Drying Characteristics of Bleached Wheat Straw Pulp

Tuija Johansson, Jouni Paltakari, Zhisheng Cheng and Hannu Paulapuro

ABSTRACT:-- The drying behaviour of pure wheat straw pulp compared to birch pulp was studied using the single-sided contact drying simulator.

Dryer simulation results imply, that wheat straw-based pulps should not cause significant dewatering problems in the drying section compared to birch pulp at a specific schopper-Riegler level. If the paper machine is dryer-limited, the final moisture ratio of the paper can be higher if wheat straw pulp is used instead of hardwood pulp.

***KEYWORDS**: Non-wood fibres, straw, drying, evaporation rate, dewatering, critical moisture.*

INTRODUCTION

Non-wood fibres such as wheat straw, reed, bagasse and rice straw are widely used in the pulp and paper industry in countries with limited wood resources. These pulps have recently also attracted attention in other papermaking countries as an alternative to hardwoods such as birch (1). One of the main problems with non-wood fibres as a raw material in pulping and papermaking is that they have poorer dewatering properties than wood pulps.

In previous studies (2,3) the dewatering properties of wheat straw pulp have been discussed from the viewpoint of the wire and press sections of the paper machine. In the present work, drying dewatering curves are presented for wheat straw and birch pulps and the drying characteristics of wheat straw pulp are briefly discussed.

EXPERIMENTAL

The handsheets used in experiments were made from never-dried hypochlorite-bleached wheat straw soda pulp from China (*Triticum spp*) with a Schopper-Riegler degree of °SR 23 before beating and never dried Scandinavian birch (*Betula verrucosa*) from Finland both with a grammage of 160 g/m². All four samples were wet-pressed at 1.7 bar to an initial moisture ratio of 1.85 g of water/g of fibre.

Four test points were researched: Bleached birch kraft pulp (°SR 21) B21 and wheat straw beaten to three different Schopper-Riegler degree (°SR 23, 32 and 40) WS23, WS32 and WS40.

The sheets were dried on the single-sided contact dryer simulator described in a previous publication (4). The apparatus was modified for continuously measuring the rate of evaporation from a moist sheet. Sheets were held against a convex hot surface by tensioned steel bands situated at the edges of the sheet and evaporation occurred over the open surface. The dewatering rate of the sheet was continuously registered by a scale under the hot plate. Both the hot surface and the air inlet parameters, shown in Table 1 (*See on next page*), were kept constant throughout drying.

Helsinki University of Technology, Laboratory of Paper Technology, Vurimiehentie 1A, FIN-02150 Espoo, FINLAND

Table 1 conditions in drying experiments.

Temperature of the hot surface	95 ± 1°C
Temperature of the inlet air	60±1°C
Air flow into the hood	$36 m^3/h$
Moisture of the inlet air	15 g H_2O/Kg dry air

The conditions within the contact dryer simulator differ from those in conventional cyclical drying, although the surface temperatures and moisture ratios in the sheet resemble conditions in conventional cylinder drying. Results from the simulation can be used to predict the dewatering behaviour of a web in conventional cylinder drying.

DEFINITION OF EVAPORATION RATE PARAMETERS

The evaporation rate is defined as:

$$m/A=-W.\delta z/\delta t, \ (gH_2O/m^2s) \qquad /1/$$

where

m is mass flow (gH_2O/s)
A is area, (m^2)
W is oven dry grammage of the sheet, (g/m^2)
$\delta z/\delta t$ is derivative of moisture vs, time, (1/s)

In the present work moisture ratio is given by:

$$z=(1-DS)/(DS), \ (gH_2O/g \text{ dry fibre}) \qquad /2/$$

where

DS is the dry solids of the sheet, (g dry fibre/g moist fibre)

When the overall evaporation rate is plotted against the moisture ratio, four drying zones can be distinguished; A warm-up zone, a constant-rate zone, a first falling-rate zone and a second falling-rate zone. The constant and falling-rate zones can be illustrated by a sharp transition in the evaporation rate, corresponding to the critical points.

To calculate the critical points (1 cp and 2cp) from the evaporation rate curve, a new mathematical method was developed. In this method the evaporation rate curve is integrated and a point (dp) which divides the area below the curve into two equal sections is determined, A line from this point to the origin is drawn and the maximum distances between the line and the evaporation rate curve are determined as corresponding to the 1cp and 2cp. The calculation was carried out with the Mathematica[R] computer software. A simplified idea of the definition of 1cp and 2cp is given in Fig. 1.

