The Pulp Potential and Paper Properties of Willows with Reference to *Salix viminalis*

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SUMMARY

In view of the early interest shown in growing willows as a novel source of pulpwood in Northern Ireland a review of the pulp and paper properties of the genus *Salix* was carried out. In general pulp yields were acceptable and the quantities of chemicals consumed in the pulping process not excessive.

A practical evaluation of the pulp and paper properties of juvenile *Salix viminalis* stems indicated that the material could be pulped whole but chemical consumption was high. A high-strength pulp with barely adequate drainage properties was produced. This would tend to limit the range of paper types for which the pulp would be suitable but this range could probably be increased by using more mature stems from plants grown on a longer harvesting cycle.

INTRODUCTION

Projected world shortages of wood pulp from conventional forestry led, in 1973, to the initiation of studies in Northern Ireland to evaluate novel plant sources for the production of cellulosic pulps (Anon., 1975). Initial trials on a range of species suitable for growth on poorly drained land showed that species of willow (*Salix*) were most promising (McAdam, 1975). Subsequent research and extension work was carried out on the establishment, growth and harvesting of willows on such land (Anon., 1979; Stott, McElroy, Abernathy and Hayes, 1981). The emphasis of this work was later changed to include the growing of willows as a source of biomass.

It is an essential pre-requisite to embarking on any such programme that the final product is of adequate quality to be readily utilised. Following an extensive review of the literature, the pulping potential of willow was ascertained by carrying out a practical evaluation of the pulping quality of a sample of wood of *Salix viminalis*.

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PULP AND PAPER QUALITIES OF *Salix* spp.

The pulp and paper qualities of *S. babiana* (Dyer, Chase and Young, 1968), *S. viminalis* (Lebska, 1963; Janin and Durand, 1973), *S. vistulensis* and *S. americana* (Marchlewska-Srajer, 1957) and *S. aquatica-gigantea* (Hilf, 1956) have been studied (Table 1). In all these studies the samples were pulped using the Neutral Sulphite Semi-chemical process (NSSC) which combines mild chemical treatment of chips with mechanical separation of the fibres. The chemical stage consists of cooking the wood chips with sodium or mixtures of sodium sulphite and sodium bicarbonate at about 170°C. The cooling liquor is initially alkaline but reaches approximately the neutral point as it reacts with the wood. Cooking is discontinued when sufficient lignin has been broken down to enable the fibres in the chips to be separated with minimum power consumption in disc refiners. The remaining pulp is further washed to remove soluble lignin and then further delignified as necessary using bleaching compounds, giving a higher quality pulp with a corresponding reduction in pulp yield. (See Tables 1 and 5).

All the sources quoted state that willow produces a pulp of satisfactory quality. It is accepted that paper made from juvenile wood pulp will lack the physical properties normal in mature wood. Nonetheless, the pulp made from juvenile wood is adequate for the making of good quality corrugating medium, lower quality newsprint and writing papers.

The yields cited, except for those of 12 year old *S. babiana* (Dyer, Chase and Young, 1968) are satisfactory and the quantity of chemicals consumed in the cooking processes are not excessive. With juvenile wood no difficulty was encountered when the willow was not debarked.

EVALUATION OF THE PULP POTENTIAL AND PAPER PROPERTIES OF 1 YEAR OLD S. viminalis

Materials and methods

A sample of 1 year old *S. viminalis* variety 'Northern Ireland' (Scott, 1971) harvested in November from the Department of Agriculture for Northern Ireland's forest nursery at Muckamore, Co. Antrim, was taken to the Paper Industry Research Association (P.I.R.A.) at Leatherhead, Surrey, England where facilities were available for carrying out studies on the pulp and paper properties of raw materials potentially suitable for the paper industry.

Table 1: Summary of results of pulping conditions and yields of six willows (*Salix* spp.)

Species	Age (yrs)	Permanganate number	Sulphidity[1] %	Max temp (°C)	Time to max temp (hrs)	Active[2] Alkali %	Chemical to wood ratio	Yield % air dry raw material	Reference
S. viminalis (+bark)	2	16.9	30	170	1.5	20	—	46.9 (fibre)	Janin & Durand (1973)
S. babiana	12	16.3	25	171	1.0	25	10:1	34.0 (fibre)	Dyer *et al* (1968)
S. vistulensis (+bark)	3		18.7	160	2.0	21	5:1	51.2 (cellulose)	Marchlewska-Szrajer (1957)
S. americiana (+bark)	3		18.7	160	2.0	21	5:1	47.7 (cellulose)	Marchlewska-Szrajer (1957)
S. viminalis 'Clay Rod'			28.6					66-72	Lebska (1963)
S. aquatica-gigantea (+bark)	6							44-51.3	Hilf (1956)

(1) Sulphidity of the cooking liquor has the formula: $\text{Sulphidity} = \frac{Na_2S}{Na_2S + NaOH} \times 100$

(2) Active alkali is calculated as percentage NaOH

Sample preparation

Stems were cut into 5 cm lengths and, following crushing to increase surface area and subsequent rate and evenness of liquor penetration, were loaded into 1.8 litre digestion 'bombs'.

