D.C. TAPADAR

PULPING PROCESSES—PRESENT STATUS AND TREND

Pulping processes have been classified according to modern technique, plant equipment and expected yield of pulps. The effect on different components of wood and other raw materials has been examined in detail and scope of further modification to process and equipment has been discussed for wider coverage of both raw materials and products.

INTRODUCTION

Fibrous materials are ground, cooked, digested or delignified, fiberized or refined to pulp for conversion to paper and board. A variety of equipment from a simple but massive grinder or giant sized autoclave to computerized digesters is used for the purpose. The pulping processes involve unit operations such as size reduction, gas absorption, evaporation, extraction, filtration, etc. etc., which are common to many other industries. A thorough knowledge of the anatomy, physics and chemistry of the plant materials, theory and practice involved in fluid-flow and heat transmission, principles of the modynamics, kinetics and colloid chemistry, are essential for complete understanding of the physico-chemical changes that take place in successive stages of treatment and conversion to final products.

PRESENT STATUS OF PULPING

Pulping of wood or any other plant tissue consists essentially in separation of fibres. But, as the fibres are usually held together by strong natural adhesives, mechanical separation between the surfaces of fibres cannot be performed without a considerable damage to the fibres, particularly due to separation or splitting through the walls. The power required for mechanical pulping is 30-75 kw-days/per tonne of air dry pulp, depending on the condition of raw material and the fineness of the resulting pulp. The consumption of mechanical energy can be considerably reduced if the adhesive forces or agent are weakened, reduced or removed by heating or application of suitable chemicals. Complete isolation of fibres can be accomplished only by dissolving the lignin which constitute the principal natural adhesive, under carefully controlled conditions of concentration of chemicals, temperature, pressure and duration of treatment. The consumption of mechanical energy in such cases is limited to size reduction of materials such as chipping, transport of material and chemical during operations, and mechanical separation incidental to the process. One tonne of air dry pulp would require 10-15 Kw-days by soda and sulphate processes, and 15-20 kw-days by sulphite process. A combination of mechanical and chemical treatment as used in semi-chemical pulping processes, can produce pulps of varying degrees of fineness and quality resulting out of a mixture of whole fibres, fibre bundles and fragmented fibres. The modern pulping processes can be classified as shown in Table I.

Prior to pulping processes, wood requires debarking, splitting and cutting into suitable sizes. Mechanical pulping consists in grinding logs of wood by pressing against grind-stone under a shower of water. There is no chemical reaction involved in the process excepting that the water soluble components are lost in the process of grinding and screening. But it is now an accepted fact that the lignin and hemicelluloses get softened to certain extent due to rise of temperature on the face of the grind-stone to the extent of 170 to 190° C.

The advantage of heating and partial melting of the lignin materials is the basis of Masonite process in which the wood is steam-heated to a very high pressure (upto 80 atmospheres) and then suddenly released to atmospheric pressure whereby the wood material explodes to fibres. There are several other processes like Asplund defibrator and Sprout-Waldron, in which wood chips are subjected to temperatures upto 200°C so as to soften the lignin and then reduced to pulp by mechanical grinding or refining between rotating disks.

There are several chemical processes of separation of fibres by removal of lignin. The unit operations and processes involved in the manufacture of chemical pulp may be broadly listed as follows:—

OPERATION I.

Slashed and debarked logs are chipped on rotating chippers to pieces about 2 cm. long and 3 mm. thick.

OP.II.

Chips are screened to exclude fines and oversized pieces and conveyed to chip bin.

OP. III.

Chips are fed into digester, either stationary or rotary, made of suitable materials to withstand chemicals, temperature and pressure used.

DR. D.C. Tapadar Principal
Institute of Paper Technology Saharanpur

*Paper presented at the symposium at F.R.I., Dehradun by the Society of Indian Foreste r June 8-10, 1972.

PROCESS I.

Cooking chemicals added in solution and steam turned on.

PROC. II.

Temperature and pressure raised to the maximum as scheduled and digestion continued till the delignification has proceeded to the desired extent.

OP. IV.

Pressure reduced and content blown off into blow pits or diffusers.

OP. V.

Spent liquor separated from pulp either in blow pit or on washer where the pulp is washed with water free from spent liquor.

OP. VI.

Washed pulp screened to remove uncooked pieces and shives.

