Effect Of Refining On The Cross Sectional Behaviour Of Wheat Straw Fibre

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ABSTRACT

Agricultural residue pulps contain significant amount of fines component and the initial freeness of the unbeaten pulps is very low. As the initial freeness of these unrefined pulps is low they can not be refined much. The high fines component in these pulps severely hamper the runnability of the stock on the paper machine. In the present experiments we have tried to identify the factors influencing the refining of wheat straw fibres by studying the whole pulps and fractionated long fibres.

Wheat straw pulps contain about 35% of passing 200 B&M fraction fines, predominantly nonfibrous (parenchymatous) tissue. The whole pulps loose freeness very easily on refining. The freeness drops from 350 to 190 ml Csf with only 500 revolutions PFI mill treatment. Fibres in the refined whole pulp appear unchanged when compared with unrefined fibres. Thus, the non-fibrous component of a furnish receives the bulk of any refining treatment and the refining energy is not utilised in the developement of fibres. With this background we have studied the cross sectional changes in fibres during refining of fibre component, when segregated from, and in admixture with the non-fibrous portion/primary fines (parenchymatous fines component). Segregation of more fibrous pulp was achieved by Bauer & McNett fibre classifier where +50 and +200 fractions of the wheat straw soda pulps were collected. These fractions were refined in PFI mill to various freeness levels and studied their properties. Whole pulp and + 50 fractions were studied for changes in various cross sectional properties of fibres as a response to refining by VAX image processing technique (kibblewhite & Bailey, 1988). The results show that wheat straw fibres can be fibrillated if the primary fines (Parenchyma and epidermal tissue) content is reduced. Thick walled fibres (mostly narrow) in wheat straw pulp respond more favourably compared to the thin walled (wide) fibres during long fibre refining. The fibres in whole pulp of wheat straw when beaten to a freeness of 190 ml Csf contract, which is the initial effect in a refining process.

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INTRODUCTION

Agricultural residues are renewable source of fibre, which is abundantly available on a sustained basis to Indian pulp and paper industry. Poor drainage and low strength properties of the pulps produced from straws constrain their usage by the industry. The agricultural pulps, grasses in particular have very high nonfibrous parenchymatous tissue contents which give chemical pulps low freeness (Krishnagopalan and Simrad, 1976) with extremely high specific surfaces and water retention values (WRV) (Tables 1,2). Parenchymatous tissue is in the form of groups of cells, which break down into single cells with mildest mechanical treatment. In consequence, the fibre component of these pulps is essentially unchanged by conventional refining treatments.

Table 1 Fibre dimensions and fibre, vessel and parenchyma cell proportions

Material	Fibre (%)	Parenchyma (%)	Vessel (%)	Fibre length (mm)	Fibre diameter (μ m)
Softwood	95	1-4		3.0	30
Eucalyptus				0.8	20
Bamboo	55	40	5	2.7	15
Bagasse	30-35	50-60	5-10	1.7	23
Wheat straw	25	75	3	1.2	13
Rice straw	25	75	3	1.1	10

Table 2 Specific surface and water retention values (WRV)

Property	Wheat straw	Rice straw	Bagasse	Bamboo
Specific surface (cm^2/g)	20	43	16	14
WRV (%)	170	214	190	110

Improvement in the wet and dry strength properties of a paper web normally depends on the development of fibre flexibility, conformability and fibrillation by refining (Tamdoo and Kerekes, 1989; Mohlin & Miller, 1992). It is very difficult to develop such fibre properties, and web runnability and strength, using straw Kraft pulps and conventional refining treatments. The present study describes the response to refining of fibre component of straw soda pulps when separate from, and in admixture with, the parenchymatous fines component.

EXPERIMENTAL METHODS

Softwood, hardwood and nonwood cellular components:

Fibre and component measurement:

Length of 300 fibres was measured on projection microscope using Pira fibre length counter. The average fibre length was determined from this data.

Width for 100 fibres was measured on projection microscope using micro-scale (1-mm scale) with magnifying lens attachment and averaged out the fibre width.