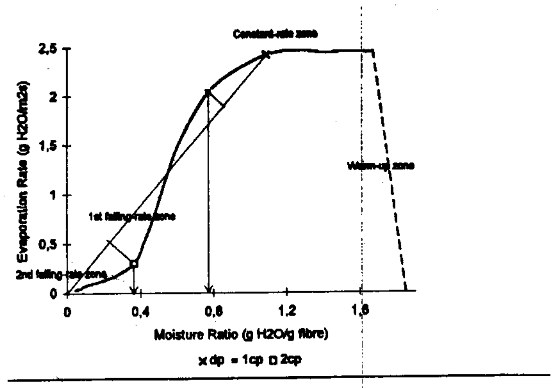

Fig. 1 Definition of critical points 1cp and 2cp.

The overall evaporation rate and the position of critical points is influenced both by heat and mass transfer conditions and the structure and composition of the porous sheet. Furthermore, the amount of water fractions varies as a function of the the moisture ratio, and the moisture gradient throughout the sheet is not uniform. This makes unambiguous determination of drying behaviour difficult. In this experiment drying conditions were kept constant and therefore the position of the critical points gives a meaningful way to compare pulps. However, it is important to note that 1cp and 2cp do not correspond to any exact values of water fractions/5/; 1cp gives a very rough estimate of the amount of free water which is easily removed. 2 cp can be interpreted as an estimate of a point separating regions of free and bound water.

RESULTS AND DISCUSSION

The evaporation rate-to-moisture ratio 0.05 g of water/g of fibre is given for all test points in Fig.2. The warm-up zone is missing because data recording started at the end of the warm-up zone.

The comparison of evaporation rates of WS23, WS32 and WS40 shows that evaporation rates under these drying conditions are almost equal for all wheat straw samples in the constant-rate zone, which is not generally the case when the beating degree varies. The maximum instantaneous evaporation rate, at dp, is about 26% higher for B21. This may be partly due to the lower thickness of B21 compared to wheat straw samples.

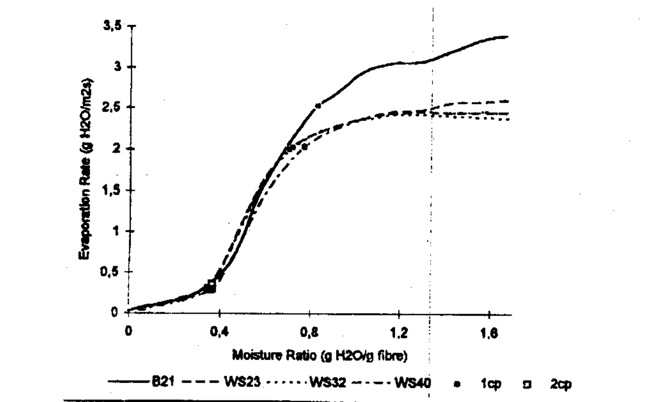

Fig. 2 Evaporation rate curves for B21, WS23, WS32 and WS40.

Beating reduces the thickness of the sheet and makes it denser, causing generally higher heat and mass transfer in the sheet, which in turn increase the overall evaporation rate in the initial drying phase. Furthermore, beating reduces surface irregularities which improves the contact heat transfer coefficient at the hot surface. On the other hand, beating increases fibrillation and water holding capability. Water is forced to penetrate through narrow capillary passages between the closely compacted fibres /6/. This can be seen as earlier decreasing evaporation rate for WS40 compared to WS23 and WS32 in the first falling-rate zone.

The cp1 values were achieved in the following descending order: B21>WS40>WS32>WS23. It should be kept in mind that the thickness of the sheet and drying rate may influence cp1 to some extent.

2 cp values are alomost the same for all wheat straw samples. It is quite natural because beating does not have a significant effect on the amount of bcund or hydrated water /5,6/. Also 2cp for B21 is very close to those for wheat straw.

Results indicating poorer dewatering properties of non-wood pulps compared to wood pulps have been reported in previous publications /7, 8/. The primary differences are that relative to birch pulp, wheat straw pulp:

- has longer average fibre length and narrower fibre width /9/- more slender fibres,
- has bigger surface area - slimmer fibres with more fines presents,
- has more flake-shaped fines,
- has highly swollen fibres - higher WRV, hemicellulose and acidic group content,
- has higher amount of non-fibre cells like parenchyma cells,
- has lower compressibility.

