High alpha-cellulose pulp from fast growing plant species

C.N. SAIKIA*

ABSTRACT

In recent years, the pulp and paper industry is facing an acute shortage of cellulosic raw materials. It has been predicted that by the turn of this century, there will be a global shortage of pulpable raw materials. This is alsp true in the case of regenerated fiber and other cellulose based industries, as the basic cellulosic raw materials used in these industries are same as that of pulp and paper industry. The article discussess the present availability of raw materials for pulp and paper industry in general and its future demand. That the fast growing plants are emerging as a potential source of alternative fiber raw material and the possibility of their use for production of high alpha-cellulose pulp has been discussed. The experimental work carried out by the author for preparation of high alpha-cellulose pulp and therefrom different cellulose esterified products have been mentioned briefly.

INTRODUCTION :

Fibrous raw materials from forests are used both for producing paper making cellulose and other highly purified cellulose for chemical conversion to a host of cellulose derivatives. About 90 percent of the world's fibre, used in the manufacture of paper and paper products, is derived from forests. The other 10 percent comes from non–wood sources like bagasse, bamboo, cereal straws, leaves and other fibrous annual plants. Many wood species are also used as material for construction and as source for energy, apart from their use as raw materials for paper and cellulose industries. So, the forest based cellulosic raw materials are depleting day by day, causing ecological imbalance.

The worldwide increase in the capacity for production of pulp and paper has necessitated the generation and identification of alternative fibre materials to meet the growing demand of cellulosic raw materials for the pulp and paper industry. The world consumption of paper and paperboard increased from 130 million tons in 1970 to 204 million tons in 1986 and it has been forecasted that a consumption level of 289 million tons will be reached in 2001[1]. To meet this consumption level, vast amount of cellulosic raw material supply has to be mobilised throughout the world. Experts are of the opinion that there will be a global shortage of conventional cellulosic raw materials for pulp, paper and other cellulose based industries by the turn of the century. According to Keays[2] by the year 2000, there will be a world wood supply short fall of 200 million cubic metres for conventional practices. The increased demand for fibre will have to be met by one or more of the following potential sources[3], (a) increased harvest of the world timber supply, (b) Improved production of timber (c) increased yield by better control of pests and catastrophies, (d) increased utilization of forest wastes, (e) increased utilization of waste paper or, (f) increased utilization of non-wood fibrous plants. The greatest potential for increasing world fibre supply rests with the production of non-wood fibrous plants. According to the FAO's pulp and paper capacities survey for 1976-1991, the average annual increase in non-wood plant fibre pulp capacity has consistently been more than double the annual increase for all paper making grade wood pulp capacity for 1980 through 1991[4] as given in Table 1.1,

*Regional Research Laboratory
Jorhat — 785006, Assam

Table—1.1

Data on FAO Pulp And paper Capacity Survey For The Period 1976-1991

(a) Total capacity in million metric tonnes

	1976	1981	1986	1991
Total wood pulp paper grade	129.9	142.1	154.4	165.6
Non-wood fibre pulp	9.7	11.6	13.9	16.5
Non-wood as % of total	6.9	7.5	8.3	9.1

(b) Average Annual increase percent

	1976–81	1981–86	1986-91
Total paper grade wood pulp	1.8	1.7	1.8
Non-wood fibre pulp	3 7	3.7	3.4

With the growth of population, the increase in literacy, the growing trend of professionalism in the work force and the greater economic activities of the society, the consumption of different varieties of paper and paper product would rise in our country, The demand for pulpable cellulosic raw material is increasing day by day. The conventional raw material for pulp and paper are mainly bamboo and soft wood. In view of the limited availability of bamboo and its high cost of plantation and low annual yield, the existing bamboo forests in the country will not be able to meet the entire requirement of cellulosic raw materials for pulp and paper industry[5]. Studies on raw material demand projection for paper, pulp and newsprint show the wide gap between demand and possible resources. The sport fall of pulp wood and bamboo would be 48 lakh and 5 lakh tons respectively towards the end of this century[6].