Tissue components in the raw material were determined from the cross sectional area occupied by each component in a unit area of the raw material cross sections.

WRV : The affinity of cellulose for water is determined using Jamey's method. A wet fibrous sample is centrifuged in such a way that the excess water is removed from the sample. After centrifuging under standard conditions of centrifugal force and time, the moisture content of the sample is reduced to a value which has been called the 'Water retention value (WRV).

Specific surface area : External specific surface area measured by passing water at constant rate through a bed of pulp pad and determined the pressure drop across the pulp pad with the help of 'Pulmac permeability test'.

$$R_p = A^2 \Delta P / Q(W) \eta \quad - \quad (1)$$
$$C = W/AL \quad - \quad (2)$$
$$C/R_p = 1/KSW^2 \quad - \quad (3)$$

Where

R_p = Specific resistance to perimeter cm/g
A = Pad area
ΔP = Pressure drop
q = Flow rate, cm^3/sec
W = pad weight, g
η = Viscosity, Poises (g/cm/s)
L = Pad thickness
K = Kozeny constant

Sample preparation and pulping:

Wheat straw was cut in a rotary cutter to a length of about 2.5 cm and pulped in a stationary vertical cylindrical digester. Soda pulping was carried out as follows:

Pulp processing and testing:

Standards followed :

Kappa number	T-236-OS-76
B & M fibre classification	T-233-OS-75
Freeness (ml Csf)	ISO-5267/2
Pulp refining, (PFI mill)	ISO-5264
Handsheet preparation	ISO-5269/1
Fibre coarseness	T-271-pm-91
Burst index	ISO-2758
Tensile index	ISO-1924
Folding endurance	ISO-DIS-5626
Tear index	ISO-1974
Porosity	T-547-pm-88

Fibre dimensions:

Cross section fibre dimensions of thickness, width, wall area and wall thickness were measured using image processing procedures described previously (Bawden et al 1987; Kibblewhite and Bailey, 1988). Fibre dimensions are based on those of dried and rewetted pulps reconstituted from hand sheets (Kibblewhite, 1989). Relative number and length weighted mean fibre length, fibre coarseness were determined with a Kajaani FS-200 instrument (Tappi method T-271-pm-91).

Light microscopy:

Microscope slides were flooded with the fibre suspensions (slightly diluted) and allowed the suspension to dry at 40 ^{0}C. The dried fibres (on the slides) were stained with Toluidine Blue for about 5 min. and placed in a beaker of water for 20 min., which were later air-dried. Coverslips were applied to some of the slides after covering with mounting medium. These fibres were observed with Zeiss Photomicroscope-II using, bright field, dark field, phase contrast and interference contrast illuminations. The dried fibres of other slides were examined directly using phase contrast illuminations. This method was superior since fibre fibrillation was more clearly visible. The reason being the absence of artefact created by cover glass and. mounting medium (perhaps due to absence of interference of refractivity of the mounting medium and cover glass with that of cellulose fibrils).

RESULTS

Unrefined whole-pulp contains bundles of parenchyma, epidermal cells and fibres in addition to free cells (Figure 1). Refined whole-pulp, on the other hand, consists mainly of single cells with few small tissue bundles (Figure 2). Tissue bundles are readily disrupted by refining and converted into small tissue clumps and single cells (Figure 2). Mean number and length weighted fibre length decrease with whole -pulp refining (Table 3). Whole-pulp length weighted population distributions show increase in the proportion of particles of length 0.2 mm as a result of refining. Such change is absent in the number average distributions. Previous studies have shown the length dimensions of parenchyma tissue cells to be within the range of 0.05 to 0.2 mm for straw pulp (Roy et al 1992; 1993). Since the vessel elements are narrow and long (about 0.5 mm), they contribute to the strength and considered alongwith fibres for bonding strength. A portion of nonfibrous tissue/cells or fines is retained in the classified +50 pulp fractions (Figures 3, 4). The unrefined +50 pulp fraction pulps contain a few bundles of nonfibrous tissue as well as single cells and fibres (Figure 3). Fines (nonfibrous) contents in the +50 fractions increase in the initial stages of refining as tissue bundles are disrupted with the release of single nonfibrous cells (Figures 3, 4).

