Influence of papermaking system closure on paper properties

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ABSTRACT: Papermaking system closure causes an inevitable increase of fines and organic and inorganic substances in the process water. The accumulation of these substances can significantly reduce product quality and process efficiency. To effectively close the process water circuit, mills must understand the influence of the level of papermaking system closure on product quality and process efficiency. To examine the influence of papermaking system closure on paper properties, we used reverse osmosis technology to prepare highly contaminated white water. We used that water to form handsheets from linerboard, newsprint, and fine paper stocks. Results showed that the quality of process water affected the strength properties of these paper grades. We also examined the influence of colloidal and dissolved materials on linerboard properties. Results showed that the amount of colloidal substances in the process water—rather than the amount of dissolved substances—is critical for sheet strength.

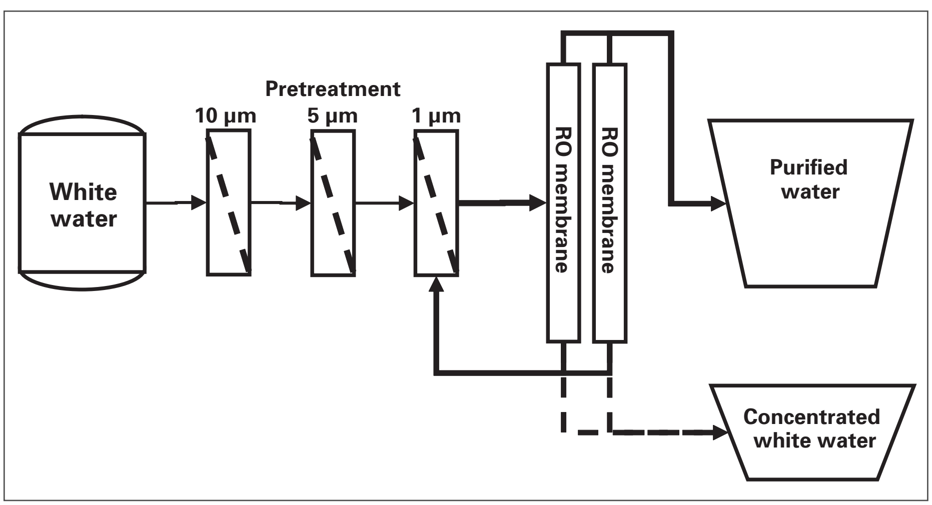
Application: This study may help mills evaluate and cope with some of the advantages and disadvantages of closing process water loops.

Closing up the process water loops in paper and paperboard mills has tremendous environmental appeal. In addition, there are significant economic benefits to this system closure in terms of fiber and energy savings. Papermaking system closure, however, often results in negative consequences due to the accumulation of organic, inorganic, cationic, and anionic materials in the process water. The amount of fines and colloidal materials also increases with system closure [1-3].

The changes of papermaking process water quality that accompany the system closure often reduce paper quality and runnability [4-7]. Dexter [8] has shown the effects of contaminants on the physical properties of linerboard. Dissolved and colloidal substance are among the critical substances that reduce strength properties. Despite the detrimental effects of the system closure on product quality, many mills wish to increase the level of their system closure to cope with ever-tightening environmental regulations and to take economic advantages.

When a paper mill plans to close its papermaking water circuit, it must know the changes that may occur in its product quality. If they can predict and ascertain the product quality changes associated with closing the water circuit, they can better decide whether to go ahead with closing that process. Information on the product quality changes accompanying system closure is particularly needed to reasonably determine how much the system can be closed while still meeting product quality specifications. Answering that question requires a systematic and logical approach. All related experimentation needs to be carried out using the white water and stock samples that represent the target process in a highly closed situation.

The immediate purpose of this study was to examine the influence of papermaking system closure on some properties of paper products, and to evaluate the significance of the colloidal contaminants on linerboard properties.