As the wood was green, a trial digestion was performed to assess the necessary range of pulping conditions. From previous experience at P.I.R.A. it was suggested that 10% sodium sulphite based on oven dry wood would produce a usable high yield unbleached pulp. From the trial digestion it was found that double this concentration would be required for green, immature *S. viminalis*. Unfortunately, while the pulping of green wood invariably provides the strongest pulps, chemicals contained in the wood, and in this case probably in the epidermal layers also, tend to neutralise the effectiveness of the cooking liquors. Fairly typical pulping conditions for hardwood, with the exception of higher liquor concentrations, were therefore chosen.

Processing

A 2x2 factorial experiment was carried out using an electrically heated multiple bomb digester unit. Details of the various processing conditions are given in Table 2.

After digestion, the washed material was dispersed in a propellor disintegrator. Despite the comparatively low yield values (Table 2), none of the pulps produced were properly dispersed. Further treatment was given in the form of disc refining, usually only necessary for semi-chemical pulps with a yield in excess of about 60%.

The conditions for refining were a gap setting between rotating and static discs of 25 micrometres and a pulp consistency of 5% (i.e. 5 g of fibre per 100 cm^3 water). The unresolved fibre bundles remaining after this treatment were screened out on a vibrating 150 micrometer slotted screen (Somerville fractionator).

Since the two pulps produced at the lower liquor concentration (20% Na_2SO_3) were of dark brown colour, indicating reprecipitation of the dissolved lignin, these were discarded.

The other two pulps were normal and similar in appearance but, due to the unexpectedly low yields, were in insufficient quantity to permit a full evaluation of each and were bulked together.

Simple hypochlorite bleaching was carried out to assess the bleachability of the pulp.

RESULTS

Sample material

The fresh wood sample had a moisture content of 48% and the outer epidermal layer was intact. The stems, 4-16 mm in diameter,

Table 2: Pulping details and pulp yields (% air dry wood) of 1 yr old. *S. viminalis* "Northern Ireland" shoots.

Digestion No.	Cooking Conditions				Cooking Liquor Residues		Bleach consumed	Total pulp yield	Yield[1] after screening
	Chemicals	Time (Hr)	Temp (°C)	Liquor Ratio	Na_2SO_3 consumed	pH			
1	20% Na_2SO_3 4% Na_2SO_3	2	170	4:1	20.0%	7.1	—	47.7	43.8
2	20% Na_2SO_3 4% Na_2SO_3	4	170	4:1	19.9%	7.0	—	45.5	43.9
3	25% Na_2SO_3 5% Na_2SO_3	2	170	4.4:1	20.0%	7.5	9.0% (combined sample)	46.7	45.0
4	25% Na_2SO_3 5% Na_2SO_3	4	170	4.4:1	24.0%	7.5		39.0	37.0

(Bleached yields were not measured as these would not be meaningful. Approximately 10% yield loss was assumed with this treatment).

possessed a pithy centre approximately one third of the total diameter. Pith cells do not contribute to desired paper properties and inhibit drainage. The cambium contained some bast fibre but not in sufficient quantity to have a significant effect on strength properties. Removal of bark, an essential prerequisite in the pulping of mature wood, was not necessary as only the first sign of its formation on the more easily dissolved epidermal layer was apparent.

Pulp bleachability

The chlorine consumption was not excessive, approximately 9% being consumed. Pulp colour was not as bright as might have been expected but commercial scale operation using a bleaching sequence of chlorine (aqueous), caustic soda extraction and chlorine dioxide, for example, would easily provide a pulp of good whiteness with economical consumption of chemicals.

Beating

The unbeaten pulp when made into laboratory sheets displayed a low apparent density compared with those quoted in the literature for willow pulps. The strengths were, however, high in comparison. This indicated that little or no beating was necessary, a fact comfirmed by experimentation. Using a laboratory PFI beater with a normal load and a pulp consistency of 10%, a maximum development was obtained after only 500 revolutions (Table 3). This is about one fifth of the energy needed for a hardwood such as birch and showed the young willow fibre to be weak for papermaking.

Table 3: Bleached pulp freeness (standard Canadian)

Beater	Load		Freeness
PFI	Heavy Load	2,500 rev	(305)
PFI	Light Load	2,500 rev	(305)
PFI	Light Load	500 rev	280
Unbeaten	—		390

N.B.: Bracketed figures indicate invalid results due to inversion because of fines loss.

The resultant pulp gave paper with exceptionally good tensile strength and burst resistance but with tear similar to that obtained from many commercial hardwood pulps. Stretch was, however, poor. (Table 4). The breaking length, burst, tear, grammage and bulk factors for test papers made from the pulp sample were similar to those obtained from willow pulps tested by other workers (Table 5).

