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EFFECT OF MORPHOLOGICAL CHARACTERISTICS OF INDEGENEOUS FIBERS (E. tereticornis and S. officinarum) AND THEIR IMPACT ON PAPER PROPERTIES

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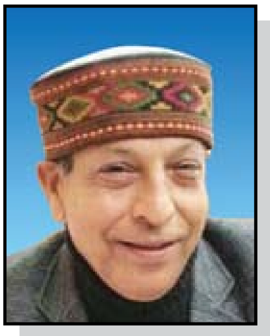

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Abstract :

The properties of paper are dependent on morphological characteristics of fibers that compose the sheet. Undoubtedly the most important of these are fiber length, fiber width, lumen diameter and cell wall thickness. These are the fundamental characteristics which are used for the derivation of more derived values like Luce's shape factor, Slenderness ratio, Solid factor, Runkel ratio, Flexibility coefficient and Rigidity coefficient. All these characteristics play a major role in deciding the strength properties of paper. Curl and kink are also important morphological characteristics that affect the paper properties. In the present study, fundamental and derived fiber morphological characteristics of two indigenous raw materials of paper industry, hardwood (Eucalyptus tereticornis) and agro-residue sugarcane bagasse (Saccharum officinarum) were analysed and were studied for their effect on paper sheet properties.

Key words: Fiber morphology, fiber length, lumen diameter, Runkel ratio, curl, kink and tensile index.

1.0. INTRODUCTION

The basic component material in paper manufacturing is the fiber, which determines the paper properties. Fiber morphological characteristics therefore play a key role to find out suitability of any wood species or other raw materials for pulp and paper manufacturing. Different morphological characteristics from papermaking view are fiber length, fiber width, lumen diameter and cell wall thickness. From these fundamental fiber dimensions, derived values like Luce's shape factor, Slenderness ratio, Solid factor, Runkel ratio, Flexibility coefficient and Rigidity coefficient can be calculated. These derived values play a major role in deciding the paper properties. Fiber morphology, which is an essential property of any raw material for papermaking, has been studied by various researchers. One of the most important fiber properties related to paper strength is fiber length. It generally influences the tearing strength of paper. Greater the fiber length, higher will be the tearing resistance of paper (1, 2, 3). On the other hand, longer fibers tend to give a more open and less uniform sheet structure. Fiber diameter and wall thickness govern the fiber flexibility. Paper from thin walled fibers will be dense and well formed. Fiber lumen width affects the beating of pulp (4, 5).

Strength properties of paper such as tensile strength, bursting strength and folding endurance are affected mainly by the way in which individual fibers are bonded together in paper sheet. The degree of fiber bonding depends largely on the flexibility and compressibility of individual fibers (1). Other calculated wood properties of importance are thereby the flexibility and rigidity co-efficient. Greater the fiber flexibility, better the chance of forming well bonded paper. Similarly, an increase in the rigidity of fibers results in a decrease in fiber bonding.

Runkel ratio and fiber to vessel ratio influences the basic density of wood (6, 7). Because of the necessity for the fiber walls to flatten and ensure good conformability and fiber to fiber contact in paper, it is desirable to have a Runkel ratio less than one (5). The presence of high percentage of fines has been reported to be detrimental to bursting and tensile strengths (1). Vessel element, on the other hand, based on amount actually found in a typical hardwood furnish, has little effect on tensile strength. Fibril angle is the factor that has the greatest influence on stretch properties (extensibility) of a sheet from unbeaten fibers and multiple regressions showed that interaction of fiber length plus fibril angle could account for 76% of the variation in tearing strength for unbeaten hardwood pulp (1).

In the present work, an attempt has been made for comparative study of morphological characteristics of two indigenous fast growing and high yielding raw materials of paper industry, hardwood (Eucalyptus tereticornis) and agro-residue sugarcane bagasse (Saccharum officinarum). The fundamental morphological characteristics for both raw materials were determined and derived values were also calculated.

