Press wetting as an enhanced wetting method for baled OCC material

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ABSTRACT: A procedure to mechanically force water into the bale structures of old corrugated container (OCC) material was studied and evaluated in low-consistency pulping studies. Two mechanical methods were used in the study: (1) roll pressing of sheets and (2) press wetting of bales. Mechanical pressing was first used in simple roll tests to evaluate nip pressure as an enhanced effect on wetting. Repeated press wetting treatments were found to increase water penetration into the sheets and appeared to lower wet strengths.

A simple laboratory-scale bale pressing device was constructed and the effect of different parameters in wetting method was studied. We found that when a bale was pressed under water, multiple pressings were needed to get efficient press wetting. Increased temperature was found to increase water penetration inside the porous structure of linerboard. We also discovered that there must be a delay between relaxation and pressing to allow water to travel within a board and to wet all surfaces.

The wetting procedure also evaluated the weight of water inside the bale. Results showed that the amount of water could be used as an indicator of the pulping kinetics and energy consumption needed to disintegrate OCC. The enhanced method (i.e., hydraulic pressing) could provide efficient wetting on an industrial scale. With this method, a 30% savings in the energy consumption required in pulping unit operation is possible.

Application: Mills can use this information to evaluate use of pre-wetting before pulping to increase low-consistency pulping capacity.

Packaging board is one of the fiber products that has continued to grow after the digital revolution. Confederation of European Paper Industries (CEPI) statistics show that more than 42 million tons of packaging board was produced and 31 million tons was recycled in Europe during 2013 [1]. The process for recycling packaging board is the most simplified method in the field of fiber recycling, where pulping is the first unit operation. The main task of pulping is to disintegrate the old corrugated containers (OCC) into a pumpable suspension.

Our approach was to use mechanical pressure to force the penetration of liquid into OCC materials. The aim was to study whether forced wetting by use of extensive external pressure could be beneficial for OCC pulping. Forced wetting was seen to increase the amount of water in the bales, and a shorter pulping time of the samples studied indicated a potential 30% energy savings.

Disintegration must overcome the strength of the material during pulping, so it is advantageous to reduce that strength by wetting. However, very little research has focused on wetting before or during OCC pulping. Wetting and absorption are relevant and widely studied phenomena in many other areas of papermaking (e.g., coating or sizing) and printing (e.g., ink penetration), as well as in tissue production [2-4].

With OCC grades, a decrease of 70%–90% in tensile strength is achieved by wetting due to hydrogen bond breakages and fiber swelling [5]. Liquid transfer during wetting can occur by capillary penetration and by pressure penetration that can be assessed using the modified Lucas-Washburn equation (Eq. [1]) [6]. The influential factors in capillary penetration are surface chemistry and pore size, while in pressure penetration, they are external driving pressure and pore size. In both cases, liquid viscosity also plays a role.

$$h^2 = \frac{r^2 t}{4\eta}\left(\frac{2\gamma cos\theta}{r} + \Delta p\right) \tag{1}$$

where h is distance travelled, r is capillary radius, t is time, γ is surface tension, η is fluid viscosity, θ is the contact angle between the liquid and the capillary wall, and Δp is driving pressure.

Equation (1) gives a conceptual viewpoint of the possibilities of increasing wetting and its kinetics. Wetting kinetics are ruled by properties of the raw materials, additives, and production process; thus, these properties cannot be affected unless sorting is used. Water viscosity and surface tension are dependent on temperature, and pulping at an increased temperature during wetting is known to enhance water penetration and thus pulping [7]. The most promising way to increase wetting, however, seems to be the use of extensive external pressure (i.e., nip pressure) for forced liquid transportation

Material	Phase	Ash Content 525°C, %	Tensile Index, kNm/kg	Grammage, g/m²
Test liner 1	1	8.9	80.6	160
Kraft liner	1	1.2	131.7	120
Test liner 2	1	11.9	64.0	125
Old corrugated containers	2 and 3	4.6%	N/A	200 + 130 +200

