reaction period is four hours. The liquor is recycled as in the first digestion. At the end of the digestion the liquor is blown into the blow-off tank, and the steam released on blow-off is condensed in a jet condenser. The slurry is stirred by a bottom-driven agitator. The slurry is then pumped to a multi-stage washer by the pump.

The multi-stage washer,for filtering and washing, consists of three countercurrent type two-stage vacuum filters in series. The slurry from the blow tank is pumped to the first filter, and the filtrate, called black liquor, is sent to the black-liquor-storage tank. Fresh wash water at 180° F is sprayed on the cake leaving the washer. Dilute wash liquor is pumped to the previous stage washing system. The wash liquor from the first stage is sent to the black-liquor-storage tank. Cake is passed from one stage to the other by a screw conveyer type of repulper. The washing operation takes one hour.

Part of the black liquor is recycled in the digestion process, and the rest is sent over to the recovery system.

The washed cake is dumped through a chute to the consistency regulator.

5. Screening, Refining, and Lapping

The consistency of the pulp from the digester is adjusted to 2% in a consistency regulator and the slurry stored in a stock chest for continuous supply to the screens. The screening process separates the coarser fibres from the finer and removes dirt and foreign matter. Horizontal centrifugal Cowan-type screens separate the tailings through a fine screen and discharge them into a sewer via a knotter, while the fine slurry is passed over a vacuum filter to thicken the slurry to a consistency of 16%. The pulp is now passed on to bleaching towers by a screw conveyer.

Pulp is refined in a three-stage process. The screened pulp is fed to the first-stage retention tower by flushing with dilute chlorine water so that the consistency in the tower is 2%. The temperature is maintained at 25° C for one hour. The slurry is recirculated by centrifugal pumps through a cooler. At the end of the reaction period the slurry is filtered, and the pulp is washed in a rotary vacuum filter. The liquor and wash water are stored in a weak-liquor-storage tank. The filter cake is pulped and conveyed to the next stage by a pulper-conveyor. Part of the weak liquor is then recycled and the remaining liquor is pumped over to the third stage to be used in the third-stage process. Makeup chlorine solution is prepared in a chlorine makeup tank and fed to the liquor makeup tank.

In the second stage, the alkaline extraction stage, a consistency of 10% is maintained. The alkali content of the liquor is 2%, and the retention period in the tower is one hour. The slurry is recycled through a heat exchanger to maintain the temperature at 40° C. The extracted slurry is filtered and the pulp washed with hot water at 50° C in a rotary vacuum filter. The weak liquor and wash water are stored in the weak-liquor-storage tank. The filter-cake is pulped and passed over to the final stage by a pulp-conveyor. Part of the weak liquor is recycled in the process and the rest is pumped over for use in the third-stage process. Makeup NaOCl solution is fed as 30% NaOH solution from caustic storage tanks to the liquor makeup tank.

The third stage of refining involves the treatment of pulp with dilute NaOCl solution of pH = 10 for one hour. The pulp is flushed into the retention tower with dilute NaOCl liquor so that consistency is maintained at 5%. The temperature is maintained at 35° C. The liquor is recirculated through a cooler to bring down the temperature of pulp and liquor to 35° C and to maintain the temperature. The liquor is made up of weak liquors from the first and second stages and wash water from the third stage. Makeup NaOCl solution is fed as 10% NaOCl solution from the NaOCl makeup tank to the liquor makeup tank.

The slurry is filtered and washed in a rotary filter. The pulp is conveyed by a conveyor to the wet machine. The filtrate is stored in a tank; part of it is recycled and the rest discharged to the sewer.

Lapping: In order to convert the chemical pulps to a form suitable for transportation or temporary storage, it is necessary to dewater the stock and collect the pulp into sheets dry enough to hold together. The sheets are stacked into bundles. The lap (bundle) contains 50-55% by weight of air dry pulp. A wet press or a wet machine is employed for this purpose. A wet machine has a production capacity of 5500 lbs/24 hrs of chemical pulp per foot width. A Rogers Wet Machine is installed to perform the lapping operation, and lapped pulp is either stored or transported to a rayon mill. The filtrate is thrown away as effluent.

6. Recovery Processes

The economics of the Kraft process is greatly dependent on the recovery of chemicals used in digestion.

The waste liquors from digesters at 18% concentration are stored in black liquor storage tanks and are pumped to a seven-body sextuple-effect falling film evaporator. Feed is pumped countercurrent to steam to the fifth and sixth effects, and the concentrated liquor from both of these is fed to the fourth effect by feed pumps. This process is repeated for each subsequent effect until the first effect is reached. From the first effect the liquor is flushed into a liquor storage tank at 55% concentration. Steam is fed to the first two effects, and the vapor from these two effects is passed on to the next effect, and the process is repeated until the sixth effect is reached. Condensate from all the effects is collected and pumped to a hot well. The steam pressure varies from 38.5 psi in the first effect to 22" Hg vacuum in the sixth effect. The liquor temperature rises from 130° F in the sixth effect to 285° F in the first effect. Soap formed due to the presence of fats and waxes in wood are removed in a screen tank between the third and fourth effects. The thick liquor is stored in a thick-liquor-storage tank from which it is pumped into a direct contact evaporator where the liquor comes into direct contact with hot gases from the furnace. The liquor is then sprayed in the furnace through a system of nozzles, where once ignited, the liquor at a concentration of more than 60% solids burns by itself due to the presence of organic combustibles from wood. The unburnt solids collect on the opposite wall of the furnace and form a crust. As the crust becomes larger, it cannot hold its weight and falls to the smelting floor. The smelt then drains out to the smelt-dissolver tank. A preheater and a tubular boiler are built in the furnace to recover heat from hot gases which pass through a direct contact evaporator before passing on to the stack.