OP. VII. and PROC. III.

Spent liquor taken to recovery plant where it is concentrated and burned, cooking chemicals recovered and returned to digesters, and the heat produced is used for fresh cooking and concentration of more spent liquor.

PROC. IV. Screened pulp bleached.

OP. VIII.

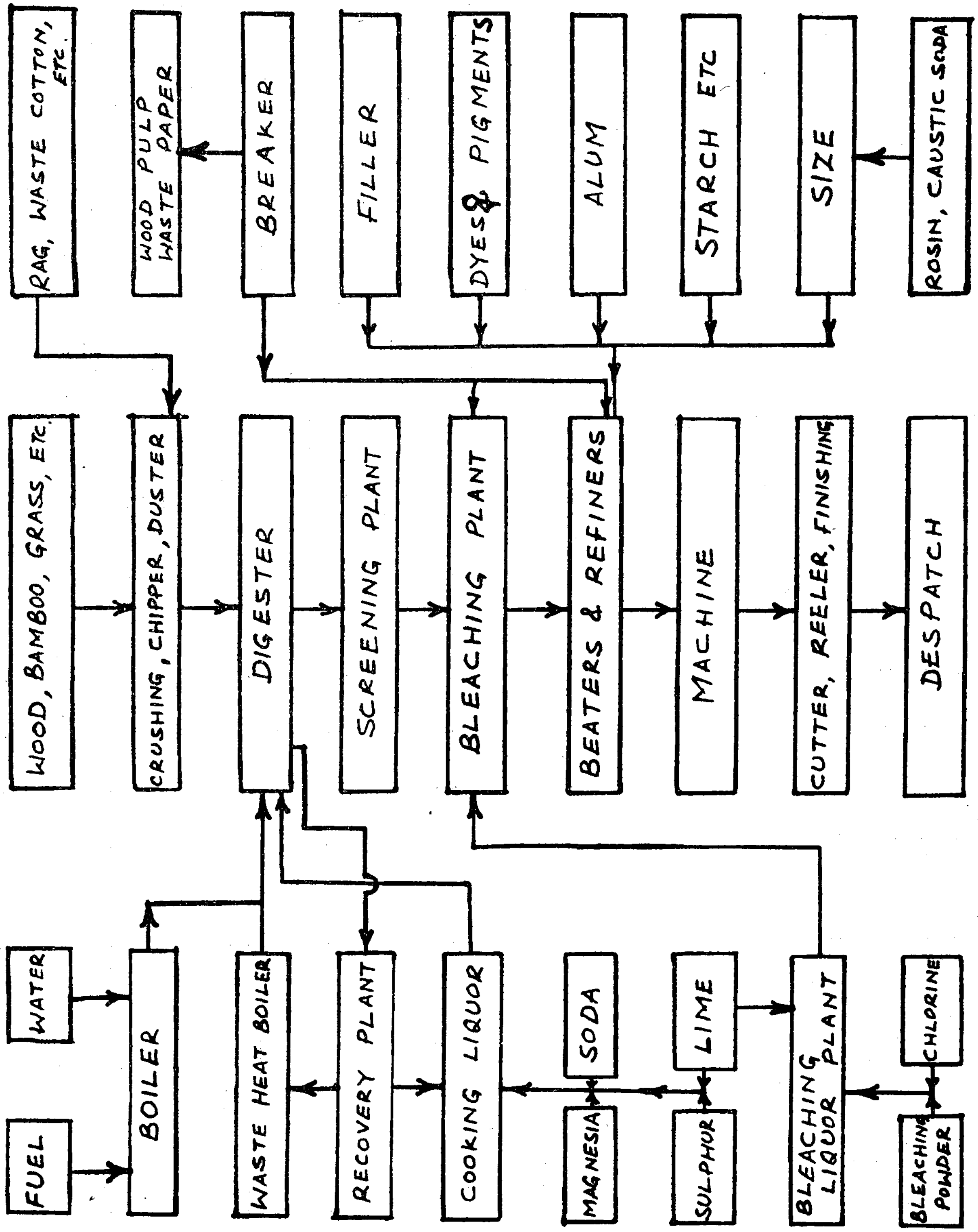
Bleached pulp thickened and made into laps and dry sheets or sent to stock preparation plant for conver-

TABLE I

CLASSIFICATION OF PULPING PROCESSES. (Ref. 1)