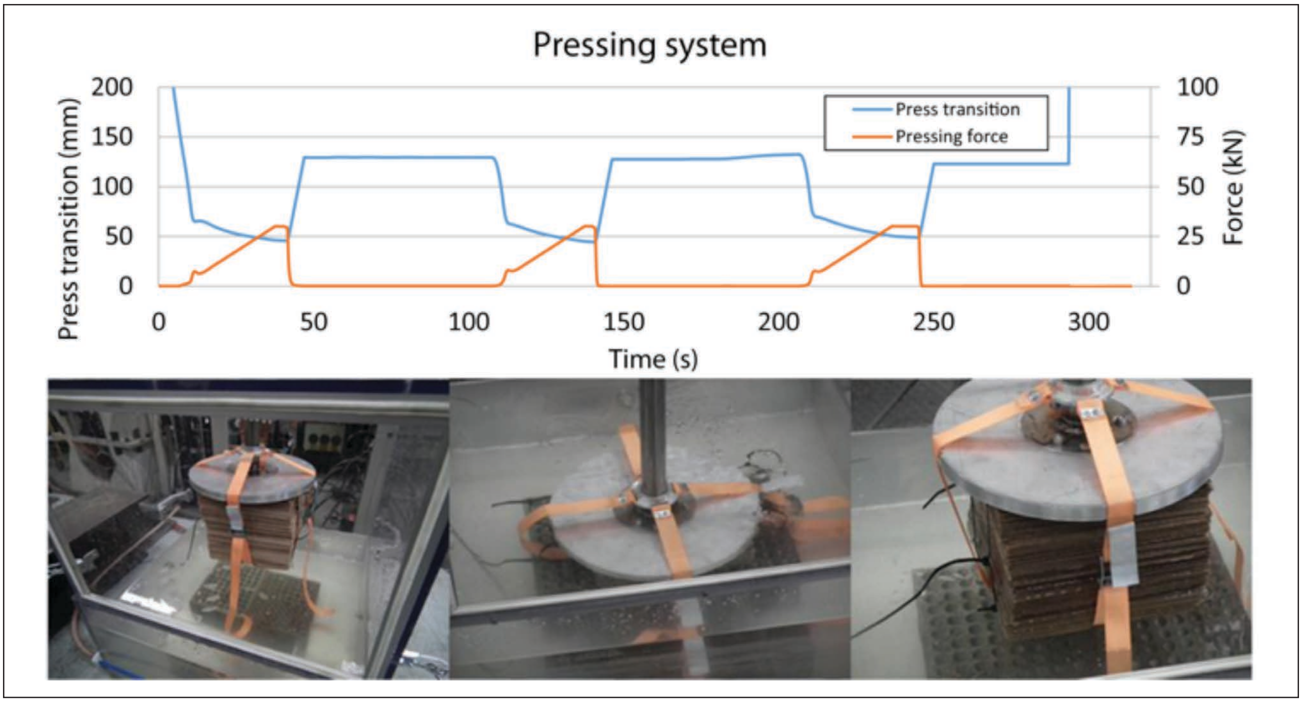
I. Material properties of materials used.

into the corrugated medium. The effect of pressure during wetting prior to pulping has been studied by Pangalos et al. and Carlson and Stockel [8-10], who used multistage pretreatment (vacuum and overpressure) of OCC bales in pressure vessels with alkaline conditions. They found that pretreatment can lead to a reduction in pulping energy by up to 50% and improved pulp strength properties.

MATERIAL AND METHODS

Experiments in this study were divided into three phases. In the first phase, wet tensile strength of soaked liner and fluting samples were studied with and without the use of external pressure. The results indicated that forced wetting lowers strength significantly. In the second phase, a forced wetting treatment of baled OCC sheets before pulping was developed and tested in various conditions. Wetting was evaluated by weighing the water in the bales. In the third phase, the results were verified with pulping tests with a low-consistency (LC) pulper.