The average analysis of the smelt is:

Na_2CO_3	65%
Na_2S	20.5%
Na_2SO_3	0.7%
Na_2SO_4	6.0%
Insolubles	2.5%

The smelt is dissolved in weak liquor from a clarifier, and solution, called green liquor, is stored in a green-liquor storage tank. The green liquor is clarified and pumped to the causticisers. The underflow of the green liquor clarifier is washed in a dreg washer. The dregs are thrown to the sewer and the overflow is stored in the weak-liquor-storage tank. The green liquor is mixed with slaked lime coming from the lime slaker and agitated for one hour in causticisers. The causticised liquor is pumped to a white liquor-thickener. The overflow is then stored as white liquor which is pumped to the digestion room and the mud is washed and thickened in a mud thickener. The weak liquor from the thickener is stored in the weak-liquor-storage tank. Part of it is used in dissolving smelt, and the remainder is sent to the sewer. The mud is filtered in a rotary vacuum filter and washed. The filtrate and wash water are pumped to the mud thickener, and the cake is conveyed to a rotary lime kiln. Make-up limestone is fed to the kiln. Lime produced is conveyed to lime bins situated over the lime slaker.

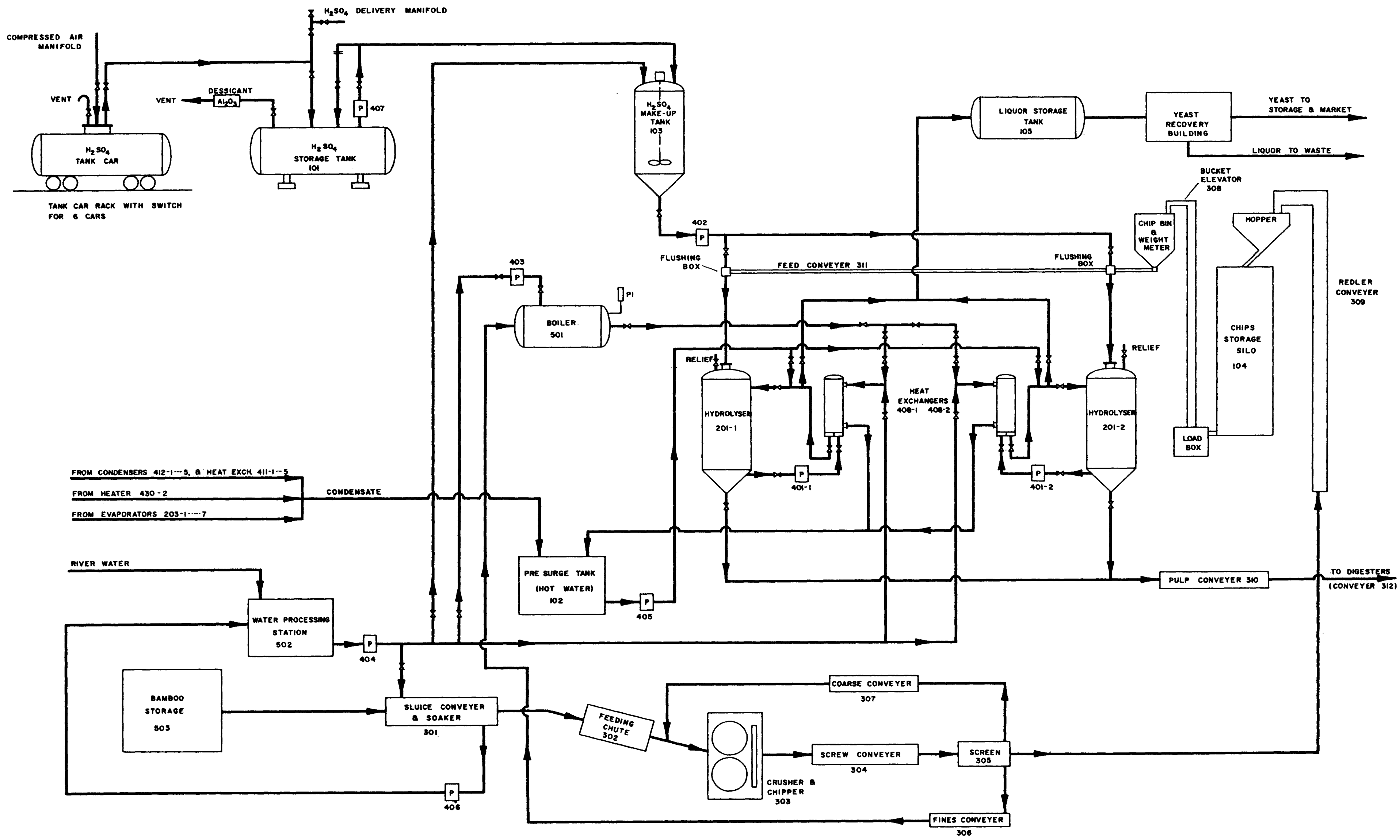


FIG. I CHIPPING & HYDROLYSING

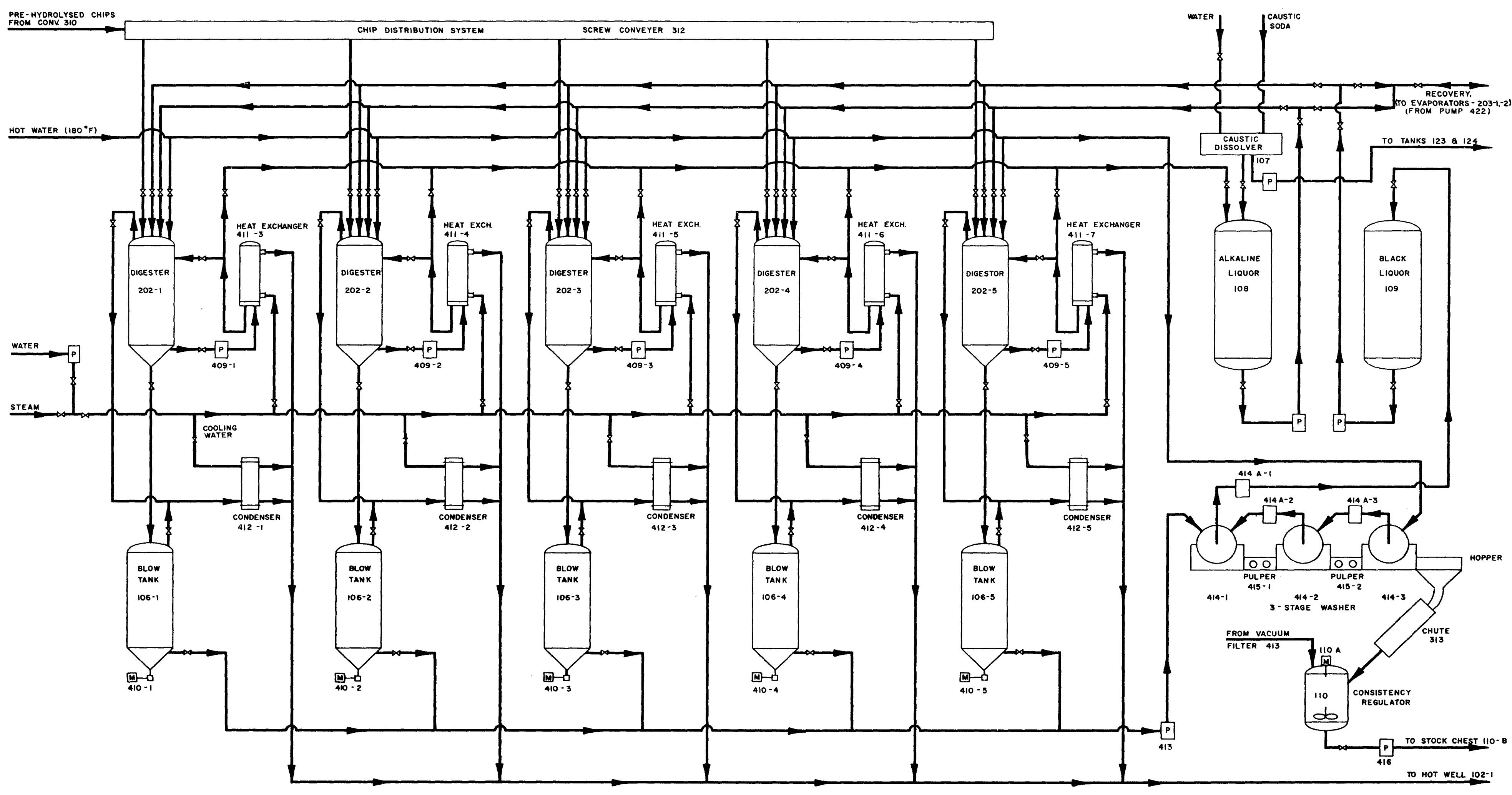


FIG. 2 DIGESTION SYSTEM

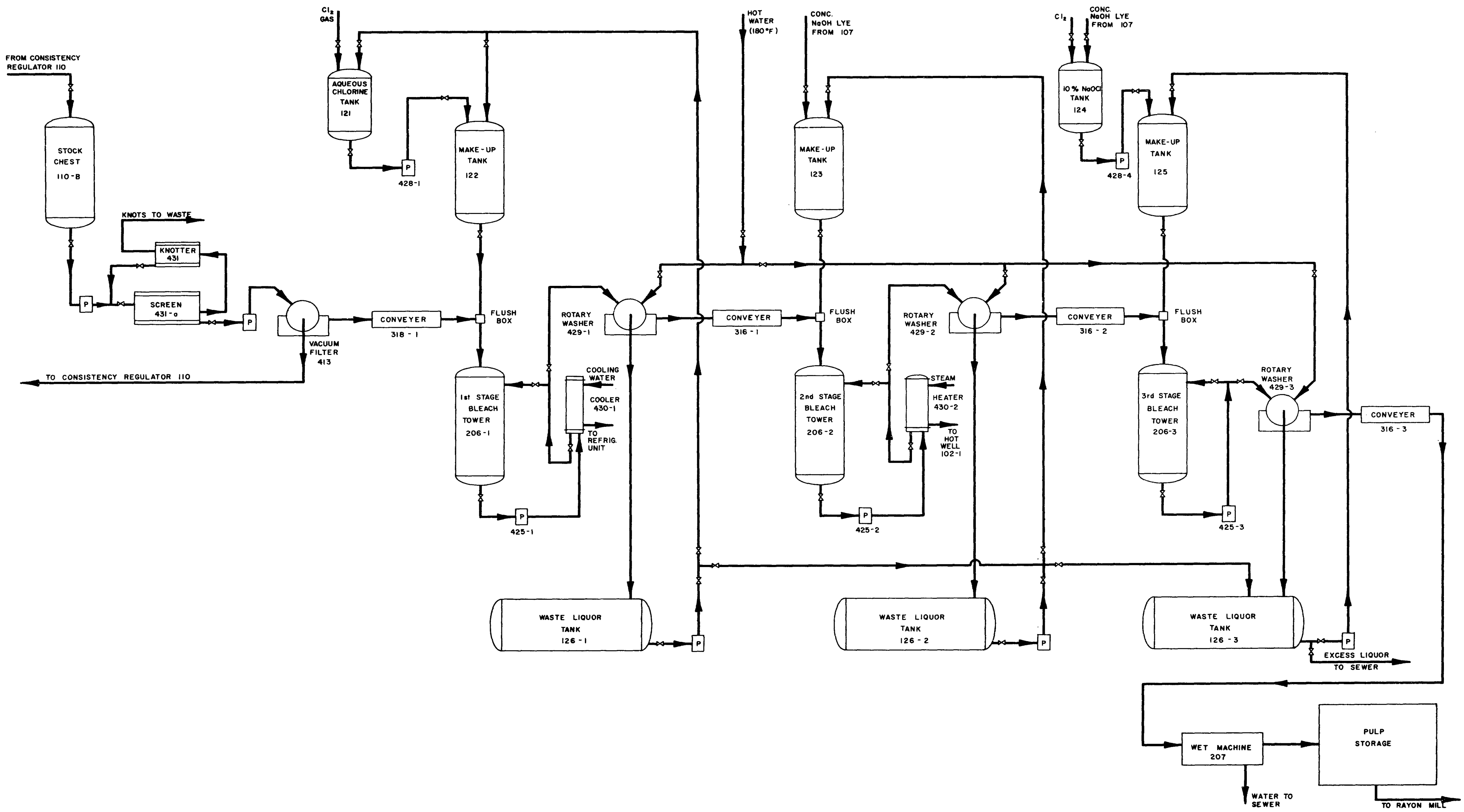


FIG. 3 BLEACHING SECTION

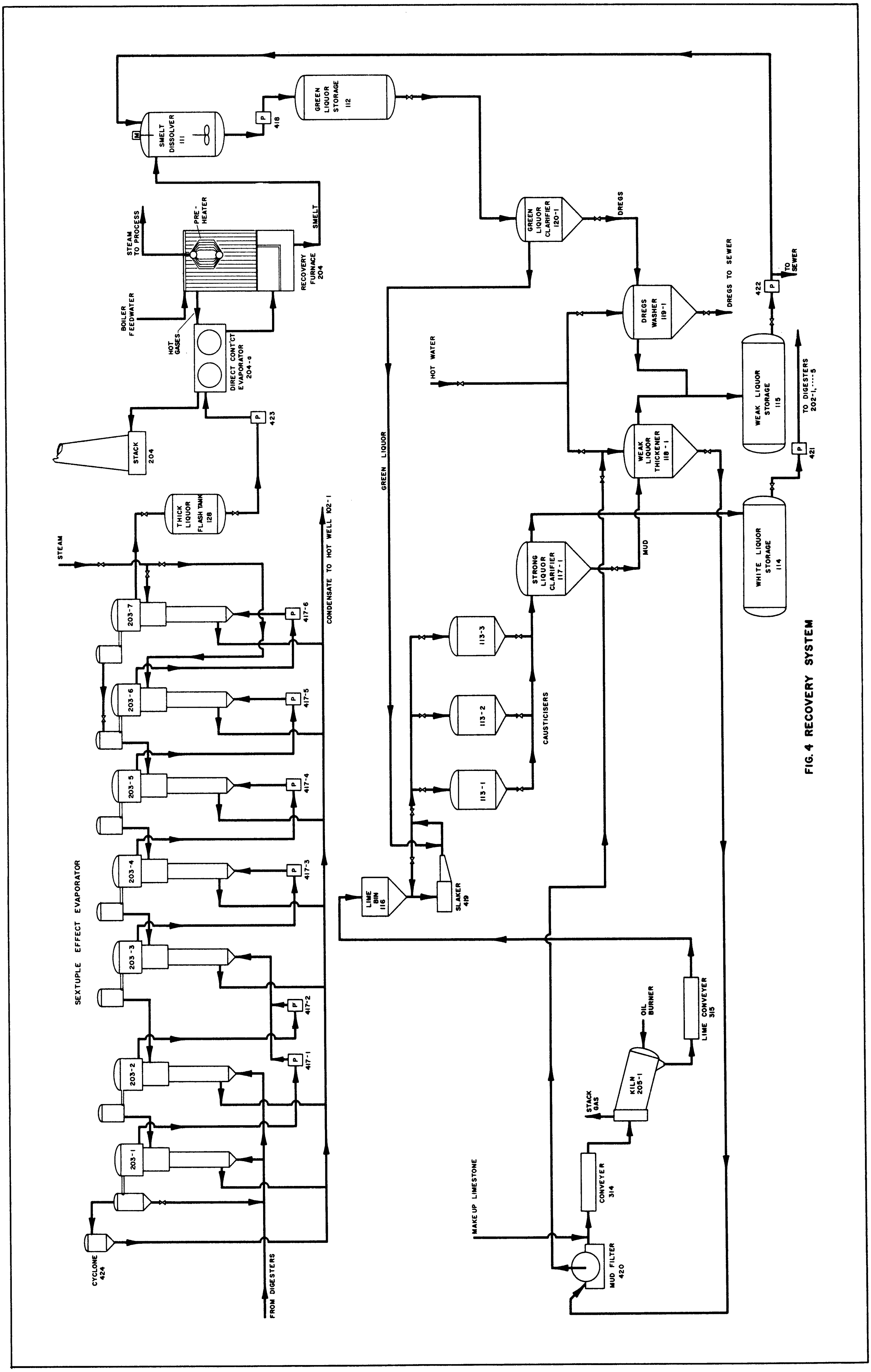


FIG. 4 RECOVERY SYSTEM

III. MATERIAL AND HEAT BALANCES

A. Material Balance

Processing Stage	Material		Weight %	Tons/day
Chipping	Bamboos			
	Cellulose		46.2	75.3
	Lignin		23.4	38.0
	Pentoses		17.6	28.6
	Ash		2.8	4.6
	Water		10.0	16.2
		Total	100.0	162.8
	Fines			
	Cellulose		46.2	3.8
	Lignin		23.4	1.9
	Pentoses		17.6	1.4
	Ash		2.8	0.2
	Water		10.0	0.8
		Total	100.0	8.1
	Chips			
	Cellulose		46.2	71.5
	Lignin		23.4	36.1
	Pentoses		17.6	27.2
	Ash		2.8	4.4
	Water		10.0	15.5
		Total	100.0	154.7
Hydrolysis	Dil. H_2SO_4 solution			
