

8 Non-energy uses of switchgrass

8.1 Introduction

Switchgrass is a C4 grass native to the North American Tall grass prairies. It was first collected and utilised for erosion control in the 1930's. For this purpose it is still being used. Other uses include as a fodder crop during hot and dry summer periods. In the last 15r years switchgrass has been developed for energy (power) and ethanol production mainly in the USA and Canada. In more recent years switchgrass has also been evaluated for paper pulp production, fibreboard and as a reinforcing fibre for composite materials where it may replace fibreglass.

Thermal conversion of switchgrass is presented in the previous chapter. In this chapter we will present short studies to establish the suitability of switchgrass as a feedstock for:

- Paper pulp production (Chapter 8.2)
- Fibre reinforced composites (Chapter 8.3)
- Production of ethanol through lignocellulose to ethanol processes (Chapter 8.4)

8.2 Switchgrass as a raw material for paper pulp production

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Introduction

Although non-wood fibres have been used for papermaking during two millennia, the use of non-wood fibres is limited to about 9% of the world pulp production. China and India are the most important users of non-wood fibres in pulp and paper production. There is an increasing interest in non-wood fibres as a source for pulp and paper production as a result of the environmental problems that arise due to increasing harvesting from wood.

A part of the non-wood fibres exists of long fibres that can be used in specialities like cigarette-, bible-, teabag- and security paper. The bast fibres of hemp and flax and abaca fibres which are longer than softwood are used for this type of specialities.

The main part of non-wood fibre pulp is produced from short fibre sources like straw and bagasse. These pulps are comparable with hardwood pulps that are normally used in printing and writing papers. Short fibres are mainly used to give good surface properties or stiffness to paper and board. The quality of short-fibre pulp is better defined by the number of fibres per weight, fibre stiffness and optical properties, than by strength properties.

Switchgrass is one of the non-wood short fibre sources that have been studied recently for application in paper (Girouard, and Samson, 2000; Goel, et al., 1998; de Jong et al., 1998; Law et al., 2001; Madakadze et al., 1999; Radiotis et al., 1999; Ruzinsky and Kockta, 2000). Especially in Canada this crop is seen as an alternative for hardwood pulps. Compared to aspen the number of fibrous elements smaller than 0.2 mm is high, but the length-weighted average of about 1-mm is comparable (Law et al., 2001).

Chemical pulping

Several authors describe the quality of switchgrass pulp made with different pulping processes. These processes can be separated in low yield chemical processes and high yield mechanical processes. Table 1 gives an overview of their results regarding to yield, optical and strength properties after pulping with different chemical process. As paper properties are depending on the freeness, they should be compared at the same freeness levels. Most of the strength properties are somewhat lower than those of typical birch or eucalypt pulp, but if switchgrass pulp is used in printing or writing papers this is not a disadvantage. Remarkable is the high bulk of the switchgrass pulp, which makes it profitable to add switchgrass pulp in pulp mixtures for high bulk printing and writing papers. In a total chlorine free process (TCF) switchgrass is

easy to bleach to high brightness levels (Radiotis, et al., 1999). The yield is in the same order of that of chemical pulps of hardwood.

One of the disadvantages of chemical pulping of non-wood fibres is that they can contain high concentrations ash and/or silica. Well known is the high concentration of ash in cereal straws and the extreme ash content of 18% in rice-straw. Silica causes wearing- and scaling problems in the chemical recovery. Law et al. (2001) report an ash content of about 5% for switchgrass, but Samson and Mehdi (1998) report a much lower concentration of 1.7%. In the current project ash contents of 1.8, 1.9 and 4.4% are reported, depending on the soil type and other conditions. So ash content of switchgrass is low compared to other non-wood fibres, nevertheless wood has normally an ash content below 1%. The ash content must be kept as low as possible by choosing the right soil and preventing that adhering soil is harvested with the grass. Because leaves will fall off, over-wintering is also an expedient that can lower the ash content (Law et al., 2001). It can also raise the average fibre length (Radiotis, et al., 1999) and improve the bleachability (Goel, et al., 2000). The yield will be lower, but the quality of the fibres will improve. Improvements are also possible by using refining methods that remove part of the leaf and node fraction.