Materials used in these studies were virgin and recycled pulp containing linerboard and OCC obtained from a Nordic board mill. **Table I** summarizes the specifications of materials used in this study. Ash content was analyzed with Prep-ASH129 (Precisa Gravimetrics AG; Dietikon, Switzerland) according to TAPPI Standard Test Method T 211 om-02 "Ash in wood, pulp, paper, and paperboard: combustion at 525°C." The tensile strength of materials was tested with an Instron 5544 (Instron; Norwood, MA, USA) equipped with a 100 N load cell using TAPPI Standard Method T 456 om-03 "Tensile breaking strength of water-saturated paper and paperboard." OCC material was from a Nordic board factory before converting. The material consisted of surface layers made from kraft liner with grammage of 200 g/m². The corrugated layer was a fluting made from semichemical pulp with grammage of 130 g/m².



1. (Top) Press transition and force graph during three times of pressing with 30 kN force and with 1 min delay between pressings. (Bottom) Experimental arrangement of press wetting bales. A pressing-relaxation cycle: immersion of bale into pool (left), pressing of bale under water level (middle), and relaxation of bale under water (right).

Preliminary tests of forced wetting

Linerboard was cut into tensile strength testing specimens that were 15 mm wide and 200 mm long. Specimens were stored for 2 days in humidity- and temperature-controlled rooms according to SFS-EN 20187 "Paper, board, and pulps-standard atmosphere for conditioning and testing and procedure for monitoring the atmosphere and conditioning of samples." The wetting procedure was conducted at a temperature of 23°C. Forced wetting was done by rolling a soaked specimen on the table using a 9.6 kg roll with a 9 cm diameter. Soaking time was 30 s for every specimen. After soaking and rolling, tensile strength was measured for 10 specimens. In addition to soaking, three different forced press wettings were done on specimens:

1. Forced wetting 1: Soaking and rolling once.
2. Forced wetting 2: Soaking and rolling twice.
3. Forced wetting 3: Soaking and rolling twice, additional soaking, and rolling once.

Bale press wetting

OCC boards were cut into 200 mm x 200 mm sheets and piled into bales, changing the orientation of every other sheet. The weight of the bales was 1.25 kg. After piling, the bales were pressed to the density of 310 kg/m^3 and wired for storing. The bales were then 100 mm in height.

Fig. 1 illustrates the experimental arrangement of the impregnation pool and pressing system used in press wetting studies. The pool was filled with water with temperature between 24°C and 55°C, but most often at 43°C. An Instron 8500 hydraulic pressing device (equipped with 125 kN load cell) was used to achieve the desired pressing force. The device was adjusted to take 30 s to achieve the target pressing force linearly. The effects of the following parameters were studied: number of press-relaxation cycles, press force, delay between presses, and temperature of impregnation water.

After a press wetting experiment, the bale was removed from the pool. To remove excess water from corrugated layers, the bale was placed sideways on the sieve for 30 s. The bale then was rotated 90° degrees and another 30 s of drainage occurred. To measure water within the bale, all strings were removed and then then the bale was weighed. Infused water was calculated as a water-to-fiber ratio using Eq. (2):

$$IR = \frac{m_{b1} - m_{b0}}{m_{b0}} \qquad (2)$$

where *IR* is impregnation ratio, m_{b1} is saturated bale weight, and m_{b0} is bale dry weight.

Pulping of bales

The press-wetted bales and reference samples were pulped in an unconventional LC batch pulper. The pulper had four deflectors and a helical rotor (**Fig. 2**), which is normally used in high-consistency pulpers. Pulping was operated in 4% consistency. The batch size was 31.25 kg (1.25 kg dry) and the temperature during pulping was adjusted to 43°C.

2. Low consistency pulping system (h = 280 mm and Ø = 400) mm with helical rotor (rotor h = 170 mm); rotor speed = 1450 rpm.

Two reference pulpings were done to clarify the effect of press wetting. Reference pulpings were done without any pretreatment and with soaking in water at a temperature of 43°C. For this pretreatment, the bales were kept under water for 4.5 min, which was the same time as the press wetting experiments where the bales were pressed three times with a 1 min delay between pressings.