	H_2SO_4 (100%)		7.08	8.9
	Water		92.92	128.2
		Total	100.00	137.1
	Process Water		100.00	417.6

Processing Stage	Material	Weight %	Tons/day
Hydrolysis	Hydrolyzing liquor		
	Water	95.64	545.8
	H_2SO_4 (dil.)	1.56	8.9
	Cellulose	0.00	0.0
	Lignin	0.00	0.0
	Pentoses	2.44	13.9
	Ash	0.36	2.1
	Total	100.00	570.7
	Hydrolyzed Chips		
	Cellulose	51.5	71.5
	Lignin	26.0	36.1
	Pentoses	9.7	13.3
	Ash	1.7	2.3
	Moisture	11.1	15.5
	Total	100.0	138.7
Digestion and Chemical Recovery	Makeup 30.7% NaOH solution		
	NaOH	30.7	4.73
	Water	69.3	10.70
	Total	100.0	15.43
	Makeup salt cake (Na_2SO_4, 10 H_2O)	100	7.65
	Makeup limestone to kiln	100	11.8
	Water to the system	100	2372.0
	Steam to evaporator	100	188
	Air to furnace	100	300
	Weak liquor from recovery		
	Water	98.95	1153.5
	Na2S + Na_2SO_4, 10 H_2O	0.65	7.6
	NaOH	0.4	4.73
	Total	100.0	1165.83

Processing Stage	Material		Weight %	Tons/day
Digestion and Chemical Recovery	Material lost as hot gases			
	Vapors		27	110
	Air		73	300
		Total	100	410
	Steam condensate			