1. Procedures for concentrating white water.

MATERIALS AND METHODS

Process waters obtained from the white water silos of fine paper, newsprint, and linerboard mills were concentrated using reverse osmosis technology. Before treatment with reverse osmosis membranes, the white water was filtered using coarse filters with pore sizes of 10, 5, and 1 µm (**Fig. 1**). The white water was concentrated until the volume decreased to 1/6 to 1/10 of its original volume. Properties of the concentrated white water, including pH, conductivity, COD, turbidity, cationic demand, total dissolved solids, and surface tension, were determined by conventional methods. We diluted the concentrated white water with distilled water to prepare process water samples having different levels of contamination. The concentrated white water obtained after reverse osmosis was used as the process water at a contamination level of 100%. We used the distilled water as the process water at a contamination level of 0%. Process water at a contamination level of 20% was prepared by mixing 20% of the concentrated white water at a contamination level of 100% with 80% of distilled water.

We prepared the bleached hardwood kraft pulp in a Valley beater to 450 mL CSF and diluted it with the prepared white water. To make linerboard stocks, we used either Korean old corrugated containers (KOCC) or unbleached softwood kraft pulp (USKP). To minimize the effect of the water used in beating, the beaten pulp was dewatered by vacuum before dispersing it in the prepared process water. Handsheets were made on a handsheet former equipped with a white water recirculation unit. The fines contents were not constant in the handsheets made in the early stage of forming, so we were discarded those handsheets. Only those handsheets prepared after the handsheet forming and white water recirculation unit reached steady state were used in physical testing. The properties of handsheets were examined by TAPPI Test Methods.

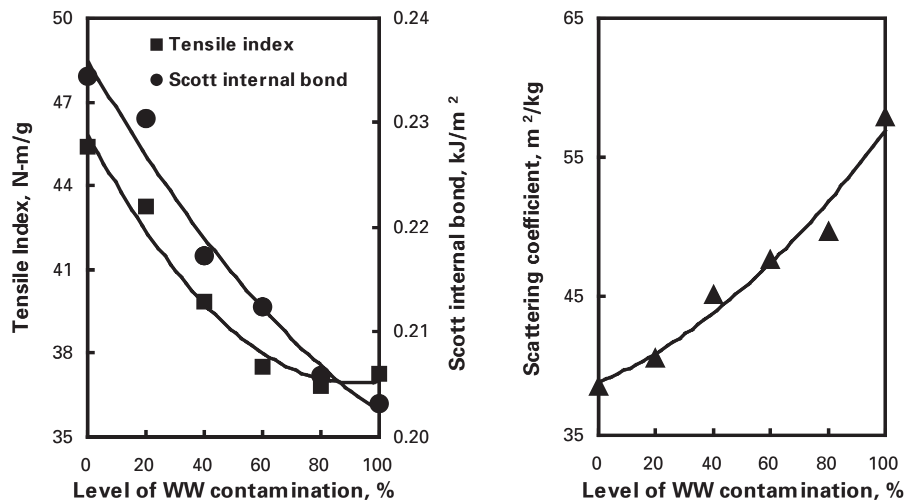
RESULTS AND DISCUSSION

Fine papers

Process water obtained from the white water silo of a fine paper mill was concentrated with the reverse osmosis unit until the volume of the concentrated white water decreased to 1/10 of its original volume. **Table I** lists the properties of white waters at different levels of contamination. It shows that conductivity and total dissolved solids increased continuously, while surface tension decreased as the contamination level of white water increased. **Figure 2** depicts the change of paper properties as a function of process water quality. Closure of the papermaking system caused substantial reduction of tensile strength. An increase of the light scattering coefficient with the increase of white water contamination suggested that this reduction of tensile strength was due to the reduction of interfiber bonding.

	0%	20%	40%	60%	80%	100%	WW
pH	6.4	7.6	7.5	7.5	7.5	7.5	7.6
Conductivity (µS/cm)	3	1161	2250	3260	4250	5240	780
Calcium – hardness (ppm)	0	292	496	748	1036	1224	200
Turbidity (FTU)	0	173	325	555	735	920	116
Total dissolved solids (ppm)	0	1123	2781	4261	5858	7466	443
Calcium – demand (µeq/L)	0	52	91	490	980	1152	36
COD (ppm)	0	1120	2164	2320	3000	3810	630
Surface tension (mN/m)	72.2	60.1	58.4	56.0	53.1	50.1	60.0

I. Properties of the white waters of a fine paper mill at various levels of contamination (WW = white water in the mill).