2.0 RESULTS AND DISCUSSION

Strength properties of paper depend on structural properties of fiber network as well as strength of individual fibers. The fiber morphology plays an important role in deciding the strength of individual fibers. The present study focused on the determination of various morphological characteristics like fiber length, fiber width, lumen diameter and cell wall thickness of E. tereticornis and S. officinarum. Luce's shape factor, Slenderness ratio, Solid factor, Runkel ratio, Flexibility coefficient and Rigidity coefficient for both S. officinarum and E. tereticornis were derived using above fiber dimensions.

The morphological characteristics of S. officinarum and E. tereticornis are given in Table 1.

Table-1: Morphological characteristics of S. officinarum and E. tereticornis

S. No.	Particulars	*S. officinarum*	*E. tereticornis*
	Fibrous cells		
1	Minimum fiber length, mm Maximum fiber length, mm Average fiber length (L) (Weight Weighted)	1.50±0.09	0.24 2.43 0.774±0.08
2	Mean fiber width (D), μm	21.5±1.5	19.81±1.5
3	Lumen diameter (d), μm	6.26±0.3	7.87±0.25
4	Cell wall thickness (w), μm	7.76±0.1	4.12±0.62
5	Luce's shape factor $(D^2–d^2)/(D^2 + d^2)$	0.84	0.727
6	Slenderness ratio (L/D)	69.77	39.07
7	Solid factor, $(D^2 –d^2)\times L$	0.634	0.256
8	Runkel ratio, 2w/d	2.479	1.047
9	Flexibility coefficient, (d/D)×100	29.12	39.73
10	Rigidity coefficient, 2w/D	0.722	0.416
11	Fiber curl index (length weighted)	0.152	0.17
12	Fiber kink index	1.88	2.32
13	Total kink angle, degree	37.8	31.1
14	Kink per mm	0.94	0.91
	Non-fibrous cells		
15	Length of vessel, μm	152.1±2.4	358.0±3.2
16	Width of vessel, μm	28.2±1.1	161.0±2.3
17	Length of parenchyma, μm	326.7±4.1	88.1±1.2
18	Width of parenchyma	53.1±2.8	28.7±1.9
19	Arithmetic fines (L=0.01-0.20 mm)	30.31	29.54
20	Length weighted fines (L=0.01-0.20 mm)	7.59	5.16

Results show that the average fiber length of S. officinarum is 1.50 mm, average fiber width 21.5 mm, average lumen diameter 6.26 μm and average cell wall thickness 7.76 μm. The fibers have a relatively broad middle region and abrupt to gradually tapering pointed ends which are sometimes separated.

On the other hand, average fiber length of E. tereticornis is 0.774 mm, average fiber width 19.81 mm, average lumen diameter 7.87 μm and average cell wall thickness 4.12 μm. The fibers are uniformly thick to thin-walled with gradually tapering pointed ends, smooth walls, narrow to wide lumen and very sparse slit-like pits. They are often bent, curved or folded and invariably show compressed, somewhat buckled areas with transverse markings, which stand out rather prominently in the thick-walled fibers. The walls sometimes may be as much as 10mm thick, often showing a distinct multi-lamellate or multi-layered structure.

Fiber length affects the tearing strength of paper. The greater the length of fiber, the higher will be the tearing strength of paper. Results indicate that the fibers of S. officinarum are wider and thick-walled compared to E. tereticornis.

Cellwall thickness of fibers is related to the fiber flexibility. Thick-walled fibers affect the bursting strength, tensile strength and double fold number of paper negatively. The reason is that thick-walled fibers when pressed after delignification tend to retain their tubular structure as such without forming double walled ribbon structure. In this way, they provide less surface contact area for bonding. Therefore, the paper made from thick-walled fibers will be porous, more opaque, bulky and coarse-surfaced with a large void volume.

On contrary to this, thin-walled fibers are effortlessly converted into double walled ribbon structure and comparatively provide more fiber surface contact area for bonding after pressing.