	From relief vapors		13	146.5
	From evaporators		87	942.0
		Total	100	1088.5
	Causticising mud			
	Water		78	40.0
	Insolubles		4	2.2
	$CaCO_3$		18	11.8
		Total	100	53.0
	Pulp			
	Cellulose		15.15	48.45
	Lignin		0.07	0.21
	Pentoses		0.78	2.55
	Ash		0.002	0.07
	Water		84.000	270.00
			100.000	321.28
Screening	Knots			
	Cellulose		15.15	1.00
	Lignin		0.07	0.004
	Pentoses		0.78	0.040
	Ash		0.002	0.000
	Water		84.000	5.56
		Total	100.000	6.60
	Screened pulp			
	Cellulose		15.15	47.45
	Lignin		0.07	0.21
	Pentoses		0.78	2.51
	Ash		0.002	0.07
	Water		84.000	264.44
		Total	100.000	314.68

Processing Stage	Material		Weight %	Tons/day
Screening	Chlorine gas		100.00	1.45
	NaOH		100.00	2.03
	NaOCl		100.00	0.95
Bleaching and Wet-machine	Wash water		100.00	1317.00
	Waste water			
	Water		99.71	1548.11
	Cl_2			1.45
	NaOH		0.29	2.03
	NaOCl			0.95
	Lignin, etc.			0.24
		Total	100.00	1552.78
	Pulp			
	Cellulose		56.95	47.45
	Lignin		0.13	0.11
	Pentoses		2.84	2.37
	Ash		0.08	0.07
	Water		40.00	33.33
		Total	100.00	83.33