Mechanical pulping

Table 2 gives an overview of the different mechanical pulping processes applied to switchgrass and the comparison with aspen APMP pulp, which is the most common hardwood mechanical pulp.

The strength properties of the switchgrass pulps are at the lower site of the aspen pulps.

Except for the tear-index the Alkaline Peroxide Extrusion Pulp of Switchgrass distinguishes itself from the other switchgrass mechanical pulps by its higher strength properties. As with chemical pulps, the bulk of switchgrass pulp is higher than the bulk of hardwood pulps. The mechanical pulps described by Ruzinsky and Kokta (2000) did not undergo a bleaching step. The bleaching of the extrusion pulp was integrated in the process. The brightness was low compared to aspen APMP pulps, but optimisation of the process is still possible by adjusting the Alkaline and Peroxide concentrations, the consistency and incorporation of a washing/pre-treatment stage.

The opacity of the AP extrusion pulp is low compared to the optimal bleached aspen pulp.

Mechanical pulp from switchgrass can replace a part of hardwood mechanical pulps in printing papers if brightness and opacity can be improved. The bulk of the papers will be increased. The yield is low compared to mechanical wood pulps that normally is in the range of 85-95%.

The energy needed to produce mechanical pulps forms a substantial part of the costs of a mechanical pulp. A commercial mechanical pulp normally requires 1200-1800 kWh/ton. The energy needed for an AP extrusion pulp of switchgrass is only 400 kWh/ton.

Ruzinsky and Kokta (2000) report that switchgrass needs half to three quarters less energy for high yield pulping of aspen. So regarding the energy costs the production a mechanical pulp of switchgrass is much cheaper than of a hardwood mechanical pulp.

Addition of switchgrass pulps to pulp mixtures for printing and writing papers is profitable. It will give a higher bulk and lower energy costs in mechanical pulping. Data with respect to printability are not yet available. Further research in that field is necessary.

Other aspects

Studies show that switchgrass is comparatively inexpensive to produce. In the current study the price of switchgrass biomass appears to be favourable compared to other perennial grasses. Economic studies (Fox et al., 1999) indicate that switchgrass should be an attractive crop especially on marginal soils that have restricted uses because of low fertility, erosion, or for example strict environmental controls switchgrass may be an attractive crop for paper pulp production.

Conclusions

Switchgrass can replace a part of the hardwood pulps in printing and writing papers. Due to its high bulk it will especially be suitable for bulky printing papers.

Mechanical pulping of switchgrass needs far less energy than mechanical pulping of aspen or other woods. The high productivity under low input conditions results in low cost per tonne of biomass making switchgrass a potentially cost effective replacement for hardwood pulps in printing and other paper types.

References

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Table 1: Chemical pulps from switchgrass.

		Switchgrass Kraft	Switchgrass Soda-AQ	Switchgrass Kraft TCF (OZEQPo)	Switchgrass Kraft	Switchgrass soda	Switchgrass Sulphite *	Birch Kraft	Birch Kraft	Eucalypt Kraft	Eucalypt Kraft
Yield	(%)	50	48	45	50	44	60-80				
CSF	(ml)	417	289	310	407	100	100	362	320-450**	290-420**	320-450**
^o SR								27.1	25	28	25
Bulk	(cm ³ /g)	2.1	1.9	1.5	2.1		4.5-3.6	1.2	1.4	1.3	1.7
Tensile index				61.8	74.9	87	22-36	74			
Breaking length	(km)	6.9	8.3	6.3	7.7	8.9		7.5	7.0	6.5	6.2
Stretch	(%)	1.6	1.8	3.1	2.0			3.9			
Burst index	(kPa m ² /g)	3.6	4.5	3.6	4.2	5.6	0.8-2.2	4.9		5.1	
Tear index	(mN m ² /g)	5.2	5.1	4.7	6.7	8.5	4.5-6.8	7.9		8.1	
Brightness	(%)			87.2	29.3	30	30-40	84.1		81.8	
Opacity	(%)				97.7		92-98	71		75.6	
Source		Goel, et al., 2000	Goel, et al., 2000	Radiotis et al., 1999	Madakadze, et al., 1999	Law, et al., 2001	Law, et al., 2002	ATO result	Rydholm, 1985	ATO result	Rydholm, 1985
* production of high yield chemical pulps with different concentrations of different carbonates											
** interconversion from Schopper-Riegler to Canadian Standard Freeness according to Tappi TIP 0809-01											