2. Properties of handsheets prepared with the use of fine paper white water at different levels of contamination.

Newsprint

We used concentrated white water obtained from a newsprint mill to examine the effects of newsprint mill process water on paper properties. In this experiment, refined bleached hardwood kraft pulp rather than newsprint stock was used to simplify the system and examine the effect of process water only. **Table II** describes the quality of the concentrated white water. Because surfactants are being used for deinking of old newspapers, the surface tension of the newsprint white water decreased more rapidly when the contamination level is low.

Figure 3 shows that tensile strength and internal bond strength decreased linearly as the level of contamination increased. Light scattering coefficient of the paper increased as the level of contamination increased.

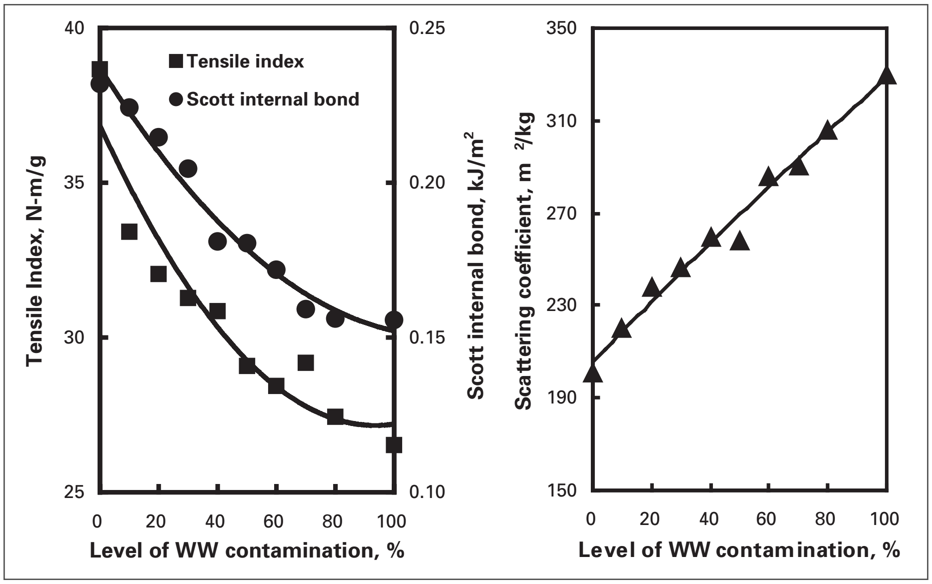
	0%	20%	40%	60%	80%	100%	WW
pH	6.4	8.2	8.2	8.2	8.1	8.1	7.9
Conductivity (µS/cm)	3	2760	5330	7670	9770	11,520	2230
Calcium – hardness (ppm)	0	500	928	1420	1900	2360	368
Turbidity (FTU)	0	175	322	535	705	885	129
Total dissolved solids (ppm)	0	2760	5640	8760	11,760	14,630	1960
Calcium – demand (µeq/L)	0	145	274	435	609	706	95
COD (ppm)	0	1338	1800	2880	3650	5000	996
Surface tension (mN/m)	72.2	58.6	50.7	47.5	45.3	43.8	52.0

II. Properties of the white waters of a newsprint mill at various levels of contamination (WW = white water in the mill).

Linerboard

White water obtained from a linerboard mill was concentrated with the use of reverse osmosis. USKP beaten to 470±10 mL CSF and KOCC with 390±10 mL CSF were used to make handsheets. **Table III** shows the quality of the concentrated process water. Results showed that the amount of total dissolved and colloidal substances increased linearly as the contamination level increased. The change of linerboard properties was similar to that of other papers. (**Fig. 4**)