B. Heat Balance

	Nature of Heat Load	Btu of Heat Consumed per Day	Btu of Heat Recovered per Day	Btu of Net Heat Load per Day	Btu of Net Heat Load per Ton of Pulp	Lbs of Steam Consumed per Ton of Pulp
Hydrolysis	Hydrolyser:					
	starting load	20.95×10^7				
	continuous load	1.44×10^7				
	heat recovered from exit liquors		13.3×10^7	9.09×10^7	18.18×10^7	1818
Digestion and Recovery	1st digester:					
	starting load	16.561×10^7				
	continuous load	2.19×10^7				
	blow heat		6.08×10^7			
	heat recovered from discharge liquor		3.50×10^7			
	sensible heat of pulp by lowering temp. to 180° F.		0.291×10^7			
	water heating load	8.78×10^7		17.460×10^7	34.92×10^5	3492
	2nd digester:					
	starting load	19.951×10^7				
	continuous load	2.358×10^7				
	blow heat		12.410×10^7			
	heat recovered from discharge liquor		2.68×10^7	16.808×10^7	33.616×10^5	3361.6
	sensible heat of cooling pulp to 180° F		0.191×10^7			
	water heating load	8.78×10^7				
Recovery	Evaporator					
	continuous	37.6×10^7		37.6×10^7	75.2×10^5	7520
Bleaching 2nd Stage	Heat required to heat liquor to 104° C	2.36×10		2.36×10	4.72×10	472
					Total	16663.6

Cooling

Nature of Load		Btu of Heat to be Removed per Day	Tons of Refrigeration Required per Day
Bleaching 1st Stage	Retention tower: Heat removed in cooling liquor	$3.54 x 10^7$	123 tons

C. Summary of Raw Materials and Utility Requirements

No.	Material	Consumption per ton of dry dissolved pulp	Consumption for 50 tons per day production of dry pulp
1.	Bamboo	3.256 tons	162.8 tons
2.	Sulfuric Acid (100%)	0.1416 ton	7.08 tons
3.	Caustic Soda	0.135 ton	6.76 tons
4.	Salt cake ($Na_2SO_4 \cdot 10\ H_2O$)	0.153 ton	7.65 tons
5.	Limestone	0.235 ton	11.80 tons
6.	Chlorine gas	0.029 ton	1.45 tons
7.	NaOCl	0.0189 ton	0.95 ton
8.	Water	20,400 U.S.G.	4240.30 tons
9.	Steam	16,663 lbs	416.5 tons
10.	Power	400 KWH	20,000 KWH

IV. PRELIMINARY ECONOMIC STUDY

A. Item List and Cost of Equipment

Item No.	Equipment	Unit Capacity	Number Required	Approximate Cost in Dollars	Material of Construction	Remarks
101	H_2SO_4 (98%) storage tank	8,000 U.S.G.	1	2,500	steel 308	
102	Presurge tank	10,000 U.S.G.	1	3,000	steel	
103	H_2SO_4 makeup tank	4,000 U.S.G.	1	3,200	lead-lined steel	
104	Chips storage silos	32,000 cu ft	1	17,000	steel	
105	Liquor storage tank	8,000 U.S.G.	1	2,500	steel	
106	Blow tank with agitators (410)	3,000 cu ft	5	65,000	stainless-clad steel	
107	Dissolving tank	5,000 U.S.G.	1	2,000	steel	
107A	Storage tank for NaOH	6,000 U.S.G.	5	26,000	steel	
108	Alk. liquor storage tank	2,500 U.S.G.	10	48,000	steel	
109	Black liquor storage	25,000 U.S.G.	5	24,000	steel	
110	Consistency regulator	1,000 U.S.G.	2	1,700	steel	
111	Smelt dissolver	16,000 U.S.G.	1	3,500	steel	
112	Green liquor storage tank	16,000 U.S.G.	1	3,500	steel	
113	Causticizers	1,000 U.S.G.	3	2,400	steel	
114	White liquor storage tank	15,000 U.S.G.	1	3,300	steel	
115	Weak liquor storage tank	15,000 U.S.G.	1	3,300	steel	
116	Lime bin	1,000 U.S.G.	1	850	steel	
117	Strong liquor clarifier	25' diam.	1	9,600		
118	Weak liquor thickener	30' diam.	1	11,500		
119	Dreg washer	1,000 U.S.G.	1	2,500	steel	cost of agitated vessels
120	Green liquor clarifier	16,000 U.S.G.	1	8,000	steel	
121	Dilute chlorine tanks	12,500 U.S.G.	2	26,000	stainless-clad steel	
122	Chlorine makeup tank	1,000 U.S.G.	1	3,000	type 304 stainless	
123	Dilute caustic liquor tank	12,500 U.S.G.	2	9,600	steel	
124	NaOCl preparation tank	1,000 U.S.G.	1	3,000	type 304 stainless	
125	Dilute NaOCl makeup tank	20,000 U.S.G.	1	12,000	stainless-clad steel	
126	Waste liquor storage tank	4,000 U.S.G.	6	28,800	steel	
201	Hydrolyzers	3,000 cu ft	2	34,000	stainless-clad steel	
202	Digesters	5,200 cu ft	5	125,000	stainless-clad steel	
203	Evaporators, falling film and vertical tube type	3,000 sq ft heating surface each	7	25,000	steel	
204	Recovery furnace (tubular)	20×10^6 Btu/hr	1	40,000	steel tubes	
205	Lime kiln (rotary)	300 sq ft peripheral area	1	20,000	steel	
206-1	Bleaching tower	50,000 U.S.G.	1	20,000	stainless-clad steel	
206-2	Bleaching tower	15,000 U.S.G.	1	9,500	stainless-clad steel	
206-3	Bleaching tower	30,000 U.S.G.	1	16,000	stainless-clad steel	
207	Wet-machine	16,000 lbs of H_2O	1	50,000		cost is assumed
			Total	$ 604,250		