Flake content of the pulp was analyzed according to TAPPI Standard Test Method T 275 sp-02 "Screening of pulp (Somerville type of equipment)." For screening, a 40 g sample (as dry matter content) was taken and flake content was calculated as the mass of retained pulp on the screen compared to the mass of feed sample.

RESULTS

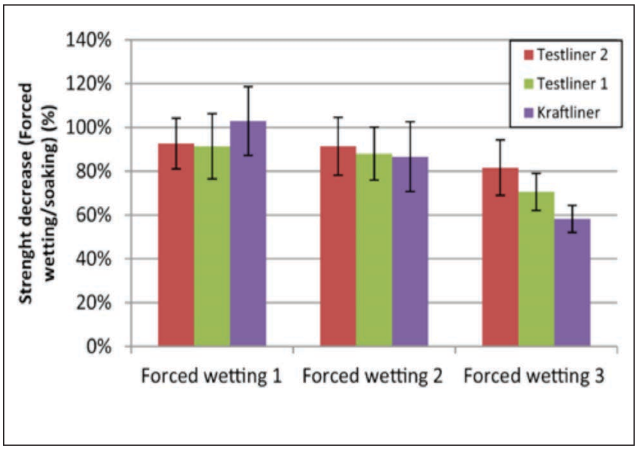
Preliminary testing of forced wetting

Preliminary tests with liner specimens evaluated the potential of forced wetting. **Table II** presents tensile strength of dry specimens, wet tensile strength of soaked specimens, and wet tensile strength of specimens that underwent forced wetting.

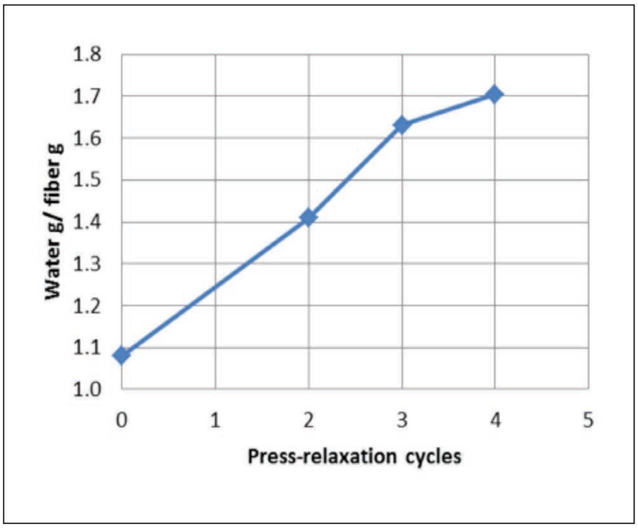
To clarify the tensile strength decrease by forced wetting, the results are presented as proportional values in **Fig. 3**, where forced wetting strength figures were divided by the strength figures of soaked specimens. The results showed the press roll treatments of soaked liner grades to reduce wet tensile strength compared to merely soaking. Rolling the specimen once reduced wet strength about 10%; rolling the specimen twice reduced wet strength about 15%. A considerable change, especially with kraft liner, was seen when specimens were resoaked between rollings:

Material	Dry Strength, kNm/kg	Wet Strength after Soaking, kNm/kg	Wet Strength after Forced Wetting 1, kNm/kg	Wet Strength after Forced Wetting 2, kNm/kg	Wet Strength after Forced Wetting 3, kNm/kg
Test liner 1	80.6	6.8	6.2	6.0	4.8
Kraft liner	131.7	22.4	23.0	19.4	13.0
Test liner 2	64.0	4.1	3.8	3.7	3.3

II. Tensile index of dry and wetted samples.



3. The tensile strength decrease by forced wetting of linerboards compared to soaking only in three press wetting cases; one rolling of soaked specimen, two rollings of soaked specimen, and two rollings of soaked specimen that included resoaking and one rolling of specimen.