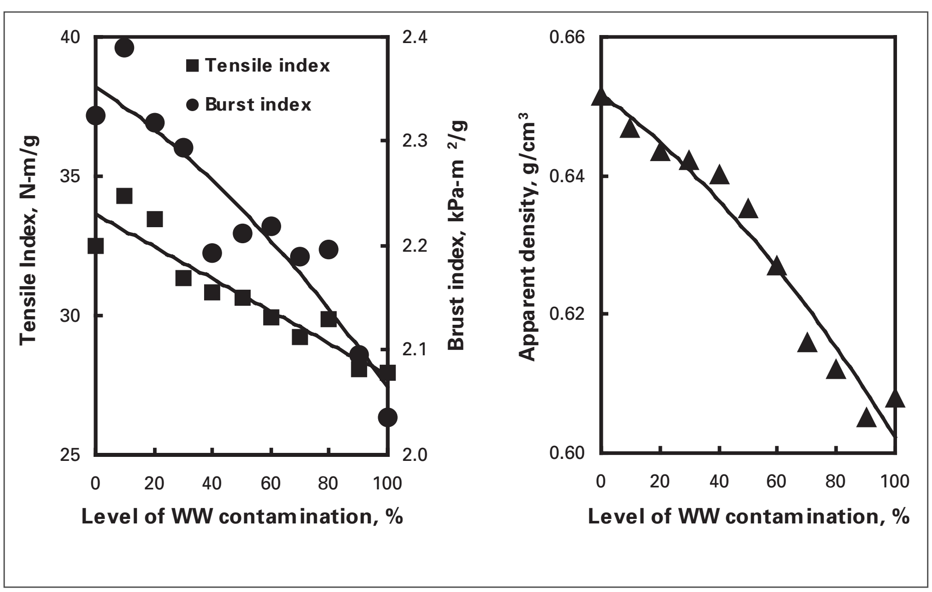
These results show that contamination of the papermaking process water causes substantial reduction of the paper properties. It is not clear however, which component of the contaminated process water is the most critical in reducing



3. Properties of the handsheets prepared with the use of newsprint white water at different levels of contamination.

	0%	20%	40%	60%	80%	100%
pH	6.4	6.9	6.9	6.8	6.8	6.7
Conductivity (µS/cm)	3	3260	5950	8360	10,680	12,810
Calcium – hardness (ppm)	0	570	1500	2040	2730	3290
Turbidity (FTU)	0	396	860	1250	1615	2050
Total dissolved solids (ppm)	0	3651	7109	10,556	14,064	17,449
Calcium – demand (µeq/L)	0	419	904	1300	1780	2680
COD (ppm)	0	2280	4290	6960	9360	15,620
Surface tension (mN/m)	72.2	63.1	53.8	51.8	50.5	49.9

III. Properties of the white waters of a linerboard mill at various levels of contamination.



4. Properties of handsheets prepared with the use of white water obtained from linerboard mill at different levels of contamination.

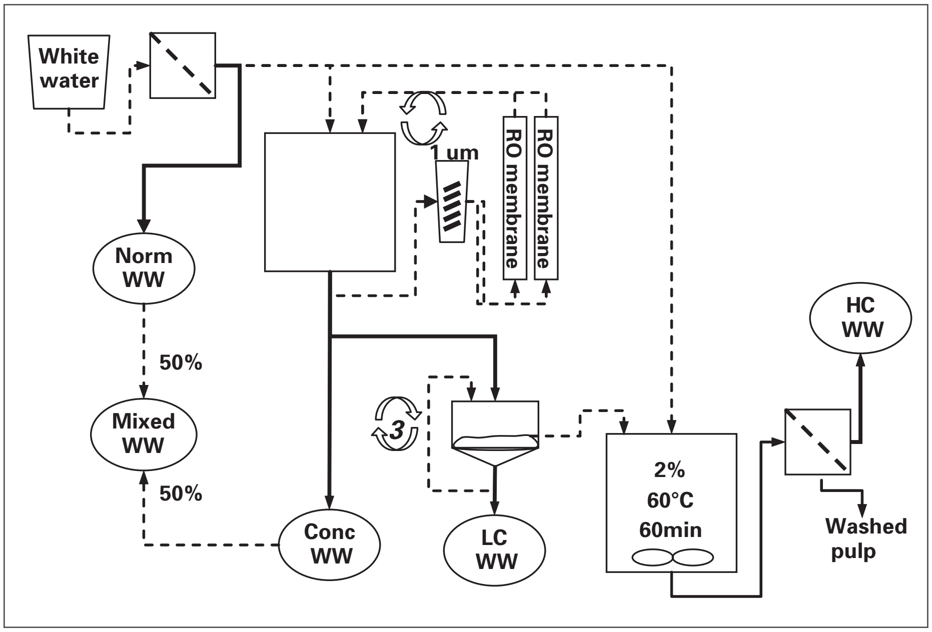
paper properties. All of the contaminants in the process water would cause the deterioration of paper properties. The level of detrimental effect, however, should differ for each type of contaminant. Among those, one critically important component may cause the most severe reduction of paper properties. If so, it may be possible to decrease the deteriorating effects of papermaking system closure by controlling this critical component, while keeping remaining components intact.