Item No.	Equipment	Capacity	Number Required	Approximate Cost in Dollars	Material of Construction	Remarks
		Total of previous sheet		604,250		
301-316 except 303, 305, and 317	Conveyors of different types	{Equivalent of 700 ft of screw conveyor of 9" diam.}		39,200	steel	
303	Crusher and chipper	50 H.P.	1	8,000		
305	Chips-screen	200 sq ft surface area, 445 H.P.	2	2,000		
317	Pulp screen	400 sq ft surface area, 27 H.P.	1	5,000		
401-428 except 408, 410, 411, 412, 413, 414, 419, 420, and 424	Pumps, centrifugal					
	(1) steel	Avg. 10 H.P.	40	48,000	steel	
	(2) stainless steel	Avg. 10 H.P.	22	110,000	stainless steel	
408	Hydrolyzer heaters	480 sq ft	2	14,600	steel-shell and stainless steel tubes	
411	Digester heaters	3000 sq ft	5	110,000	steel-shell and stainless steel tubes	
412	Blow-off condenser	500 sq ft	5	10,000	steel	
413	Vacuum filter	12'diam. x 8' width	1	3,000	screen of monel	
414	Rotary vacuum washer	12'diam. x 8' width	3	9,000	screen of monel	
419	Lime slaker	6 tons/hr of lime	1	5,000	steel	
420	Mud-filter	12'diam. x 5' width	1	3,000	screen of monel	
424	Cyclone-vapor separator	15' diam.	1	1,500	steel	
429	Bleach pulp washer	12'diam. x 12' width	3	12,000	screen of monel	
430	Bleach heaters	500 sq ft	2	15,000	steel-shell and stainless steel tubes	
431	Screened pulp rotary thickener	12'diam. x 8' width	1	4,000	screen of monel	
501	Boiler (tubular)	17,000 lb/hr steam	2	102,000		three dollars per lb/hr of steam
502	Water processing station	353,000 lb/hr		86,000		
503	Bamboo storage yard including handling equipment			5,000		
			Total	$ 1,196,550		

The total equipment cost on the basis of 400 E.N.R. index = 1,196,550 dollars

∴ Cost of process equipment including foundation supports and installation = 1.715×10^6 dollars

B. Summary of Preliminary Estimates on Capital Cost

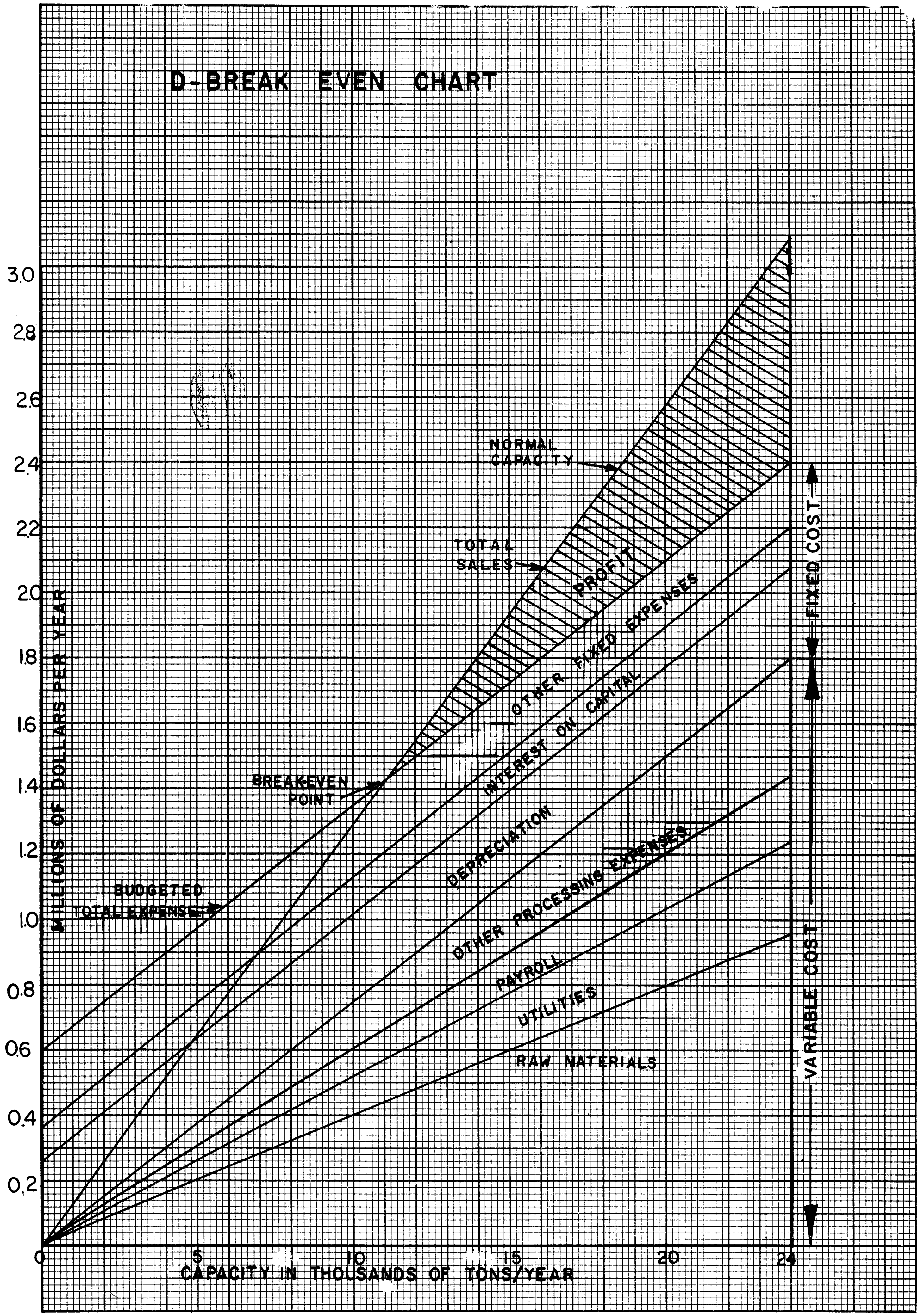
	Items of Expenditure	Estimated Cost[1] in $
A	Yard maintenance and improvements	83,660
B	Buildings including services	334,640
C	Process equipment	1,715,030
D	Piping	418,300
E	Electrical installations	167,320
F	Service facilities	418,300
G	Contingency	472,000
H	Insurance premium and taxes	245,200
I	Field office expenses including temporary construction and central office expenses including overhead	328,550
	Total cost	$ 4,183,000