Table 3 Bauer McNett pulp fraction analyses

Pulp fraction	Number of cells per gram (x 10^6)	Cell Coarse-ness	Number of fines <0.2mm	Weight of fines <0.2mm	Number average fibre length (mm)	Length weighted fibre length (mm)
Whole Pulp	30.05	0.096	54.21	15.31	0.39	0.71
+50 fraction	17.80	0.102	28.38	4.04	0.55	0.85

Note: In the present experiment +50 fraction or long fibre means the fibre collected using only +50 mesh in the B&M fibre classifier.

Changes in the distribution of pulp components:

Fines content increase in the whole pulp when refined (Fig. 1, 2). Unrefined pulp has bundles of parenchyma, epidermal cells and fibres in addition to free cells as they are observed under microscope. Refined whole pulps have very few bundles of tissues and numerous single cells (Fig. 2). Bundles of tissues breakdown and release small groups and/or individual cells during the process of refining of whole pulps. The number of small (short) cells released is very high.

Fines (nonfibrous) content is present in the +50 B&M fraction (long fibre) pulp (Table 3) and complete removal of fines by the fractionator is not possible. Long fibre fraction has a few bundles of nonfibrous tissues and some nonfibrous single cell alongwith fibres (fig 3) as revealed by microscopic observations. Freeness of unrefined long fibre is about 615 ml Csf. The difference in freeness between unbeaten whole pulp and long fibre is due to reduction of fines content in long fibre fraction. This difference between the pulps shows that the nonfibrous fines largely contribute the higher specific surface area of whole pulp. Drainage time for the whole pulps is very high as compared to that of the long fibre fraction (Roy et al., 1992) at 195 ml Csf. This slowness of the whole pulp is obviously due to nonfibrous portion. Long fibre is subjected to different degrees of refining to obtain pulps with freeness levels of about 500, 395, 295, 195 ml Csf. As populations in the lower length classes for these pulps are studied, the following changes are noticed:

a. Population in lowest length classes increase appreciably when the long fibre is refined from 615 to 500 ml Csf.

b. Pulps below 500 ml Csf eventhough do not vary significantly; fines content rise marginally with increased refining.

These observations suggest that initial rise in fines content during refining of long fraction is due to breakdown of a few bundles of nonfibrous portion to single cells (Fig. 3, 4). Microscopic observations on long fraction show increase in finer fibrils in a free state (Fig. 5, 6) with progressive refining.

Changes in the cross sectional dimensions:

Dimensions of two hundred fibres are measured for each pulp for the analysis by VAX-Image processing method. The data was analysed statistically. Statistical data out put includes basic dimensions and derivative values like ratios of the basic dimensions. Two types of pulp compositions analysed in the present study are:

i) whole pulp
ii) long fibre pulp (+50 fraction)

Fibre behaviour is explained mostly based on the basic cross sectional dimensions of fibres.

Whole pulp:

Unrefined wheat straw fibres are rigid with compact wall structure. Refining process bring in changes in various dimensions of fibres. Fibre width of the whole pulp (Table 4) is reduced in the mechanical treatment as the freeness reduced from 350 ml Csf to 190 ml Csf. In the initial stages of refining of chemical pulps, the stresses within fibre wall leads to contractions of fibre wall and structural reorganisations. These changes cause overall fibre and lumen diameters to decrease (Kibblewhite, 1989). Fibrillation is not observed in whole pulp fibres even at a freeness of 190-ml Csf (Fig. 2)

Long fibre pulp:

Unrefined wheat straw fibres are rigid with compact wall structure (Fig. 7). On refining the fibre wall swells due to internal fibrillation (delamination of