Experimental results from our laboratory showed that inorganic ions do not cause significant reduction in paper strength. This is fortunate, because inorganic ions are the component that can be removed only by the costly technology of reverse osmosis. This suggests that either dissolved or colloidal substances are the prime cause of strength reduction. But which one of these two components-dissolved—or colloidal substances—is the prime cause for the reduction of paper strength?

Effect of dissolved and colloidal substance on paper properties

To see the influence of dissolved and colloidal substance on paper properties, we prepared white water with different levels of dissolved and colloidal substances. **Figure 5** illustrates the procedure. We used a reverse osmosis filtration method to concentrate the white water. Concentrated white water (Conc WW) contained greater amounts of dissolved and colloidal materials than did the original white water (Norm WW). Concentrated white water was diluted with the silo white water to obtain mixed white water (Mixed WW). The concentrated white water was filtered three times through a thick pad of hardwood bleached kraft pulp formed on a Büchner funnel. This removed some of the large colloidal materials; giving us white water containing lower amounts of colloidal materials. Because filtering through the pulp pad did not remove dissolved substances, the prepared white water contained similar levels of dissolved materials, but lower amounts of colloidal substances (LC WW).

By redispersing the filtered colloidal particles from the pulp pad fibers into the Norm WW, we were able to prepare a white water containing high amount of colloidal substances (HC WW). **Table IV** shows the properties of the white waters. As shown in **Fig. 6**, removal of colloidal materials with the pulp pad

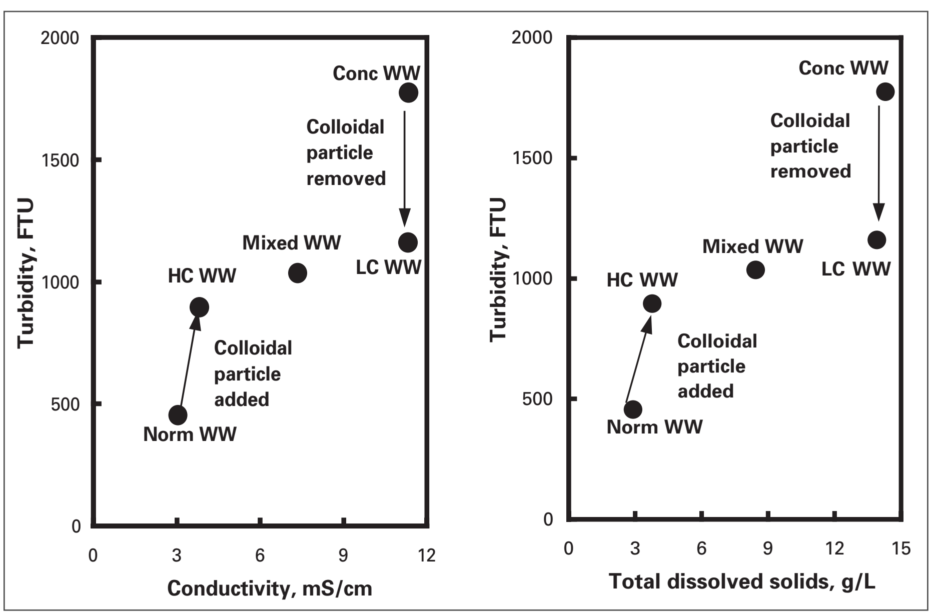


5. Schematic diagram of separation of colloidal substance and dissolved solids in concentrated white water.

gave a white water with a lower level of colloidal substance, but the amount of dissolved materials and conductivity remained relatively constant. Redispersion of the pulp pad fibers gave us a white water with a large amount of colloidal materials. We used the five different white waters to make distinct handsheets (basis weight = 100 g/m^2) on a handsheet former equipped with a white water recirculation system.