The Development Council for Paper and Allied Products has estimated that the demand for paper in India, by 2000 AD is likely to be two times the production in 1987 and the per capita consumption of paper will rise from 2 kg in 1987 to 4.5 kg. in 2000 AD. By this time the demand for paper, paper boards and newsprint is expected to be 31.68 and 9.44 lakh tonnes respectively. There will be a growing need for additional sources of raw materials. Table 1.2 indicates the extra raw materials that need to be mobilized to cope with the expected rate of production of paper in the years to follow[7],

TABLE—1.2

Amount of raw material need for the future

(Lakh tonnes)

Year	Raw material available			Demand for paper, paper-board and newsprint	Paper that can be produced	Extra material needed
	Bamboo	wood	Total			
1995	19.0	13.1	32.1	31.61	12.11	19.50
2000	19.0	13.1	32.1	41.12	12.11	29 01

The National Commission on Agricultcure (NCA) has also estimated a domestic consumption pattern of various categories of paper and pulp for the year 2000 AD which is given in table 1.3[8].

Table—1.3

Requirement of Paper by the Year 2000 as by NCA

Sl. No.	Item	Average estimated (in 000 tonnes) 1985	Consumption in the year 2000
1	Printing and writing paper	1055	2726
2	Newsprint	417	1014,5
3	Industrial paper	373,5	1023,5
4	Paper Board	464	859,5
5	Rayon grade pulp	2355,5	6899,5

The existing forest resources in the country are not sufficient to meet the future demand of raw mater ials for the required pulp and paper products.

Search for Alternative Fibre Raw Materials

With the expected shortage of the presently used pulpable plant raw materials, mainly bamboo and soft-wood, there will be also shortage of fibres for producing

higher grades of cellulose, used mainly for regenerated fibres and other cellulose derivatives. Throughout the world, therefore, concentrated efforts have been put, for generation of a certain alternative pulpable cellulosic raw material, not only for paper industry, but also for other cellulose based industries. The plant kingdom provides a reservoir of 2,50,000 to 3,00,000 known plant species, out of which a few have been or are now, cultivated to any great extent[9]. Search for new fibre crops has been under way during last three decades or so, to find and develop new fibre supplies for paper and cellulose industries. It is desirable that a new fibre crop must fit the technical requirements for processing into pulp of acceptable quality of high yield. The non-wood plant fibres, some of which are currently being used, can be considered as a potential soure of cellulosic raw material for pulp and paper industry. TheNon-wood plant fibres include the agricultural residues such as bagasse and straw, the natural growing plants such as bamboo, reeds and grasses and the plants which are grown for their fibre content such as kenaf, crotalaria, jute, hemp, abaca, sisal and cotton etc. The most promising amongst the fibre bearing plants, some of which have already been proved to be ideal for pulp and paper making is the group of fast growing plant species. Many fast growing plant species have been indentified, cultivated and their suitability for pulp and paper making has been studied. This includes a large number of annual and perennial plants[10-21]. Development of scientific cultivation technology for raising some of these fast growing annual and perennial plants, to give optimum wood production, has helped to a great extent to fill the gap between the demand and supply of raw material for paper industry in many of the developed and developing countries.

High Alpha-Cellulose Pulp

Wood pulp or any other highly purified from of cellulose, manufactured for use in chemical conversion into derivatives, is known as alpha pulp or dissolving cellulose. Dissolving cellulose finds application in many chemical and paper making end uses and as such chemical purity is the main requirement of such a pulp[22]. Dissolving pulp are used for manufacture of man made fibres like viscose and acetate cellulose ethers as carboxy methyl cellulose, hydroxy ethyl cellulose, ethylcellulose etc and esters like cellulose nitrate, propionate, phthalate and also for manufacture of lacquers, plastics, sponges, etc. Small amounts of this high purity cellulose is also used for filter papers, saturating papers, for resin laminates, vulcanized fibre and artificial leathers[23].