Table 4. Cross sectional dimensions of whole pulp and Long fibre pulp

			WHOLE PULP		LONG FIBRE (+50 FRACTION) PULP				
Se. No.	Fibre Dimensions	LSD	350	190	615	500	395	295	195
1	Fibre Width	1.08	13.31	13.31	11.75	11.35	13.22	12.44	12.27
2	Fibre Thickness	0.37	6.601	6.076	6.001	6.028	6.156	6.461	6.108
3	Min.Rect.Area	9.93	91.3	83.1	73.1	70.1	84.4	83.7	77.9
4	Wall Area	6.49	62.76	58.38	52.11	50.75	59.05	59.54	55.95
5	Wall Thickness	0.20	2.558	2.587	2.674	2.942	2.525	2.893	2.856
6	% Fibre	1.19	92.31	94.22	95.54	96.01	93.34	94.79	95.66
7	%Lumen	1.01	4.79	3.2	2.92	2.46	4.28	3.66	2.60
8	FW/FT %	0.19	2.122	2.328	2.027	1.966	2.255	2.007	2.087
9	WT/FT%	2.73	39.82	43.66	45.58	49.52	41.71	45.81	47.53
10	WT/FW %	2.71	22.64	23.22	26.18	30.42	22.21	27.09	26.81
11	Rect.A./Wall Area	0.03	1.4295	1.3983	1.3775	1.3565	1.4061	1.3854	1.3782
12	Rect.A./Wall T.	3.84	36.99	34.57	28.54	26.37	35.17	30.87	28.86
13	Rect.Dg.	1.05	15.05	14.81	13.35	13.02	14.76	14.19	13.87
14	Square Dia.	0.50	9.158	8.778	8.241	8.097	8.826	8.799	8.498
15	Square Dg.	0.71	12.951	12.414	11.655	11.451	12.481	12.444	12.017

wall layers) (Fig. 8). Extensive refining leads to loss of wall material (Fig. 9, 10). Refining process, hence, bring in changes in various dimensions of fibres. Fibre width of the long fibre pulp (Table 4) is reduced in the initial stages of mechanical treatment as the freeness reduced from 615 ml Csf to 500 ml Csf. Fibre width increased on further refining of the pulp to 295 ml Csf. Extended refining of the pulp lead to reduction in fibre width as the freeness of the pulp reached 195 ml Csf. Marginal reduction in fibre width in the initial stage of refining of wheat straw long fibre pulp is due to similar effect. Increase in fibre width during further refining is due to increased delaminations in the wall (internal fibrillation) leading to increased collapsibility. Loss in wall material (Fig. 9, 10) due to excessive mechanical treatment at 195 ml Csf causes reduction in fibre width. Fibre thickness of the long fibre pulp (Table 4) remains unchanged in the initial refining process upto a freeness level of 500 ml Csf. Increase in fibre thickness is noticed in further refining upto a freeness level of 295 ml Csf where it reaches maximum fibre thickness indicating continuous swelling of the fibre due to fibrillation. Below this freeness level, thickness of the fibre is reduced marginally due to loss of cell wall material. Minimum rectangle area (MRA) of the fibre cross section, which is a product of fibre width and fibre thickness (FW x FT), also is reduced initially upon slight refining upto a freeness level of 500 ml Csf suggesting the contractions in the fibre wall (Table 4). Further refining caused the fibre to swell upto 295 ml Csf and refining beyond this level MRA of the fibre is marginally reduced due to loss of cell wall material. Maximum fibre thickness alongwith stabilised MRA of fibre plausibly indicate the attainment of optimum swelling (internal fibrillation) resulting in practically obtainable level of fibre conformability where the strength development in the web is most balanced. Fibre wall area is an indicator of the fibre swelling follow similar changes as described for the MRA. Thickness of the fibre wall also reaches a maximum and becomes' stable even on further refining (Table 4). The minor fluctuations in these dimensions are due to the loss of wall material, which may be regained, in further stages of refining due to swelling.

Comparison of dimensional changes in fibre cross sections of long fibre & whole pulp:

Whole pulp fibres do not vary significantly in their cross sectional dimensions in response to refining (Table 4). The trends in fibre behaviour for unbeaten and minimum beaten (500 ml Csf) long fibre are comparable to the trends of the unbeaten and maximum beaten (190 ml Csf) whole pulp (Table 4). In both the cases MRA and wall area are reduced whereas wall thickness, % fibre wall increased marginally (Table 4). Mild refining of the fibres of long fibres to a freeness of 500 ml Csf resulted in contractions in fibre wall. Such an effect is achieved with very high refining of the fibre in the whole pulps to a freeness of 190 ml Csf. This comparison gives us an idea regarding the limitations for the fibre development in whole pulps.