Figures 7 and 8 show the tensile and burst strengths of the linerboard handsheets made from KOCC and USKP, respectively. The tensile and burst strengths of linerboard made with the use of normal white water were substantially greater than those of linerboard made in concentrated white water. Mixed white water gave strength properties in the middle range. Addition of colloidal substances to the normal white water caused substantial reduction of tensile and burst strength of linerboard made from KOCC and USKP. On the other hand, removal of colloidal materials slightly improved the relative strength, indicating that the colloidal substances filtered by the fiber pads and redispersed from the fibers caused the more significant strength reduction of linerboard. To be filtered by pulp pads, this colloidal materials should be large in diameter and have weak attachment to the fiber so it can be redispersed into the fiber suspension.

It is quite interesting that the negative effects of colloid substances were greater when KOCC rather than USKP was used as fibrous materials. This is very important because recycled fibers should contain substantially larger amounts of colloidal materials compared to virgin fibers. Mills using recycled fiber as raw materials also tend to close their papermaking systems more tightly, which causes detrimental materials to build up in the system. This indicates that the deterioration of papermaking potential of recycled fibers and the detrimental substances accompanying the recycled fibers cause strength reduction of the linerboard. A more selective and economical method to remove the colloidal materials from the white water circuit might allow mills to keep the quality specification of the linerboard a lot higher, even within a highly closed papermaking system.



6. Turbidity and conductivity of white waters. This figures show that white waters with different amounts of colloidal substances, but with similar content of dissolved substances.

CONCLUSIONS

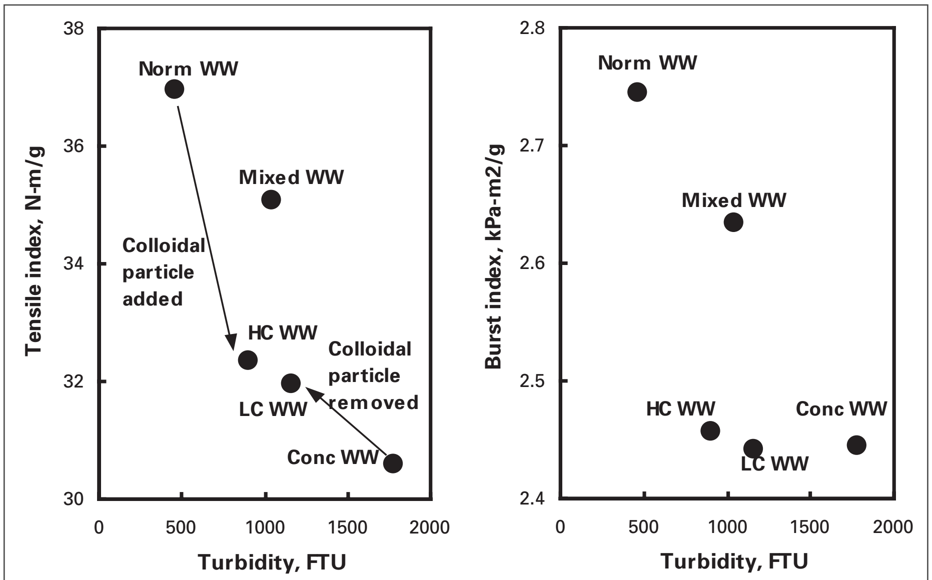
To examine the influence of papermaking system closure on paper properties, process waters obtained from the white water silos of fine paper, newsprint, and linerboard mills were concentrated with a reverse osmosis unit and used in handsheet forming. Experiments with that material revealed that concentrating the white water with reverse osmosis units is an effective method to prepare highly contaminated white water. Conductivity and total dissolved solids increased continuously, while surface tension decreased as the contamination level of white water increased. Closure of the papermaking system led to a substantial reduction of strength properties, and an increase of the light scattering coefficient.

To see the influence of dissolved and colloidal substance on paper properties, white waters with different levels of dissolved and colloidal substances were prepared. Adding colloidal substances to the normal white water caused a substantial reduction of tensile and burst strength of linerboards made from KOCC and USKP.