All the mechanical strength properties except tear index will be improved due to greater hydrogen bonding. The sheet made from thin-walled fibers will be less opaque, less porous, denser and well formed. Cell cavity influences the beating of pulp. Wider the fiber lumen better will be the pulp fibrillation in shorter period because of the penetration of liquids into the fiber lumen.

Effect of derived values on paper properties

Luce's shape factor

The Luce's shape factor is based on circular shape of cell wall and cell cavity; therefore it estimates the tendency of fibers to collapse. Moreover, the collapsing of fibers depends upon its location in a paper sheet. Luce's shape factor is related to density of paper sheet and may be correlated to breaking length of paper (8). The principle factor that determines the breaking length of paper is the fiber density. This, of course, estimates fiber flexibility and degree of fiber collapse, both of which control the degree of fiber conformability and as such the size and number of inter-fiber bonds. The Luce's shape factor of S. officinarum (0.84) is higher in comparison to E. tereticornis (0.727). It indicates that breaking length of S. officinarum is better than E. tereticornis.

Slenderness ratio (L/D)

The slenderness ratio (L/D) is also known as felting power which is inversely proportional to the fiber diameter and influences the pulp yield positively and digestibility of cellulosic raw materials negatively (9). Slenderness ratio when used for paper, the slenderness ratio of individual fiber affects the flexibility and resistance to rupture the fibers (10). The fibers of S. officinarum (69.77) are more slender compared to E. tereticornis (39.07). The fibers of S. officinarum offer lower degree of collapse and conformability within the paper sheet and tend to produce opaque and bulky sheet with higher air permeability as compared to E. tereticornis.

Solid factor

Thick-walled, narrow lumen fibers with long fiber length result the high solid factor. S. officinarum gives more solid factor (0.634) as compared to E. tereticornis (0.256). Having long fiber length, S. officinarum produces a high solid factor. On the other hand, thick cell wall and narrow lumen of E. tereticornis do not allow the fibers to convert into double walled ribbon-like structures, which favour the positive side of the solid factor but due to shorter fiber length, it does not contribute significantly to higher solid factor. Therefore, the fibers of E. tereticornis are readily converted into double-walled ribbons compared to S. officinarum.

Runkel ratio

Fibers which have Runkel ratio less than 1.0 are considered as thin-walled fibers (11). On contrary to this, fibers having Runkel ratio above 1.0 are considered as thick-walled, stiffer and rigid in nature and form bulky and more opaque paper with lower bonded area (12). These fibers are predicted to have poor mechanical strength properties. The Runkel ratio greater than 1.0 is predicted to have an inevitably negative effect on tensile and burst indexes as well on double fold numbers (8). The Runkel ratio of S. officinarum is 2.479 while the Runkel ratio of E. tereticornis is 1.047.

The value of Runkel ratio of E. tereticornis is at the boundary line where the classification of thin-walled and thick-walled fibers starts. Therefore, compared to E. tereticornis, S. officinarum fibers are less flexible and show less wet plasticity and result in a poor degree of fiber collapse and lower degree of conformability) within the sheet and give rise to a sheet of low density or higher bulk. The mechanical properties along with other properties of paper are related to wet plasticity which may be increased by fibrillation and by the presence of hemicelluloses or use of enzymes like cellulase or other wet end bonding additives.

Flexibility coefficient

The flexibility coefficient is directly governed by fiber diameter and inversely affected by cell cavity. The lumen diameter of S. officinarum (6.26) is less than E. tereticornis (7.87) and fiber diameter of S. officinarum (21.5mm) is more than that of E. tereticornis (19.81 mm).This decreases the fiber flexibility of S. officinarum as compared to E. tereticornis. The fiber flexibility enhances the area for bonding among fibers due to better fiber collapsing and improves all the mechanical properties like burst index, tensile index and double fold numbers. Tear index is the function of fiber length. As S. officinarum fibers are longer compared to E. tereticornis therefore, S. officinarum is supposed to give better tear index.