Influence of fibre microstructure on hand sheet properties:

Physical strength properties are influenced by the changes in the microstructure of fibres as well as the other tissues. In the present experiment as the whole straw pulp is examined, the tearing strength of hand sheets is marginally reduced and the tensile strength is not improved significantly (Table 5). This can be viewed from the fibre structure point where there are no significant changes in the fibre cross sectional dimensions other than consolidation of microfibrillar structure in the fibre (Table 4). The improvement in the tensile strength in the whole pulp refining can be attributed to:

1. consolidation of fibre microfibrillar structure
2. consolidation of sheet to increased surface area of the nonfibrous tissues
3. adhesive strength of hemicelluloses

The strength properties of the handsheets from long fibre pulp improved consistently upto a freeness level of 295 ml Csf (Table 5). Tearing strength has improved remarkably upto 295 ml Csf which can be attributed to improved fibre swelling (internal fibrillation) as can be visualised from the fibre structural changes viz. Fibre thickness, fibre wall area and wall thickness (Table 4). Fibre swelling improves fibre bonding which in turn influence positively both tensile strength and tearing strength of handsheets through sheet consolidation. The findings of Dr. Seth on softwood fibres suggests that the fibre bonding also significantly contributes to the tearing strength as long as the intrinsic strength and length of the fibre is maintained (Seth, 1990). Refining of long fibre pulp below 295 ml Csf has a negative impact on the tearing strength (Table 5) due to loss of fibre wall layers (Fig. 9, 10) leading to reduced fibre wall thickness and related microstructure of the fibres (Table 4).

Table 5 Strength properties of Wheat straw pulps

Se. No.	Properties	Units	Whole Pulp		Long Fibre Pulp (+50 Fraction)				
1	PFI	rev	0	500	0	500	1000	2000	4000
2	Freeness	ml Csf	350	190	615	500	395	295	195
3	Drainage time	s	7.31	16.64	4.53	4.65	5.84	8.52	13.46
4	Apparent density	g/cm^3	0.68	0.77	0.62	0.72	0.73	0.79	0.80
5	Burst Index	$KPam^2/g$	2.0	3.45	1.80	3.35	4.0	4.70	5.20
6	Tensile Index	N.m/g	32.0	48.5	26.0	46.0	55.5	58.0	67.5
7	Stretch	%	4.2	5.0	3.9	4.8	5.3	5.6	6.1
8	Fold KM	log	1.40	2.13	1.17	2.18	2.68	3.05	3.06
9	Tear Index	mNm^2/g	7.30	6.85	8.10	10.60	10.50	11.20	9.60
10	Porosity Bendtsen	ml/min	195	25	1950	510	220	50	20

CONCLUSIONS

a) By reducing the nonfibrous component in the wheat straw pulp the freeness of unbeaten pulp impoved. It indicates that nonfibrous tissue contributes substantially to slowness of whole pulp.

b) As the freeness drop is rapid in refining of whole pulps, fibres in whole pulps can not be developed.

c) During refining, the fibres in whole pulp consolidate their internal structure (which is the initial effect in a refining process). But these fibres do not fibrillate to improve conformability which affects bonding strength of sheet.

d) Fractionated long fibres show significant improvement in fibrillation during refining process. It shows that fibres can be fibrillated if the primary fines (parenchyma and epidermal tissue) content is reduced.