The chemical purity of the dissolving pulp determines its use for various purposes mentioned above. The specifications for a suitable pulp for manufacture of viscose rayon and fibres for tirecords[24-28] are given in table 1.4.

TABLE—1.4

Specifications of a typical Dissolving Pulp

Alpha cellulose	%	greater than 88.0
Pentosan	%	less than 5.0
Lignin	%	less than 0.15
Ash	%	less than 0.15
Alcohol benzene solubility	%	less than 0.5
Viscosity (TAPPI),	Cp	1 to 25
Brightness (Higgins)	%	greater than 85
Copper number		0.1—1.2

There is variation in the compositional characteristics of each and every cellulose bearing forest raw material. Because of the rigidity of specifications for dissolving grade pulp, it is absolutely necessary to examine each and every variety of plant raw material individually to ascertain its suitability for production of high alpha-cellulose pulp.

During last hundred years, enormous work has been carried out in different parts of the world on preparation of high alpha-cellulose pulp from various wood species, bamboo, reed and agricultural wastes. Many forest based cellulosic raw materials have been identified and commercially utilized for preparation of dissolving cellulose since the first man made fibre industry was established[29]. Both hardwoods and soft woods are used to make dissolving wood pulp. Cotton linters and bamboo are also employed as raw materials for preparation of dissolving cellulose apart from a few agrowaste material. A great deal of study has been made by a number of workers in India and abroad on production of rayon grade pulp from bamboo[30-40], reeds and agricultural wastes.[46-48] Production of dissolving grade pulp from hardwood and softwood species has also been reported by many workers

throughout the world [49-58]. All the above mentioned conventional and non-conventional cellulosic materials are also used for feeding the raw material needs of the pulp and paper industries.

There are at present three units engaged in the manufacture of rayon grade pulp in our country withan installed capacity of 1,18,000metric tonnes per annum. As mentioned earlier in Table 1.3 the average estimated consumption of rayon grade pulp would rise to 6,89,9500 metric tonnes by the year 2000 In all the above three units, the principal raw materials used for dissolving cellulose manufacture, are tropical hardwoods, bamboo and eucalyptus.

To meet the growing need of rayon grade pulp and in view of the scarcity conditions imposed by the fast exhausting supplies of the conventional raw material has to be indentified. While identifying the suitability of a particular raw material as an industrial source of cellulose, factors such as(i) availability of the raw material i.e. quality, ease of planting and collection (ii) yield of pulp, (iii) cost, and (iv) quality of the pulp obtained, etc. are to be considered. It view of these, onlv those raw materials, which are easily available or can be made available by scientific plantation within short period, have to be chosen to meet this ever increasing demand of raw material.

Fast growing plants and high alpha-cellulose pulp

Although many of the fast growing plants have been utilized for pulp and paper making in different parts of the world, but not much work has been reported on preparation of high alpha cellulose pulp from this group of plants, though some investigations have been reported[54-59]. It is envisaged that if high alpha-cellulose could be extracted from fast growing plant source, it may be an ingradient for a great future of cellulosics.

Experimental

Studies relating to the extraction of high alpha-cellulose pulp from fast growing plant material have been undertaken and alpha-cellulose pulp was extracted from two types of fast growing plant materials viz. a perennial plant, *leucaena leucocephala* and an annual plant, *Hibiscus cannabinus*, H-583. Water prehydrolysis sulphate process followed by multistage bleaching was employed for extraction of pulp from both the plant raw materials. Alpha-cellulose was extracted from the stem portion of a 5 year old *leucaena leucocephala* plant. The wood chips were water prehydrolyzed under varying conditions of temperature and time, and then sulphate cooked at 163+2°C for 3hr with 18% total chemicals ($NaOH:Na_2S=3$ 1). The unbleached pulp was bleached by multistage bleaching sequence with intermediate distilled water washings[60]. Also alpha-cellulose pulp was extracted from *H. cannabinus*, prehydrolyzed under different conditions of temperature and time. The prehydrolyzed chips were cooked with 16% chemicals ($NaOH:Na_2S=3:1$) for 3hr at 160+2°C at a material-liquor ratio of 1:5. Here again, standard multistage process of bleaching was adopted for the unbleached pulp purification[61].