Rigidity coefficient

The Rigidity is controlled by cell wall thickness and inversely by fiber diameter. The Rigidity coefficient of S. officinarum (0.722) has been found to be more than E. tereticornis (0.416). Therefore, the fibers of S. officinarum are more rigid compared to E. tereticornis. Hence, the fibers of S. officinarum are more rigid as compared E. tereticornis.

Curl index

The curl index of S. officinarum (0.152) has been found to be less than that of E. tereticornis (0.17). Generally, the wood fibers are comparatively straight, but they may be curly due to some deformations caused by growth stresses. The defects in fibers like fiber curl, deformations and damage may also be caused during chipping of logs, defiberization (passing the pulp from digester to blow tank), medium pulp-consistency unit operations and hitting the turns in pipe lines. The treatments carried out to separate the cellulosic fibers together with pulp washing operating parameters and flow of pulp in an approach flow system may lead to a pulp of lower strength. But fiber deformation and fiber damage are altogether different as deformation is beneficial to some of the paper properties while fiber damage causes loss in pulp strength. The curly fibers develop a paper of low tensile index, but may lead to high tear index due to uneven distribution of stresses along the length of a curled fiber in a fracture-zone. If curl index is more, it affects the tensile strength and the bonding ability of fibers in a network adversely.

Kink index, Kink angle and Kink per mm

Kink index has been found to be less in case of S. officinarum (1.88) as compared to E. tereticornis (2.32). Fiber kink is described as an abrupt change in the fiber curvature. Although, the fiber kink is calculated as a part of fiber curl, its effect on paper properties is different than that of the curl. Kink affects the wet strength and wet rupture energy of the paper. These dislocations in fibers also reduce the bending stiffness of fibers significantly. The presence of dislocations reduces the modulus of elasticity of the fibers similar to curl index. Dislocations are the weak locations in the fibers that reduce the strength of the individual fibers and thus lead to a decrease in average effective fiber length. The kink per mm is slightly more in case of S. officinarum (0.94) compared to E. tereticornis (0.91). In case of an increase in the number of dislocations in fibers, it causes an increase in tear strength and stretch. However, it decreases the bonding strength. The kink angle is slightly more in case of S. officinarum (37.8) than for E. tereticornis (31.1)

Non fibrous cells

The average length of parenchyma cells of S. officinarum with numerous pits has been found to be 326.7 μm and width 53.1 μm. The average length of vessel elements of E. tereticornis is 358.0 μm and 161.0 μm in width. Parenchyma cells slightly affect the strength of pulp sheets for both S. officinarum and E. tereticornis.

These cells have large surface area and act as fillers. They affect the mechanical strength properties of paper adversely. Being thin-walled and highly perforated, the vessel elements are broken into smaller fragments during pulping. If these cells are not well bonded just below the surface of the sheet, then it is picked-up during printing. The vessel picking problems are affected by vessel width, length, and number per unit weight.

3.0 CONCLUSIONS

- E. tereticornis has an average fiber length of 0.774 mm with a fiber width of 19.81 μm while S. officinarum has average fiber length of 1.50 mm with average fiber width of 21.5 mm. The Lumen diameter and cell wall thickness for E. tereticornis fibers were found to be 7.87 μm and 4.12 μm respectively and for S. officinarum fibers these were 6.26 μm and 7.76 μm respectively.

- E. tereticornis has low Slenderness ratio (39.07), low Solid Factor (0.256), less Runkel ratio (1.047), high Flexibility coefficient (39.73) and low Rigidity coefficient (0.416) as compared to S. officinarum where Slenderness ratio, Solid Factor, Runkel ratio, Flexibility coefficient and Rigidity coefficient are 69.77, 0.634, 2.479, 29.12 and 0.722 respectively. As a result, S. officinarum fibers are less flexible as compared to E. tereticornis and do not convert into double walled ribbons on pressing and provide less surface contact area for bonding. The sheets made from S. officinarum are found to be porous, more opaque and have less tensile index, burst index and double fold number as compared to E. tereticornis. Tear index is the function of fiber length, therefore in case of S. officinarum, longer fibers result in pulp sheets with better tear index as compared to E. tereticornis.