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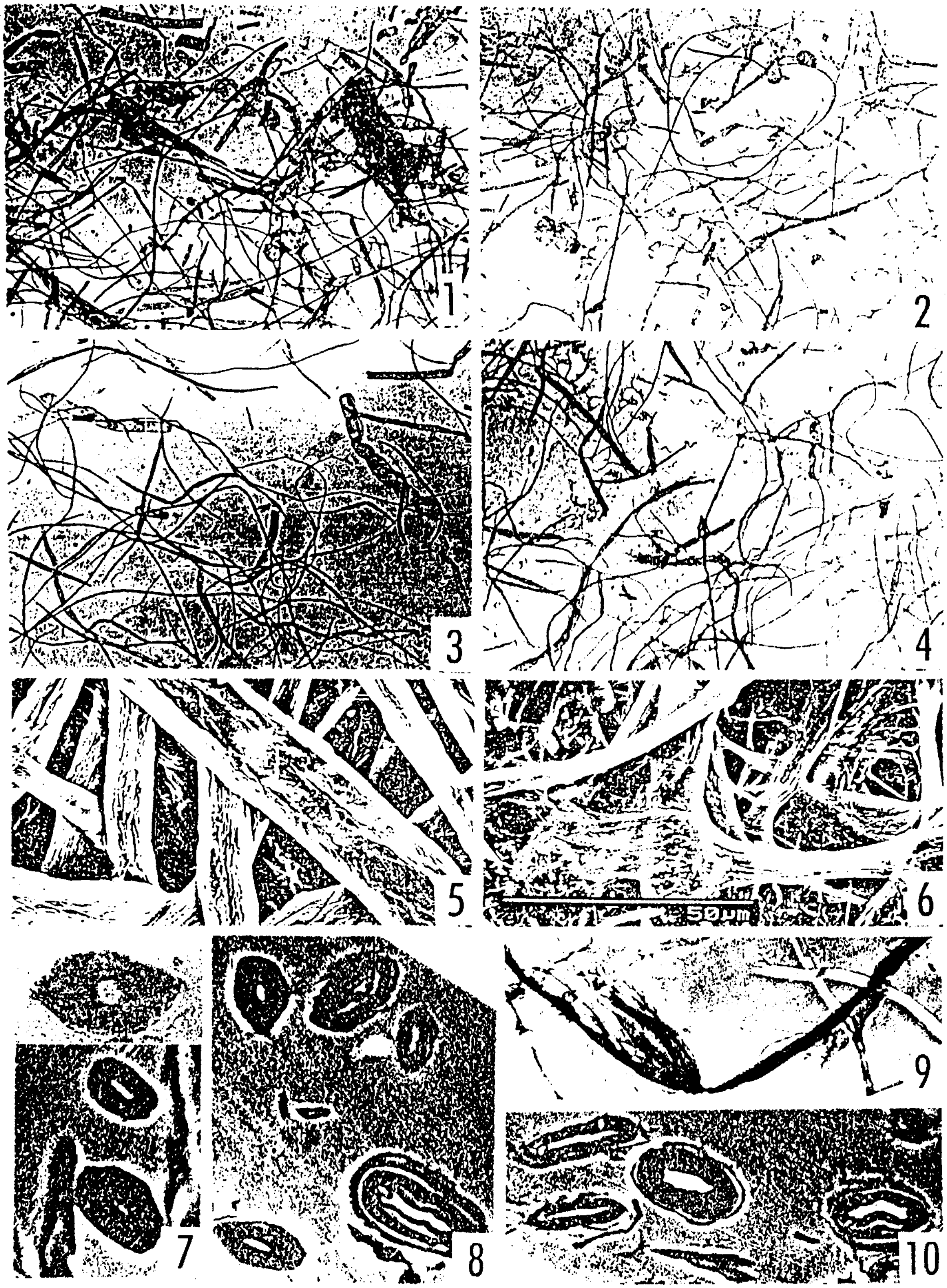

Figures 1 - 10 : Wheat straw fibres. 1. Unbeaten whole pulp (350 ml Csf); 2. Beaten whole pulp (190 ml Csf); 3, 5. Unbeaten long fibre pulp (615 ml Csf); 4, 6. Beaten long fibre pulp (195 ml Csf); 7. Cross section of Unbeaten long fibres (615 ml Csf); 8. Cross section of Beaten long fibres (295 ml Csf); 9, 10. Extensive fibrillation of Beaten long fibre pulp (195 ml Csf).