Category	Pulping Process	Chemical Treatment	Mechanical Treatment	Pulp Yield %Unbleached
Mechanical				
Bolts.	Groundwood, cold	None	Grinder	93-98
,,	Hot	,,	,,	93-98
Chips	Bauerite, Sprout-Waldron	None or bleach	Refiner	93-98
,,	Isogrand	,, ,,	Defibrator	93-98
,,	Asplund	Steam	Defibrator	92-95
,,	Mason	,,	Steam expansion	80-90
Semichemical				
Bolts.	Groundwood, steamed	Steam	Grinder	80-90
,,	Decker	Acid-sulfite	,,	—
,,	Fish	Kraft	,,	—
,,	Chemigroundwood	Neutral sulfite	,,	80-90
Chips.	Water hydrolysis	Steam	Refiner	70-95
,,	High yield sulfite	Acid sulfite	,,	60-90
,,	High yield bisulfite	Bisulfite	,,	60-90
,,	High yield kraft	Kraft*	,,	55-70
,,	Neutral sulfite, NSSC	Neutral sulfite	,,	65-90
,,	Cold caustic	Alkali	,,	80-90
Straw	Mechanichemical	Alkali or Kraft	Hydrapulper	50-75
Chemical				
One stage	Acid sulfite	Acid sulfite	Opener or none	40-60
,, ,,	Bisulfite	Bisulfite	Opener or none	45-60
,, ,,	Kraft (Sulfate)	Kraft*	None	40-55
,, ,,	Soda	Alkali	None	40-55
,, ,,	Nitric acid (Delbay etc.)	Nitric acid	None	40-60
,, ,,	Organo-solvent (dioxane, alcohols)	Acid in solvent	None	40-60
,, ,,	Hydrotropic	Hydrotropic	None	40-60
Multistage	Neutral sulfite Acid sulfite	Neutral & Sulfite	Opener	50-65
,,	Bisulfite-acid sulfite	Bisulfite & acid sulfite	Opener	40-60
,,	Neutral sulfite bisulfite	Neutral & bisulfite	Opener	50-65
,,	Bisulfite-carbonate	Bisulfite-carbonate	Opener	40-50
,,	Acid sulfite-carbonate	Acid sulfite-carbonate	Opener	30-45
,,	Acid-sulfite-Kraft	Acid sulfite-kraft	Opener	30-45
,,	Prehydrolysis kraft	Acid or water & Kraft	Opener	30-45
,,	Carbonate kraft	Green liquor & Kraft	Opener	40-55
Multistage (Straw)	Celdecor (Pomilio)	Alkali & chlorine	Opener	35-45

*Sodium hydroxide and sulfide.



FLOW SHEET FOR THE MANUFACTURE OF PAPER

sion to paper, board etc.

There are semi-chemical and chemi-mechanical processes where advantage is taken of the action of chemicals for softening and partial removal of lignin and the separation of fibres is completed by further mechanical treatment such as refining with disc refiners.

The flow sheet of pulp and paper manufacture is different for each process. A simplified flow diagram has been prepared to show the principal operations and reactions which are applicable to most of the processes. (Flow sheet).

ANALYSIS OF RAW MATERIALS

Plant constituents can be conveniently classified tino four groups; cellulose, lignin, hemicelluloses and extraneous matters including inorganic residues.

Cellulose is a carbohydrate containing 44.44% carbon, 6.22% hydrogen and 49.34% oxygen. It is built up from a hexose sugar, glucose, arranged end to end in a particular fashion resulting in long chains lying parallel to one another. The number of glucose units in cellulose may be 1000 or more, but commercial pulps may have as low as 100 to 200 units equivalent to a molecular weight of 16,000 to 32,000.

Hemicelluloses are also essentially carbohydrates but are built of many other sugars besides glucose. These are amorphous and do not form into chains like cellulose The number of building units (called Degree of Polymerisation or D.P) varies between 120 and 180 in plant tissues and considerable less in commercial pulps. Hemicelluloses are characterised by inclusion of a high percentage of pentose sugars and their presence in the raw materials as well as in chemical pulps is often designated by pentosans, meaning, carbohydrates which when hydrolized yield pentose sugars.