Table 2: Mechanical pulps from switchgrass

		Switchgrass AP Extrusion	Switchgrass CTMP	Switchgrass CMP	Switchgrass SEP	Aspen APMP	Aspen* APMP	Aspen* APMP
Yield	(%)	70-80	79	68	66			
CSF	(ml)	170-260**	100	100	100	213	200-290**	170-260**
^o SR		42					38	42
Bulk	(cm ³ /g)	1.8	4.3	4.1	3.5	2.47	1.66	1.33
Tensile index								
Breaking length	(km)	5.1	2.3	3.3	3.5	3.1	3.6	6.1
Stretch	(%)							
Burst index	(kPa m ² /g)	3.1	0.8	1.3	1.6	1.1	2.3	3.5
Tear index	(mN m ² /g)	3.4	4.5	6.5	6.5		2.8	4.7
Brightness	(%)	52.2	38	26	31	70.8	82.9	81.8
Opacity	(%)	72.5	99	97	96	87.6	77	74
Porosity	(ml/min)	417	1300	230	220		1890	140
Source		de Jong, et al., 1998	Ruzinsky, 2000	Ruzinsky, 2000	Ruzinsky, 2000	Xu E.C., 2001	de Jong, et al., 1998	ATO-result
* Two different pulps								
** interconversion from Schopper-Riegler to Canadian Standard Freeness according to Tappi TIP 0809-01								

8.3 Switchgrass (*Panicum virgatum* L.) as a reinforcing fibre in polypropylene composites

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A study on the suitability of switchgrass as a stiffening and reinforcing agent in polypropylene (PP) composites was executed. The results have been presented in a paper that has been submitted for publication in the Journal of Applied Polymer Science⁷.

Abstract

In this study the switchgrass (*Panicum virgatum* L.), a biomass crop being developed in North America and Europe, was tested as a stiffening and reinforcing agent in polypropylene (PP) composites with and without maleic anhydride grafted PP (MAPP) as a compatibilizer and to evaluate the effect of pulping and different sources of switchgrass on composite characteristics. The refiner pulping yield for two switchgrass varieties was estimated between 70-80%. The addition of 30% (by weight) switchgrass pulp resulted in an increase of the flexural modulus by a factor of about 2.5 compared to pure polypropylene (Table 3). Which was only slightly lower than values found for jute and flax. The flexural strength of PP composites reinforced with pulped switchgrass and MAPP was almost doubled compared to pure PP and approached values found for jute and flax. The compatibilising effect of MAPP has been visualised by micrographs. The good mechanical properties are achieved despite the severe fibre length reduction as a result of thermoplastic compounding which is shown by fiber length analysis. The impact strength of switchgrass/PP composites was much lower than for pure PP. The use of different switchgrass varieties and harvesting time had a minor to no effect on the mechanical performance of the respective composites. The chemical composition of different varieties was fairly constant. The low price and the relatively good mechanical characteristics should make switchgrass an attractive fiber for filling and stiffening in thermoplastic composites. Further improvement of composite mechanical properties by improved pulping should be possible.

Table 3. Flexural and Charpy impact properties of switchgrass fiber reinforced PP and PP/MAPP composites.