Some of the physico-chemical characteristics of the alpha-cellulose pulp obtained from a few bath under different experimental conditions are given in Table 1.5.

The alpha-cellulose thus extracted from *L. Leucocephola&H. cannabinus*, were used for preparing cellulose esterified products, by adopting homogeneous esterification procedure,after dissolution of the alpha-cellulose in appropriate amounts of paraformaldehyde (PF) and dimethyl sulphoxide (DMSO). Cellulose acetylated products were prepared by reacting with mono-, and tricarboxylic acid anhydrides in presence of pyridine under varied reaction conditions. Eseterifications with mono-carboxylic acid anhydrides such as acetic and trimethyl acetic anhydrides, yielded products with standard physio-chemical properties. The esterified products were further charcterized by using IR, PMR and ^{13}C-NMR techniques[61,62]. Homogeneous esterification of the cellulose was also carried out with tricarboxylic acid anhydride e.g. trimellitic anhydride under different reaction conditions and the esterified procucts were isolated and characterised adopting standard gravimetric and spectroscopic methods[63]. Thermal decomposition of the alpha-cellulose and their acetylated products were also studied using thermogravimetric and differential thermal analysis techniques to investigate the mechanisms of thermal degradation and their behaviour at d fferent temperature ranges. The details of this study has been reported elsewhere[64]

Table—1.5

Characteristics of High Alpha-Cellulose Pulp

Raw material :		*Hibscus Canabinus*[61]		*Leucaena leucocephala*[60]	
Prehydrolysis Cooking temp. °C		135	145	160	165
Prehydrolysis Cooking time, h		2.5	2.5	3	3
O Yield*	%	28.75	27.75	28.50	28.30
O Alpha-Cellulose	%	94.40	93.66	94.04	93.60
O Lignin	%	0.08	0.09	0.09	0.08
O Pentosan	%	3.65	3.52	1.46	1.26
O Ash	%	0.045	0.065	0.06	0 05
O Degree of Polymerization (average)		945	810	1080	870
O Brightness		85+	85+	86 50	87.50

*based on the original raw mateaial

Conclusion

Due to increasing popularity of man made cellulosic fibres, the demand for rayon in our country, is going on increasing at a rapid rate . To meet the demand, the rayon grade pulp, its raw material, is imported on a large scale. Moreover, the use of alpha-pulps in the gradually expanding cellulose based chemical industries, is also increasing day by day. Alternate source of raw material, such as the fast growing biomass, hold a great promise to provide a part of raw material need for the manufacture of alpha-cellulose in our country. High alpha-cellulose pulp can be prepared by water prehydrolysis sulphate process followed by multistage bleaching from fast growing plant materials like Hibiscus cannabinus and Leucaena leucocephala. The alpha-cellulose extracted from these fast growing plant species exhibits physico-chemical properties identical to those of alpha-cellulose available commercially. It is evident from the esterification experiments that the pulp is exceedingly suitable for conversion to cellulose derivatives and therefore, it is reasonable to expect that alpha-cellulose obtained from the fast growing plant species, could be employed for a broad spectrum of uses. In view of the scarcity of the conventional raw materials for production of useful alpha-cellulose pulp, these plant species may be a promising source of commercially acceptable alpha-cellulose.

Acknowledgement

The author thanks B. P. Chaliha, Acting Director, Regional Research Laboratory, Jorhat for his kind permission to publish this article.

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