The total amount of carbohydrate residue covering both cellulose and hemicelluloses is often called holocellulose which is determined by the removal of extractives soluble in cold water and neutral organic

TABLE II

COMPOSITION AND FIBRE DIMENSION OF SOME TYPICAL RAW MATERIALS AVAILABLE IN INDIA

	COMPOSITION			FIBRE DIMENSION		
	Lignin %	Hemicellulose %	Cross & Bevan cellulose %	Ave. Length mm.	Ave. Diam. Micron	Reference
Seedfibre						
Cotton (Gossypium hirsutum)	—	2.0	92–97	18	20	2
Bastfibre						
Hemp. (Cannabis sativa)	5.2	5.5	79.3	22	30	2
Jute						
(Corchorus capsularis & olitarius)	11.7	18.1	74.9	2.0	22	2
Softwood						
Chir (Pinus longifolia)	28.6	7.2	53.5	3.60	52	3
Sikkim Spruce (Picea spimlosa)	28.6	12.3	79.7	2.82	27	3
Fir (Abies spectabilis)	29.2	9.7	59.7	2.66	28	3
Hardwood						
Rubberwood (Heavea brasiliensis)	20.5	14.3	71.3	1.12	21	4
Salai (Boswellia serrata)	27.3	13.0	50.7	0.88	24	3
Mysore gum (Eucalyptus hybrid)	24.7	14.1	50.6	0.73	12	5
Grass & Reeds						
Salai grass (Euliopsis binata)	22.0	23.9	54.5	2.08	9	3
Kana (Saccharum munj)	20.5	23.7	58.2	2.06	15	3
Salai Bamboo (Dendrocalamus strictus)	27.8	15.1	59.9	1.65	12	6
Dava Bamboo (Bambusa arundinacea)	30.0	19.6	57.6	2.73	..	3
Agicultural Residue						
Bagasse (Saccharum officinarum)	21.0	26.6	54.9	1.38	18	7
Rice straw (Oryza sativa)	25.5	21.0	53.5	1.13	16	7
Wheat Straw (Triticum sativum)	21.5	23.5	51.5	1.10	12	7
Jute sticks (Corchorus capsularis etc.)	21.4	18.8	57.6	0.79	29	7

solvents, followed by careful removal of lignin by alternate treatment of the residue with cholorine and alcoholic ethanolamine. Holocellulose can be freed from hemicelluloses by treatment with strong caustic alkali, the residue being called Alpha cellulose.

The plant tissues are often evaluated by determining the cellulosic residue obtained by treating alternately with chlorine and sodium sulphite, a process originally suggested by Cross and Bevan. The fibrous residue contains a high percetage of hemi-celluloses and is called Cross and Bevan cellulose to differentiate it from holo-cellulose, alpha cellulose and hemicelluloses. Although some of the extraneous matters may play an important part in the choice of raw materials and process of pulping and also the quality of product, the cellulose, hemicelluloses and lignin are the major factors. The plant constituents and fiber dimensions are the primary considerations for the choice of the raw material for a particular quality of pulp, provided of course the raw material in question is available in adequate quantities and at economic prices. While the composition and fiber dimension vary widely from species to species and even between plants of the same species growing in different localities, the table attached (Table II) may be used as a guide for selection of raw materials.

The analysis of some typical woods of North American and Scandinavian countries and of two cereal straws are given in Table III for comparison. The spectrum of hemicelluloses and their variation from plant to plant deserve careful study. The differences in major carbohydrate polymer components of hardwood and softwood hemicelluloses may be summarised as follows.