4. Impregnation ratio after press wetting in 43°C water as a function of press-relaxation cycles when pressed with 3.75 bar. Delay between pressings was 60 s. Zero press-relaxation cycles represent soaking experiment for bales.

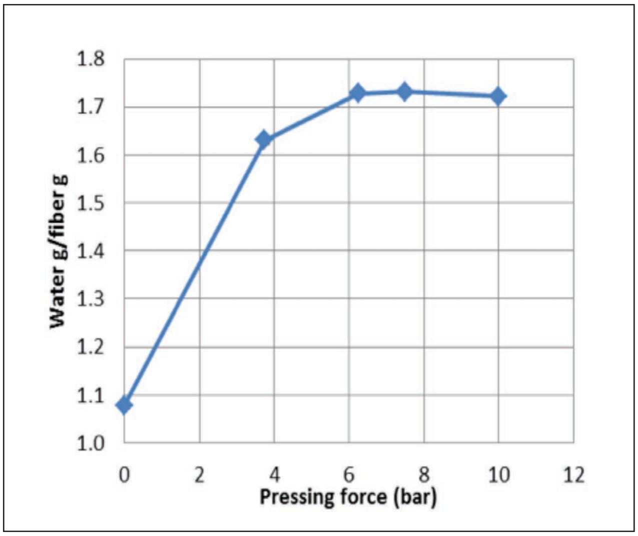
20% reduction with test liner 2, 30% with test liner 1, and 40% with kraft liner.

Bale press wetting

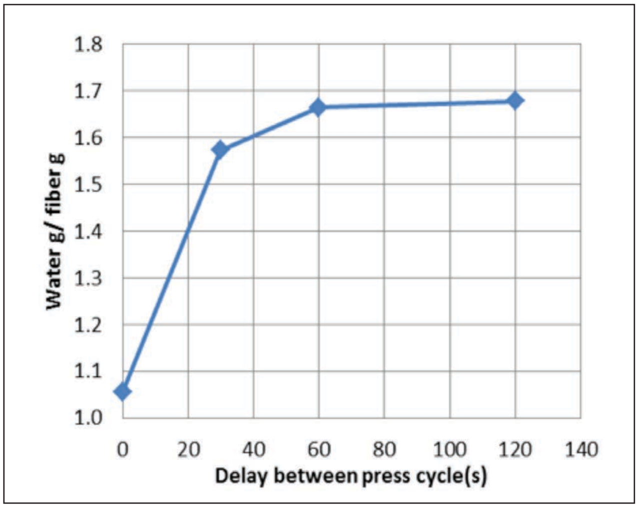
The effect of mechanical pressing on wetting was evaluated by measuring the amount of water impregnated into the bales. Coefficient of variation in bale weight with 7.5 bar pressing and with three samples was 0.8%; that value was 0.96% with soaking. The effect of press-relaxation cycles on the impregnation ratio was studied first. After three cycles, only a small increase in the impregnation ratio was seen, as shown in **Fig. 4**.

Fig. 5 illustrates the effect of pressing force on the water impregnation ratio. Pressing force within the tested range (3.75–10 bar) did not have significant effect on the water impregnation ratio. The absorption of water increased slightly when pressure force was lifted from 3.75 bar to 6.25 bar. Pressing force greater than 6.25 bar did not seem to result in additional improvement in water impregnation.