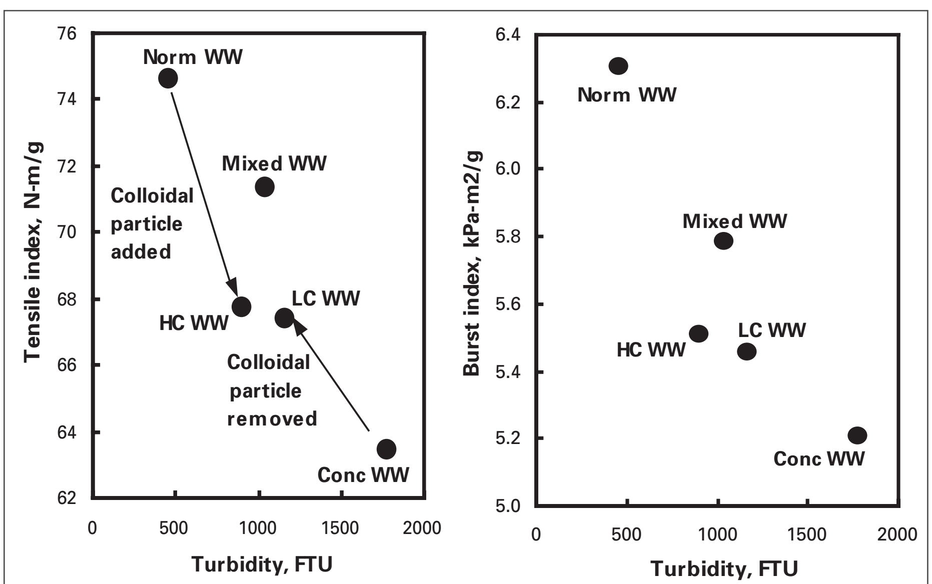
	Norm WW	HC WW	Mixed WW	Conc WW	LC WW
pH	6.9	7.6	7.1	7.0	7.2
Conductivity (mS/cm)	2.9	3.5	7.9	12.2	11.8
Turbidity (FTU)	505	1255	1825	3170	2390
Total dissolved solids (ppm)	2745	3773	9348	15,818	15,376
COD (ppm)	2260	2600	6320	10,330	9890
Surface tension (mN/m)	54.9	53.1	49.6	49.0	50.1

WW = white water, norm = normal, HC = high amounts of colloids, conc = concentrated, LC = lower colloid concentration.

IV. Properties of white waters containing different amounts of colloidal and dissolved substances.



7. Tensile index and burst index of handsheet made of Korean old corrugated containers (KOCC) in different white waters.



8. Tensile and burst Indices of handsheet made of unbleached softwood kraft pulp (USKP) in different white waters.

Removal of colloidal materials gave relatively slight improvement of the strength, indicating that the colloidal substances filtered by the fiber pads and redispersed from the fibers caused more significant strength reduction of linerboard. The negative effect of colloid substances was greater when KOCC was used as fibrous materials rather than USKP. This indicates that the deterioration of papermaking potential of recycled fibers and the detrimental substances that accumulate in the process water cause strength reduction of the linerboard. **TJ**

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LITERATURE CITED

1. Barton, A.D., Stuart, R.S., Lagace, P., et al., *TAPPI J.* 79(3): 191(1996).
2. Pietschker, A.D., *TAPPI 1996 Papermakers Conference Proceedings,* TAPPI PRESS, Atlanta, Georgia, USA, p. 523.
3. Linhart, F., Degen, H.J., and Lorz, R., *Tappi J.* 70(10): 79(1987).
4. Springer, A.M., Dullforce, J.P., and Wegner, T.H., *Tappi J.* 69(9): 106(1986).
5. Allen, L.H., *Pulp Paper Can.* 82(11): 143 (1981).
6. Zhang, X., Beatson, R.R., Cai, Y.J., et. al., *J. Pulp Paper Sci.* 25(6): 206(1999).
7. Francis, D.W. and Ouchi, M.D., J. *Pulp Paper Sci.* 27(9): 289(2001).
8. Dexter, R.J., *Pulp Paper* 70(2): 55(1996).

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