Morphology

Due to the presence of pith and retention of the epidermal layers, there was a larger quantity of cells in this pulp than would normally be experienced. This led to problems associated with drainage during pulp washing and sheetmaking. In addition, a rough estimation of fibre dimensions showed that fibre length was lower on average compared with commercial hardwood pulps and that there was an excessive number of very short fibres of less than 0.5 mm. The longer fibres were interesting in that they possessed a greater diameter to length ratio and were of thinner wall thickness than normally experienced (Hyland, 1974). This accounts for the high strength, as an even deposition of fibres with considerable bonding potential is attainable.

Table 4: Physical test data of handsheets made from *S. viminalis* pulp tested at 23°C and 50% rh using method P1F TS 6311/19/5/1971 2nd draft.

		unbeaten	beaten 50 PF1
g/m^2	Grammage cond	68.6	64.7
	OD	62.7	59.2
cm^3/g	Bulk	1.47	1.32
$kPa/g/m^2$	Burst Factor	3.94	6.82
$mN/100g/m^2$	Tear Factor	575	522
m	Breaking Length	8160	11400
%	Stretch	1.3	1.9
		(1.2-1.4)	(1.7-2.1)

DISCUSSION

Pulping wood of the dimensions exhibited by this sample of young willow does not require the removal of the outer epidermal layer. Although, in the main, good overall strength paper may be produced, tear strength and an economic pulp yield would be improved if the wood were more mature.

Table 5: A summary of the physical properties of pulps and paper from some of the willows (*Salix* spp.) referred to in Table 1.

Species	Bulk	KPa/g/m² Burst Factor		Breaking Length (m)		Tear (mN/100g/m²)		Folding	Freeness (CSF)		Grammage g/m²	
	cm³/gm	Unbeaten	Beaten	Unbeaten	Beaten	Unbeaten	Beaten	Strength	Unbeaten	Beaten	Unbeaten	Beaten
S. babiana	1.5			6,430	8,630				492	354		70.0
S. vistulensis		1.7	6.7	4,460	11,480	33	98	633				
S. americana		1.8	5.9	4,460	10,330	49	54	322				
S. viminalis			5.7–		8,290–		67.70	750				
'Clay Rod'			6.5		9,820							
S. viminalis	1.3	5.4	26.8	1,900	5,300	23.3	60.2				65.2	65.5

However, the formation of bark would lead to difficulties in the necessary removal of bark from wood of less than 5 cms diameter by normal commercial practice in which logs in excess of 5 cms diameter are usually debarked.

The consumption of cooking liquors was comparatively high. Although lower consumption might well result from some seasoning before pulping, the coincident comparatively low yields suggests that hemicelluloses and some cellulose are being removed in solution. More mature wood might well provide a more economical operation but it is also possible that research into less conventional chemical concentration and treatment conditions would give better results.

Yields in excess of 60% from mature wood might be feasible, while a bleached pulp of 45% yield should be attainable by conventional processes. It is estimated that the comparable yield range for the sample under evaluation would be 35-50%. The yields of pulps from this samble (Table 3) were similar to those obtained for two year old *S. viminalis* by Janin and Durand (1973) and are within the range of values reported from other tests carried out on willow as a raw material for pulp (Table 5).

With mature woods, neutral sulphite pulps are quoted with whiteness values of 68% whereas the maximum whiteness obtainable with single stage hypochlorite bleaching of year old growth appears to be only about 47%.

The wood appeared not to have an exceptional number of vessal elements present, nor were the epidermal cells likely to cause problems. Cells from the pithy centre, however, could create problems in, for example, printing papers since they would be difficult to screen out from a pulp and would cause 'picking' during printing.

A rough comparison of fibre length with that of a good commercial hardwood pulp is:

Fibre length	Useful minimum	Maximum	Approx. Mean
Commercial pulp	0.6	1.9 mm	0.9 mm
Willow pulp	0.4 mm	1.6 mm*	0.5 mm

* excluding bast fibre

The width of willow fibres tends to be narrower than that of the typical hardwood, approximately in the ratio 3:5.

On beating, the willow fibres tend to retain their shape and stiffness and, since beating must be of low intensity, little or no fibrillation occurs. Compared again with the commercial pulp, the willow fibres have high initial bonding potential which develops on beating to a very high level. These observations correspond to the measured poor tear and very high tensile and burst strengths.

The drainage properties of the willow pulp were not easily measured as many fine fibres passed through the apparatus with the water. Values obtained, however, suggest that the pulp would be relatively difficult to handle but would run on most paper machines. In drainage properties this willow resembles a bleached beech pulp — a pulp which has limited use in some printing and writing papers.

CONCLUSIONS

One year old *S. viminalis* 'Northern Ireland' could be pulped whole but chemical consumptions would be high.

In whole stem pulping there was not sufficient bast fibre present to enhance the tear resistance of paper produced. The pulp would need careful treatment but has the advantage of producing high strength (except tear) and even formation with the expenditure of very little energy.

Drainage properties were just adequate but there would be a limited number of paper types for which the pulp would be suitable. It is possible that with a true semi-chemical pulping the material could form a good fluting medium for corrugated boards. Many properties, at present creating disadvantages in use, could be improved by allowing the willow to mature before harvesting. Other aspects, particularly economic, could also possibly be helped by a longer harvesting cycle.

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