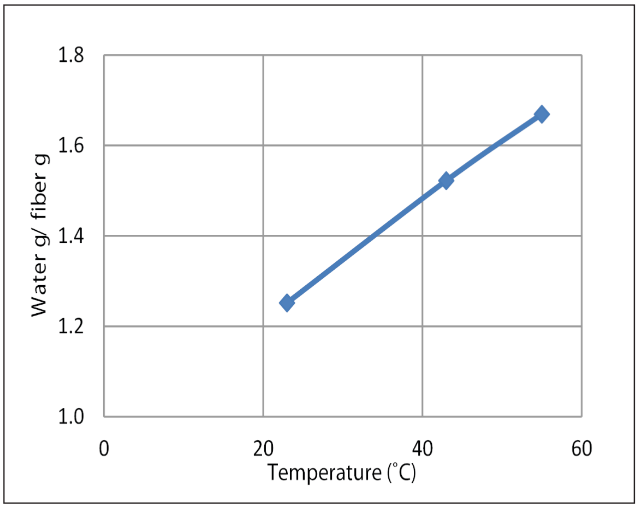
Fig. 6 illustrates the effect of delay between press stages (i.e., the duration of relaxation). The delay of 0 s meant the bale was pressed immediately after the pressing force was released to zero. A significant increase in the impregnation



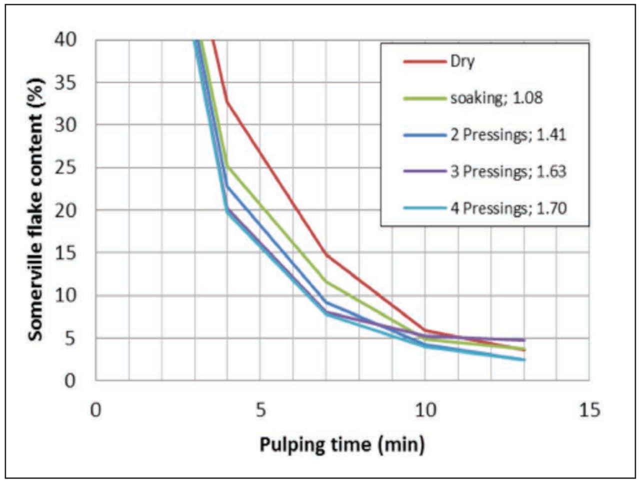
5. Impregnation ratio after press wetting in 43°C water with different pressing forces. Delay between pressings was 60 s. Zero pressing force means soaking under water in the same temperature and for the same total time.



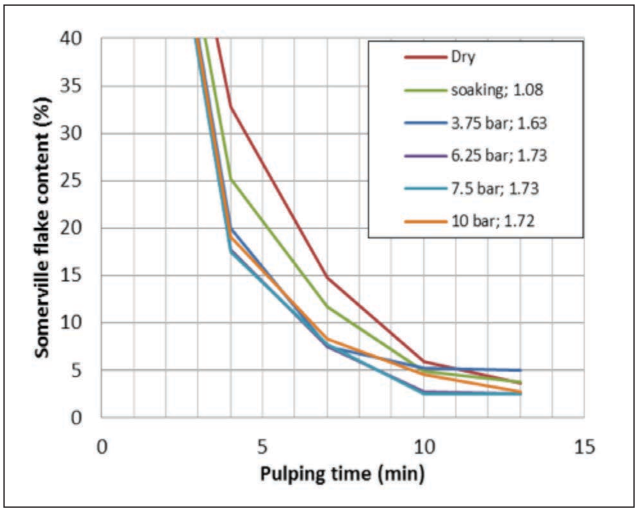
6. Impregnation ratio after press wetting in 43°C water with different delays between three pressings with 6.25 bar. Zero delay between press cycles represents soaking experiment for bales.



7. Impregnation ratio after press wetting at different impregnation water temperatures when pressed three times with 3.75 bar. Delay between pressings was 60 s. Bale weight in temperature tests was 2.5 kg with density of 310 kg/m³.



8. Pulping kinetics of bales after press wetting in 43°C water with a different number of pressings with 3.75 bar. Delay between pressings was 60 s. Impregnation ratios after wetting procedure for pulped bale samples are presented after sample name in legend.



9. Pulping results after press wetting in 43°C water with different pressing force when pressed three times. Delay between pressings was 60 s. Legend includes impregnation ratios after wetting procedure for pulped bale samples.