TABLE III

CHEMICAL COMPOSITION OF SOME NORTH AMERICAN WOOD AND SCANDINAVIAN WOOD AND CEREAL STRAWS ALL ON EXTRACTIVE FREE BASIS

	Ash %	Lig-nin %	Acet-yl. %	Uro-nic %	Glu-can %	Gal-actan %	Man-nan %	Ara-bian %	Xy-lan %	Cellu-lose %	Non cellu-losic gluan.	Glu-co man-nan (ace-tate)	Arabi no gala ctan.	4.0 meth-yl. glucu rone (ara-bian Xy-lan (ace-tate)	Cell-ulose %	hemi cel-lulo-se %	lig-nin %	Re-fere-nce
NORTH AMERICAN WOOD																		
White spruce (Picea glauca)	0.3	27.1	1.3	3.6	46.5	1.2	11.6	1.6	6.8	44	0	17	2	10	44	29	27	8
Jackpine (Pinus banksiana)	0.2	28.6	1.2	3.9	45.6	1.4	10.6	1.4	7.1	41.6	0	16	2	12	41	30	29	8
White Birch (Betula papyrifera)	0.2	18.9	4.4	4.6	44.7	0.6	1.5	0.5	24.6	41	2	3	1	34	41	40	19	8
SCANDINAVIAN WOOD																		
Spruce (Picea abies)	0.4	28.6	1.4	2.5	44.3	1.9	10.3	0.5	7.6	43	0	15	2	10	43	27	29	1
Pine (Pinus sylvesteres)	0.4	27.8	1.6	2.4	44.8	1.3	7.6	0.6	7.2	44	0	14	2	10	44	26	29	1
Birch (Betula-verrucosa)	0.3	19.5	4.8	5.9	37.5	1.0	0.5	0.5	24.6	40	0	1	1	37	40	29	21	1
CEREAL STRAWS																		
Corn stalks. (Zea mays)	1.2	14.0	4.6	5.6	47.6	1.0	0	2.8	23.3	43	5	0	1	36	43	43	12	9
Wheat straws (Triti-cum sativrm)	1.6	22.0	2.9	2.7	44.8	0.9	0	2.0	22.6	42	4	0	1	30	42	36	22	9

TABLE IV

Polymer	Relative amount Softwood	Present Hardwood	Reference
4.4 Methyl glucurono xylan (acetate)	Small or none	Very large	10 &
4.0 Methyl glucuronoarabino-zylan.	Medium	Trade	11
Glucomannan	Nil	Small	—
Galactoglucomannan (acetate)	Very large	Nil	—
Arabino-galactan	Large for Larch	Nil	—

EFFECT OF PULPING ON PLANT CONSTITUENTS

As mentioned earlier, losses involved in seperation of fibres are the least in mechanical pulping, increase gradually with increase in delignification by chemicals, reaching the maximum in prehydrolysis sulphate pulping where the fibres are freed from hemicelluloses and lignin. Further chemical treatment done for removing residual colouring matters completes the process of pulping. The physical and chemical changes brought about on plant tissues in course of pulping, are wide and various depending on the particular process of pulping and the extent of delignification. The length, strength, surface characteristics and swelling properties of the resulting pulp-fibres largely determine the quality of paper, board, rayons, and other cellulose products derived from the pulp. The removal of lignin and other plant constituents by different processes usually follow different patterns even when designed to yield the same quality of pulp. For example, when a typical temperate zone hardwood containing 50% cellulose, 24.5% hemicellulose, 22% lignin and about 3.5% extractives, was subjected to pulping, for 75% yield, the soda, kraft, acid sulphite and neutral sulphite semi-chemical processes produced pulps of different composition as shown in Table V.

The attack on cellulose and hemicelluloses was more pronounced in the case of alkaline cooking than that of sulphite cooking. The removal of lignin was significantly more by sulphite cooking while the attack on extractives was considerably less. The attack on the carbohydrate components of hemicelluloses is not uniform either. The extent of attack on a particular fraction may be dependent on its degree of polymerisation, manner of combination with other carbohydrates as well as lignin compound, and the type and concentration of the chemical employed in cooking. Some hemicelluloses are supposed to go into solution in the initial stages of cooking and redeposit on the fibre later on in a modified form. Cellulose itself undergoes considerable degradation. The changes in different carbohydrate components of the same wood subjected to pulping by different processes are illustrated in Table VI.

Calculated on the basis of 65% retained as holocelluloses obtained by Chlorine dioxide treatment, the acid and bisulfite pulping entailed a loss of 18 and 19%, equivalent to 47 and 46% on the original components. The prehydrolysis sulphate process, which is designed to remove the maximum amount of non-cellulosic components, retained 35% of carbohydrates present in the wood, out of which 34% equivalent to 97% of the residue, was actual cellulose, the remainder being xylan. Rahmnose and galacturonic acid fractions were totally absent in the pulps, whereas the effect on mannose, arabinose and xylose varied considerably.

Results of cooking two entirely different types of wood with the same chemicals are equally revealing (Table VII). The retention of xylose in hardwood pulp and mannose in softwood pulp is important from the view point of yield and beating characteristics, so important for stock preparation before conversion to paper.