Fibre ^a	MAPP	Flexural modulus ^b	Flexural strength	Strain	Charpy unnotched impact strength
		----- Mpa -----	----- % -----	----- kJ m ⁻² -----	
--	No	1210 ±74	42.6 ±1.5	6.9 ±0.2	51.8 ±12.5
--	Yes	1384 ±43	45.9 ±0.6	6.7 ±0.2	93.2 ±8.2
30% A	No	2764 ±105	47.0 ±0.6	3.6 ±0.1	7.0 ±0.9
30% B	No	2718 ±44	48.8 ±0.8	3.7 ±0.1	7.0 ±1.8
30% pulped A	No	2841 ±42	47.5 ±0.6	3.1 ±0.2	9.5 ±1.4
30% pulped B	No	2900 ±203	48.2 ±0.5	3.0 ±0.1	10.0 ±0.7
30% A	Yes	2721 ±159	56.6 ±1.1	3.5 ±0.1	8.3 ±1.1
30% B	Yes	2672 ±101	58.7 ±0.6	3.7 ±0.2	8.1 ±1.2
30% C	Yes	2650 ±126	54.1 ±0.9	3.4 ±0.2	7.6 ±1.5
30% D	Yes	2795 ±88	58.6 ±1.2	3.4 ±0.2	8.3 ±1.4
30% pulped A	Yes	3003 ±58	69.6 ±0.5	4.1 ±0.2	15.1 ±1.3
30% pulped B	Yes	3147 ±81	70.7 ±0.5	4.1 ±0.2	16.9 ±1.3
30% jute ^c	Yes	3500-3900	64-77	4.5	25
30% flax ^c	Yes	3500	76	4.5	25

^a A = Cave-in-Rock switchgrass, harvested in spring Canada; B = Cave-in-Rock switchgrass, harvested in fall in Canada; C = Kanlow switchgrass, harvested in winter at Rothamsted; D = Cave-in-Rock switchgrass, harvested in winter at Rothamsted. ^b Values are ± standard deviation. ^c Data obtained during separate research programs at ATO. These data are included for comparison reasons only.

⁷ Oever, M.J.A. van den, H.W. Elbersen, E.R.P. Keijsers, R.J.A. Gosselink and B. de Klerk-Engels. 2002. Switchgrass (*Panicum virgatum* L.) as a reinforcing fibre in polypropylene composites. Submitted to the Journal of Applied Polymer Science.

8.4 Estimate of the potential production of ethanol through a lignocellulose to ethanol processes based on chemical composition of switchgrass samples.

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In Table 4 the chemical composition of switchgrass is presented. From this we can make an estimate of the potential ethanol production which can be produced through lignocellulose to ethanol processes.

Table 4. Chemical composition of untreated and pulped switchgrass samples from different sources. Kanlow and Cave-in-Rock produced on a sandy site in Wageningen in the second growing season and harvested in winter.

	Kanlow	Cave-in-Rock	Pulped Cave-in-Rock	Radiotis ^a	Madakadze ^a
Ash	1.9	1.8	2.6	1.5	4.8
Extractives	10.4	9.5	- ^b	1.6 ^c	6.9 ^d
Lignin	18.9	19.5	22.5	21.8	23.9
Cellulose	30.5	28.8	33.6	43.4 ^e	43.4 ^e
Hemi-cellulose	30.4	31.2	31.5	35.9	30.5
Pectin	1.4	1.3	1.7	-	-

^a Literature references: Radiotis, T., Li, J., Goel K. and Eisner, R. Fiber characteristics, pulpability, and bleachability studies of switchgrass. TAPPI Journal 1999, 82, 100-105; Madakadze, I.C. Physiology, productivity and utilization of warm season (C4) grasses in a short growing season area. PhD thesis, McGill University, Montreal, Quebec, Canada, 1997.

^b Pulp characterized without prior extraction.

^c Alcohol/benzene extractives.

^d Cold water, hot water and acetone extractives.

^e Alpha-cellulose.

A calculation can be made of the potential ethanol production by adding up all the fermentable components and assuming that:

- Holocellulose (cellulose + hemi-cellulose) + pectin has a yield of $0.80 * 1.1 * 0.47 = 0,41$
- Conversion of starch to sugars and fermentation has a yield of $1.1 * 0,47 = 0,52$
- Fermentation of sugars has a yield of 0.47

This gives an ethanol yield of 262 kg ethanol/tonne dry matter for second year winter harvested Kanlow and Cave-in-Rock samples grown at a sandy site in Wageningen. This yield is comparable to the theoretical ethanol yield from hard wood like willow.