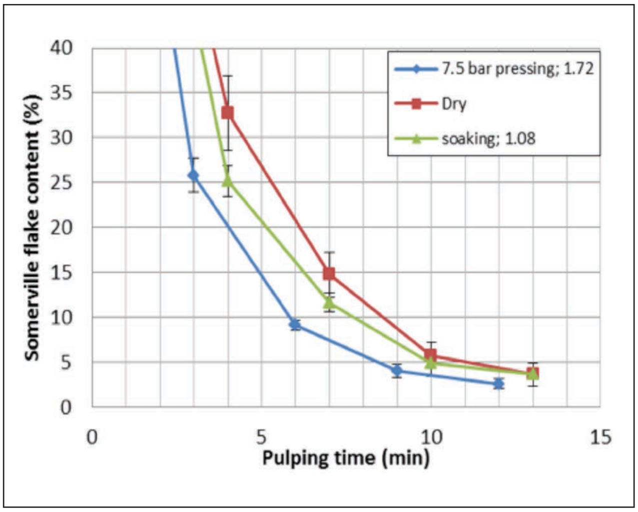
ratio was seen from 0 s to 30 s. A further, but smaller, increase was seen from 30 s to 60 s. After that, no clear difference can be seen (i.e., full wetting capability at this bale size was reached after 1 min).

The effect of temperature is presented in **Fig 7**. The temperature increased the impregnation ratio linearly between 23°C and 55°C. The increase in the impregnation ratio from 23°C to 44°C was 0.27 and from 44°C to 55°C was 0.15.

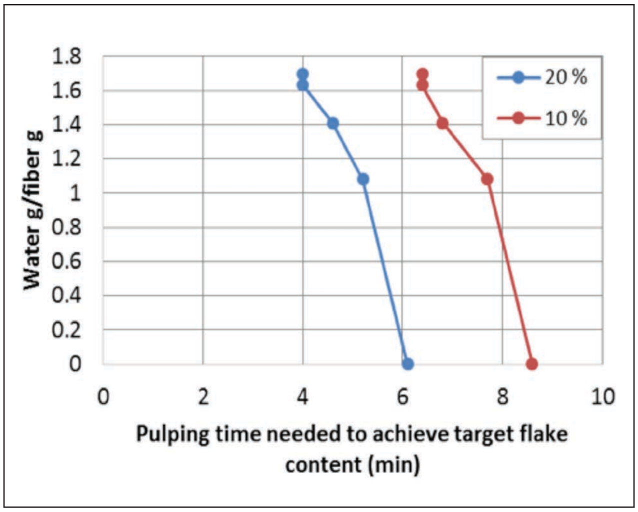
Pulping of press-wetted bales

Water impregnation results were verified by pulping a variety of wetted bales in an LC pulper. The number of pressing cycles in pulping kinetics (i.e., Somerville flake content) as a function of pulping time is presented in **Fig. 8**. The results were in line with impregnation results—a higher impregnation ratio resulted in a faster pulping rate. Dry bales without soaking showed the slowest pulping kinetics. The soaking of bales notably increased the disintegration rate of OCC. The fastest kinetics were seen when press wetting was used. Two and three press cycles increased the pulping rate, but no change was seen after that. Increasing the pressing force from 3.75 to 10 bar did not affect pulping kinetics, as shown in **Fig. 9**.

Repeated LC pulpings were performed with three samples to evaluate the reliability of pulping tests (**Fig. 10**). Repeatability was at a good level. Expectedly, the standard deviation increased with increasing flake content (i.e., reliable sampling



10. Repeated low-consistency pulpings performed with three samples to evaluate the reliability of pulping tests and the potential of press wetting. Legend includes impregnation ratios after wetting procedure for pulped bale samples.



11. Estimated pulping time needed to achieve target flake content with different impregnation ratios.

was more difficult with a higher flake content in the samples). Interestingly, standard deviation decreased significantly with the increasing amount of impregnated water in the bale, indicating that thorough wetting stabilizes the operation of the pulping process.