- The curl index of S. officinarum (0.152) has been found to be less than that of E. tereticornis (0.17). Kink index has also been found to be less in case of S. officinarum (1.88) as compared to E. tereticornis (2.32). The kink per mm was found to be slightly higher in case of S. officinarum (0.94) compared to E. tereticornis (0.91). The kink angle was also found to be slightly higher in case of S. officinarum (37.8) as compared to E. tereticornis (31.1).

4.0 EXPERIMENTAL

E. tereticornis pulp was obtained by kraft pulping of eucalyptus chips under pulping conditions of active alkali dose 17% as Na2O, sulphidity 20%, cooking time 90 min, temperature 160 ºC and liquor to wood ratio of 3.5:1 while depithed S. officinarum pulp was obtained from soda pulping under pulping conditions; active alkali dose 12 % as Na2O, cooking temperature 155 0C, cooking time 60 min, digester pressure 5.5 kg/cm2 and liquor to raw material ratio 4.5:1. The pulps so obtained were bleached using XOCEHH bleaching sequence and the bleached pulps were used to determine the morphological characteristics.

For fiber length determination, small splinters of both the raw materials were macerated with 10 mL of 67% HNO3 and boiled in a water bath at 100 ºC for 10 min. The splinters were then washed, placed in small flasks with 50 ml distilled water and the fiber bundles were separated into individual fibers using a small mixer with a plastic cap to avoid fiber breaking. About 0.5 mL of macerated fiber suspension was finally placed on a slide (standard, 7.5 cm × 2.5 cm) with a medicine dropper of about 10 cm length and 8 mm internal diameter with one end fitted with a rubber bulb and the other carefully smoothened but not tapering.

The microscope slides of cellular materials were prepared for both the samples as per IS 5285-1998 “Fiber analysis of paper and paper board”-method of test. All the fiber samples were examined under a calibrated motorized research microscope (Olympus make, Model BX-61) (Fig. 3.2) equipped with a ultra-precise motorized focus drive with a high resolution of 0.01µ and a maximum speed of 3mm/second with eco-friendly lens, noise-pieces and three objectives of calibrated focal lengths 58, 18 and 5mm, A total of 200 randomly chosen fibers were examined of kraft-AQ pulps of E. tereticornis and soda pulps of S. officinarum separately. For fiber diameter, lumen diameter and cell wall thickness determinations, cross-sections of 25 µm thickness were cut on Leitz base sladge microtome-1300 and were stained with 1:1 aniline sulphate–glycerin mixture to enhance cell wall visibility (cell walls retain a characteristic yellowish colour). The length and width of non-fibrous cell i.e. vessels and parenchymatous cells were determined by putting pulp suspension at 0.03 consistencies with the help of dropper at the centre of microscope slides. The microscope slide was moved horizontally and non-fibrous cells crossing the mark in the microscope eyepiece were counted. When the edge of the slide was reached, the slide was moved back vertically 5mm and non-fibrous cells in horizontal lines were counted. If a non-fibrous cell crossed the line several times it was counted as a new non-fibrous cell every time. The length and width of non-fibrous cells were measured from the pictures by hand using vector and chain tool in measurement module under the calibrated motorized research microscope.

The fibers of kraft pulps of E. tereticornis and soda pulps of S. officinarum were also analyzed for fiber curl index, fiber kink index, total kink angle, degree and kink per mm using Techpap make MorFi Compact LB01. For preparing the pulp samples 400 mg sample of dry pulp was taken and its suspension is made which is diluted to 8 L. The samples were then operated on DURIEUX no 400 tared filter. Pulp samples were taken in 1 L beakers and analyzed by using MorFi software.

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