TABLE V
ANALYSIS OF PULPS OF SAME YIELD

Process	Yield	Cellulose	Hemicellulose	Lignin	Extractives
Soda	75	46	10	17.5	1.5
Kraft	75	46.5	12	15	1.5
Acid sulphite	75	47.5	15.5	9.5	2.5
ASSC	75	47.5	14.5	11.0	2.5

SCOPE OF FURTHER MODIFICATION OF PULPING TECHNIQUE

While appreciating the differences in the quality of pulps obtained by various pulping processes one might wonder whether standard procedures could be evolved so as to produce standard pulps from a raw material by adopting any method available in a mill. It is generally agreed that hardwoods of one type or other or of mixed varieties will be the most dependable raw material in near future, and also that effort will have to be made to obtain the maximum possible yield by suitable modifica-

TABLE VI

A COMPARISON OF THE CARBOHYDRATE CONTENTS OF THE RESIDUES OBTAINED FROM WESTERN HEMLOCK WOOD BY VARIOUS PULPING PROCESSES (Ref. 12)

Process of Pulping	pH of spent liquor	Temp. O°C	Galactose	Mannose	Arabinose	Xylose	Rhamnose	4.0 Methyl g'ucuronic acid	Galacturonic acid	Cellulose	Total Carbohydrate
ACID SULPHITE	1-1.5	130-150									
% in Pulp	—	—	trace	8.1	tace	2.2	0	P	0	87	100
% on orig. wood	—	—	trace	3.8	trace	1.0	0	P	0	41	47
% loss of orig. component		—	100	71	100	68	100	L	100	5	28
BISULPHITE	2.5-4.0	150-170									
% in pulp	—	—	trace	9.8	0	3.2	0	P	0	83	100
% on orig. wood	—	—	trace	4.5	0	1.5	0	P	0	38	46
% loss of orig. component	—	—	100	66	100	5.2	100	2	100	12	29
CONVENTIONAL KRAFT	12-13	160-175									
% in pulp.	—	—	0.6	9.3	0.5	5.7	0	0	0	81	100
% on orig. wood	—	—	0.3	3.9	0.2	2.4	0	0	0	34	42
% loss of orig. component	—	—	90	70	71	23	100	100	100	21	35
MODIFIED KRAFT	10-11	160-175									
% in pulp	—	—	0.6	8.1	0.5	4.7	0	P	0	83	100
% on orig. wood	—	—	0.3	3.4	0.2	2.0	0	P	0	35	42
% loss of orig. component	—	—	90	74	71	35	100	2	100	19	35
PREHYDROLYSIS KRAFT	3-4 12-13	150-180 160-170									
% in Pulp	—	—	trace	1.6	0	1.1	0	0	0	97	100
% on orig. wood	—	—	trace	0.6	0	0.4	0	0	0	34	35
% loss of orig. component	—	—	100	95	100	87	100	100	100	21	46
CIO HOLOCELLULOSE	7-8	25									
% in Pulp	—	—	46	20 3	1.0	4.7	P	P	P	66	100
% on orig. wood	—	—	3.0	13.2	0.7	3.1	P	P	P	43	65

NOTE: The modified Kraft cook was buffered with sodium carbonate to maintain a pH lower than that of a conventional kraft book.
P = Present not quantitative estimate L = Extent of loss not known.

TABLE VII

NEUTRAL SULFITE PULPING OF BIRCH AND SPRUCE (Ref. 13 & 14)

Wood	BIRCH			SPRUCE		
	Wood	**Pulp**	**Losses**	**Wood**	**Pulp**	**Losses**
Yield	—	77.0	—	—	81.0	—
Pentosans	22.5	23.3	20.5	7.5	7.9	19.0
Uronic acids	4.7	2.8	54.0	2.3	1.1	61.0
Lignin	20.0	10.8	58.5	28.0	20.2	41.5
Methoxyl	6.1	4.4	—	4.9	3.5	—
Roe number	—	15.0	—	—	25.0	—
Carbohydrates total	75.5	84.0	—	70.5	75.0	—
POLYSACCHARIDES						
Galactan	1.5	trace	100.0	3.0	trace	100.0
Glucan	59.5	67.5	3.0	66.0	69.0	10.5
Mannan	2.5	1.0	66.0	17.0	19.0	3.0
Araban	2.5	1.0	65.0	1.5	1.0	33.0
Xylan	27.5	27.5	14.0	9.0	9.5	33.0
Rhamnose	0.4	0.0	100.0	0.0	0.0	100.0
Uronic acid	6.1	3.3	—	3.5	1.5	—

tion of existing methods and equipment so as to confirm to high-yield technique. The answer is indicated in Table VIII based on data available for semichemical and chemimechanical pulping by cold soda, kraft and sodium sulphite semichemical processes.