All these factors influence the drying dewatering curves, with complicated interaction, Shorter and more easily compressible birch fibres form a denser structure than wheat straw fibres, which increases heat and mass transfer compared to wheat straw, especially at the beginning of drying. The high amount of fines in wheat straw pulp improves the contact heat transfer coefficient at the hot surface. At the same time, flake-shaped fines fill up the structure of the sheet, and water must penetrate through narrow winding paths, which in turn reduces dewatering. On the other hand, the less dense structure of wheat

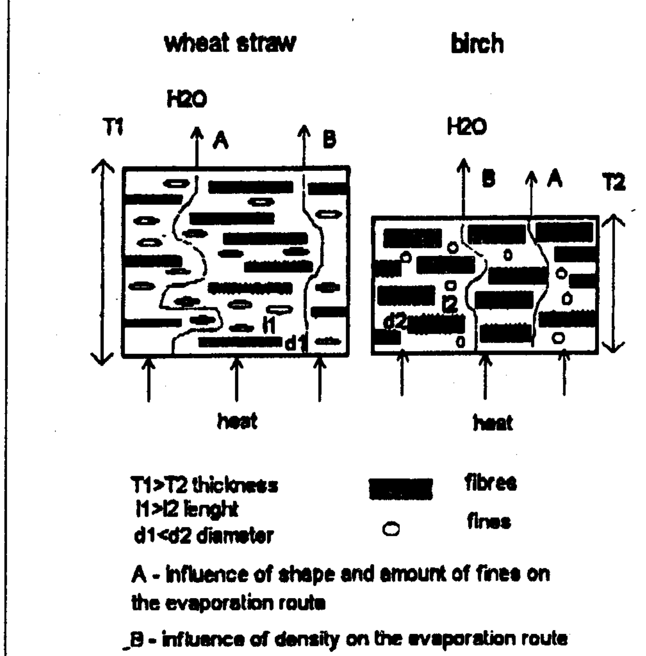

Fig. 3

straw promotes vapour diffusion inside the sheet. Furthermore, the greater swelling of wheat straw fibres increase their water-holding capability compared to birch fibres. A sketch illustrating some of these factors in the cross-section of the sheet is shown in Fig. 3.

Fig. 3 A simplified sketch illustrating some factors which affect water passage through the cross-section of the sheet. Note: not to scale.

It is important to note that the warm-up and constant-rate zones are only 11-16% of the total drying time required to dry a sheet to the final (0.05 g water/g dry fibre) dryness. To establish better falling-rate zones, the measurements of moisture ratio and evaporation rate against time were subdivided into two periods as shown in Fig. 4 and Fig. 5.

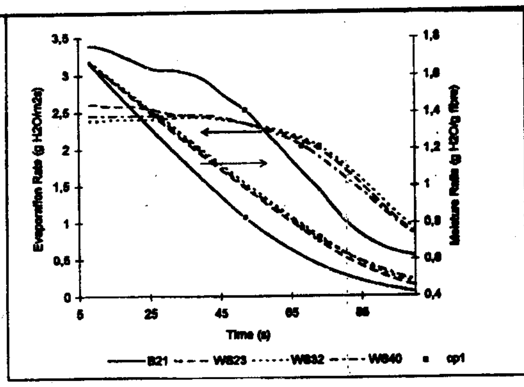

Fig. 4 Sheet Moisture ratio and evaporation rate vs. drying time during constant-rate zone for B21, WS23, WS32 and WS40.

In the limited time from 100 to 700 s. more water has been removed from the less beaten samples. The most notable result is that WS23 and B21, with nearly the same beating degree, end up with the same moisture ratio. Drying times up to final dryness are also almost identical for WS23 and B21. Higher air permeability measured for dried WS23 may explain the diminishing dewatering differences between B21 and WS23 as drying progresses. Earlier experimental findings with wood and non-wood pulps /1/ support these discoveries.

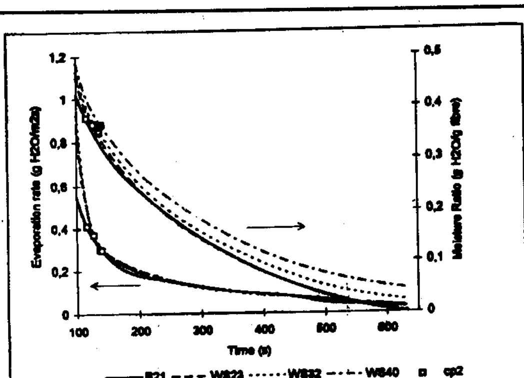

Fig. 5 Sheet moisture ratio and evaporation rate vs. time during 1st and 2nd falling-rate zone for B21, WS23, WS32 and WS40.

Besides the dewatering rate web runnability is very important for the efficiency of the drying section, It was clearly observed during the drying trials that wheat straw pulp had considerably lower wet strength and much higher paper shrinkage tendency than the birch pulp. Lower wet strength combined with a lower evaporation rate may cause increased break frequency especially in the early stages of drying.