[1]Cost figures are based on a construction cost index of 400 as compiled by Engineering News Record.

C. Summary of Annual Cost of Operation

Annual capacity: 17,250 tons of dissolving pulp

Items of Expenditure	Estimated cost in $	
Interest on fixed capital investment	125,490	
Interest on working capital	25,098	
State taxes and local taxes	83,660	
Insurance, fire, explosion	41,830	
Depreciation	245,000	
Royalties	11,380	
Research and development costs	68,880	
	601,338	
Total Fixed Expenses		601,338
Raw materials	690,000	
Operating, or direct, labor	120,800	
Supervisory labor & clerical help	12,080	
Repairs and maintenance	125,490	
Operating supplies	31,500	
Payroll overhead	19,500	
Utilities and power	195,500	
Distribution costs, contingency etc.	125,490	
	1,310,360	
Total Variable Expenses		1,310,360
Manufacturing cost for the annual production of 50 x 365 = 17,250 tons of dry dissolving pulp		$ 1,911,698



D-BREAK EVEN CHART
MILLIONS OF DOLLARS PER YEAR
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
5
10
15
20
24
CAPACITY IN THOUSANDS OF TONS/YEAR
NORMAL CAPACITY
TOTAL SALES
PROFIT
OTHER FIXED EXPENSES
INTEREST ON CAPITAL
DEPRECIATION
OTHER PROCESSING EXPENSES
PAYROLL
UTILITIES
RAW MATERIALS
BREAKEVEN POINT
BUDGETED TOTAL EXPENSE
FIXED COST
VARIABLE COST

E. Study of the Economics of the Process

The adjoining tables and break-even chart indicate the following:

1. The cost of raw materials is 36% of the cost of production.

2. The break-even point is at 11,200 tons/year, indicating that unless the operational cost is reduced considerably, the economies of the 50 tons/day pulp plant are very delicate.

3. The estimates on which this chart is based should be made on more precise data.

4. A rigorous study for a better control of raw material consumption, especially of expensive chemicals, should be made.

5. The loss of alkali from black liquor should be reduced to a bare minimum.

6. A study should be made of whether the recovery of lignins from alkaline liquor would more than offset the cost of alkali lost in neutralization and thus contribute towards reduction in operational cost.

7. Maintenance and utility requirements form the next largest bulk of operational cost. A study of liquor ratios and dilution factors should be made to bring them to optimum. This would in all probability reduce the materials handled and hence the capacities of equipment. This, in turn, would reduce the maintenance cost and utility requirements.

V. RECOMMENDATIONS AND CONCLUSIONS

A. Suggestions for Further Development

For a rigorous economic consideration of the feasibility of manufacturing dissolving pulp from bamboos, it is necessary to know the process variables more precisely. The following recommendations briefly outline the areas of the unknowns and desired development.

1. Study of the dependence of chip size on (a) cellulose, degree of polymerization, (b) reactivity, and (c) pulp.

2. Determination of the rate of change of pentosans, ash and degree of polymerization, for pressures varying from 14.7 psia to 50 psia, in the temperature range of 80° C to 120° C, using dil. H_2SO_4 and dil. HCl of different concentrations up to 30 gpl as hydrolyzing agents.

3. A study should be made of the kinetics of lignin removal during digestion of prehydrolyzed bamboo chips using sulphate liquors with varying concentrations of NaOH and Na_2S at temperatures varying from 100° C to 170° C under pressures from 14.7 to 115 psia, and using different liquor-to-chip ratios.

4. An investigation of the feasibility of a continuous bleaching system.

5. Lignin could be recovered as sodium lignates by mild acid treatment or by carbonating the liquor with flue-gases. This possibility should be explored and on the basis of experimental study, its industrial application should be evaluated.

6. Quantitative study of recovering yeast from the spent hydrolysis liquor should be made.

7. The effect of the degree of polymerization distribution in pulp on rayon yarn should also be studied.

B. Conclusions

1. It is economically feasible to manufacture dissolving pulp from bamboos.

2. A 50 tons/day capacity plant would cost $4,200,000. One can expect about 10% profit if the selling price is $130 per ton of air dry pulp.

3. More experimental rate data are needed in order to pin down the process variables and estimate the cost accurately.

4. A high break-even point suggests a need for increasing the pulp plant capacity or economically recovering the by-products, lignins and yeast or modification of the process itself.

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