The scheme is flexible to suit the specific requirements of both raw materials and final products. A sulphite mill can adopt NSSC process without any major change or heavy capital investment. Similarly, a groundwood mill using mechanical process can include cold soda pulping with great advantage and at a very reasonable capital investment.

As regards raw materials, use of agricultural residues would be a

TABLE VIII

COOKING CONDITIONS FOR SEMI-CHEMICAL AND CHEMI-MECHANICAL PULPING

	NSSC Board Pulp	Paper Pulp	Kraft SC. Board & Pulper Pulp	Cold soda chem-mechanical Board & Paper Pulp
Pulp yield of wood	70-80	65-72	65-80	85-92
Cooking chemicals				
Sodium sulfite on wood ˉ.	8-14	17-20	—	—
Sodium carbonate or equivalent buffer of wood.	2.5-4	3.5-45	—	—
Sodium hydroxide with/without sodium sulfide of wood as Na20	—	—	5-8	—
Sodium hydrozide of wood	—	—	—	6-10
Chemical requirements				
Sulphur kg/AD' Ton of Pulp	30-35	50-60	—	—
Soda ash kg/AD Ton of pulp	120-150	200-250	—	—
Cooking temperature aC	160-185	170-180	170-180	Room temperature
Time at cooking temp hr.	0.2-4	0.8-6	0.2-1.0	0.3-2.5
Energy for fiberizing and refining (to about 400 ml. freeness) kw. hr./A.D. Ton.	250-350	200-300	250-300	500-800

simple affair in a mill using hardwoods. The possibility of expansion to include manufacture of paper in a board mill and that of board in a paper mill should also be a matter of adjustment. The mills concerned or a new entrepreneur will of course have to arrange for some initial investigation including pilot plant trials before making any change or adopting any new technique.

Paper Presented at the Symposium at F.&.I. Dehradun by the Society of Indian Forester June 8-10, 1972.

REFERENCES

1. Rydholm S.A., Pulping Processes, pp 284, John Wiley & Sons, 1965.
2. Lynch, DEJ, Ind. Eng. Chem. Vol. 31, (1939) pp 149.
3. Singh, Manmohan & Mukherjee V.N., Indian Forester, 91(7) July 1965.
4. Guha SRD, & Negi J.S., Indian Pulp and Paper XXIV(3) Sept 1969.
5. Guha S.R.D, Bhola P.P., Mathur C.M., Sharma Y.K., Indian Forester 92(4) Apr. 1966.
6. Guha S.R.D., Sharma Y.K., Mukerjea V.N., Indian Pulp & Paper XIX(12) June 1965.
7. Guha S.R.D., Sharma Y.K., Yadav A.G., Indian Forester 95(7) July, 1969.
8. Timell, T.E., TAPPI 40(7) 568, July 1957.
9. Timell, T.E., TAPPI 40(9) 749, Sept. 1957.
10. Janes R.L., The Chemistry of Wood & Fiber: Pulp & Paper Manufacture Vol. 1 McGraw-Hill Book Co., New York 1969.
11. Timell T.E., Wood Science and Technology, 1(i): 45 (1967).
12. Clayton D.W., The chemistry of alkaline pulping, Pulp and Paper Manufacture, Vol. 1; McGraw-Hill Book Co. New York 1969.
13. Chidester G.H., Keller E.L., & Sanyer N., Semi-chemical and Chemi-mechanical Pulping, Pulp & Paper Manufacture Vol. 1, McGraw-Hill Book Co., New York, 1969.
14. Bjorkvist, Gustafsson & Jorgensun, Pulp & Paper Magazine Canada 55(2): 68.72 (1954).
15. Mc Govern J.N., Semi-chemical & chemi-mechanical Pulping, Pulp & Paper Science Technology Vol. 1; Graw-Hill Book Co., New York 1962.