Results from dryer simulations and some paper and pulp properties are summarised in Table 2 and 3.

Table 2 Critical points, maximum instantaneous evaporation rates and drying times for B21, WS23, WS32 and WS40.

Sample	Icp	2cp	Max. rate	Time to 0.18 g/g	Time to 0.05 g/g
	(g/g)	(g/g)	(g/m²s)	(s)	(s)
B21	0.83	0.38	3.02	260	463
WS23	0.71	0.37	2.40	258	464
WS32	0.72	0.35	2.38	272	508
WS40	0.77	0.37	2.42	305	607

* Measured at dp

Table 3 Paper and pulp properties for B21, WS23, WS32 and WS40.

Sample	Porosity*)	Thickness**)	WRV(3)
	(ml/min)	(μm)	(%)
B21	420	260	179***
WS23	500	310	189***)
WS32	195	290	
WS40	105	270	

*) Measured with Bendtsen porosity meter, **) After drying, ***) At Shopper-Riegler level °SR 26.

Research related to fibre properties - i.e. structure, chemistry and bound water content, as well as pilot-scale drying trials should be done in order to further clarify the drying characteristics of wheat straw pulps.

CONCLUSIONS

A comparison of wheat straw and birch at the same Shopper-Riegler level indicates that wheat straw pulps have higher evaporation resistance at the beginning of drying. In the later stages of drying the differences diminish as drying progresses into the hydroscopic region.

In views of industrial requirements, the analysis of the drying simulation results reveals that wheat straw-based pulps should not cause significant dewatering problems in the drying section compared to birch pulps at a specific Schopper-Riegler level. If the paper machine is dryer-limited, the final moisture ratio of the paper can be higher if wheat straw pulp is used instead of hardwood pulp. A lower wet strength of wheat straw pulp combined with a lower evaporation rate may cause runnability problems especially, at the beginning of the dryer section.

ACKNOWLEDGEMENTS

The authors wish to thank valmet Corporation and Academy of Finland for financial support, Mr. Kaarlo Nieminen, MS for his help in solving mathematical problems and Mr. Qinghua Ye for his skilful laboratory testing.

NOMENCLATURE

B21	birch pulp at SR° 21
WS23	wheat straw pulp at SR°23
WS32	wheat straw pulp at SR° 32
WS40	wheat straw pulp at SR° 40
1cp	first critical point
2cp	second critical point
dp	a point which divides the area below integrated evaporation rate curve into two equal sections
m	mass flow, (g H_2O/s)
A	area, (m^2)
W	oven dried grammage, (g/m^2)
z	moisture ratio, (g H_2O/g dry fibre)
DS	dry solids, (g dry fibre/g moist fibre)
t	time, (s)

REFERENCE

1. Paavilainen, L., Paltakari, J., Cheng, Z., Tuhkanen, T., Behaviour of Special Reed Pulp on the Paper Machine. The Third Non-Wood Pulping and Papermaking Conference, Oct. 15-18, 1996, Beijing. (To be published)

2. Cheng, Z, Paulapuro, H., Vaccum Dewatering of Wheat Straw Pulp. The Third Non-Wood Pulping and Papermaking Conference, Oct. 15-18, 1996, Beijing. (To be published)

3. Cheng, Z., Paulapuro, H., Wet Pressing of Wheat Straw Pulp. (To be published)

4. Karlsson, M., Soininen, M., Paltakari, J., Paulapuro, H., A. Simulation Model for Board and Paper Machine Dryer Section. The 29th National Heat Transfer Conference, Aug. 8-11, 1993, Atlanta, GA, p. 9-16.

5. Maloney, T., Johansson, T., Paulapuro, H., The Porous Structure and Drying Behaviour of some Unbleached Kraft Pulps. (To be published)

6. Campbell, W., A Physical Theory of the Beating Process. Paper Trade Journal 1932, 8, p. 81-85.

7. Cheng, Z., Leminen, J., Ala-Kaila, K., Paulapuro, H., The Basic properites of Chinese Wheat Straw Pulp. Proceedings of Tappi Pulping Conference, Nov. 6-10, 1994, San Diego, C.A, p. 735-744.

8. Cheng, Z., Paulapuro., Influence of Fines on Free Drainage of Wheat Straw Pulp. The Third Non-Wood Pulping and Papermaking Conference, Oct. 15-18, 1996, Beijing (To be published)

9. Fineman, I., Wagberg, L., Shiun, K., Straw Pulp as a Material for Offset Paper-Problem and Solutions, vol. 2 Jul. 11-14, 1988, Beijing, p.621.