In LC pulping, a flake content of 20% was achieved after 4 min of pulping with press wetted bales, after 5 min with soaked bales, and after 6 min with dry bales. Flake content of 10% was achieved approximately after 6 min, 7.5 min, and 8.5 min, respectively. Thus, compared to dry-bale pulping, about 10% lower energy consumption was needed with soaked bales and 30% less with press-wetted bales to achieve a flake content level of 10%.

Correlation between impregnation ratio and pulping time needed to achieve target flake content (20% and 10%) is presented in **Fig. 11**. Pulping time decreased almost linearly with increased impregnation ratio until 1.6 impregnation value with both target flake content values.

DISCUSSION

Preliminary tests showed that forced wetting of linerboard was more advantageous in reducing the wet strength compared with mere soaking. The explanation for the advantage from this forced wetting may rise from small pore size and partial hydrophobicity of the fibers. Without external pressure, water cannot penetrate the smallest interfiber pores; thus, soaking alone cannot break up all hydrogen bonds. Also, air in the pores causes counter pressure that hinders water penetration.

Fibers are usually considered to be hydrophilic but they also have a hydrophobic nature, especially if lignin is present. In addition, unbleached kraft pulp consists of hydrophobic substances (e.g., fatty acids, resins, and triglyceride fats) that may cause rehydrophobization [11]. The phenomenon is called self-sizing, which results from the increased resistance of wetting [12]. Recycling is assumed to reduce the self-sizing phenomenon of fibers, which may explain why forced wetting reduces wet strength more for kraft liner made from virgin, unbleached, softwood fibers than for test liners made from recycled fibers.

Repeated press treatment was found to increase water penetration in linerboard, which leads to lower tensile strength. Macropores probably filled in the first press treatment and micropores during the second treatment. However, the third press treatment, after the resoaking of linerboard specimens, decreased tensile strength considerably more than the second treatment. This is understandable because enough water must be available in pressing stages to get water to penetrate into small pores. Although this may seem to be self-evident, it has practical meaning if forced wetting is used in industrial pulping. Because OCC boards are multilayered products and are fed into a pulper as large bales, the challenge is to get water into the bale. This is essential in forced wetting, as well as in soaking, to allow all surfaces of OCC material to come into contact with the water.

In the second phase, forced wetting was examined for baled OCC boards. The structure of corrugated boards enables water to infuse the boards via channels of corrugated layers. When a bale is pressed underwater the first time, the corrugated layer is compressed and air is removed. Due to the elastic nature of the corrugated layers, the relaxation of pressure causes the layer to expand nearly back to its original shape, causing a vacuum inside and therefore accelerating water impregnation into the layer when the bale is under water. In the second press, water inside the corrugated layers is forced to penetrate pores of each layer of the board. There must be a delay between press and relaxation to allow water to travel within a board and to wet all surfaces. In our experiments, 30–60 s was enough of a delay, but it depends on the size of the bale. By repeating press-relaxation cycles, water can be pumped inside the bale via the corrugated layers. In our study, three cycles seemed to be enough for a thorough contact between water and all surfaces. The second and third presses forced water to penetrate the pores of fluting and linerboards, but any extra presses after that provided no additional advantage. Pressing force needs to be high enough to compress the corrugated layer completely, but the excess use of force seemed not to increase water penetration considerably.

The effect of temperature on water impregnation was as expected, but its magnitude was surprisingly large. On the basis of Eq. (1), driving pressure by mechanical pressing was expected to be the dominant parameter. Increasing temperature results in a decrease in both water viscosity and surface tension, but the effect is greater on viscosity [13]. Viscosity values at temperatures 23°C, 44°C, and 55°C are 997.0 kg/m^3, 990.2 kg/m^3, and 985.3 kg/m^3, respectively. Corresponding values of surface tension are 0.723 N/m, 0.687 N/m, and 0.671 N/m. Besides lowering water viscosity, temperature may also facilitate water infusion by changing the structural and surface properties of fiber.

The results of forced wetting were verified by pulping bales in low consistency. The kinetics of pulping (i.e., OCC disintegration rate) correlated closely to the amount of water permeating the bale by soaking and forced wetting (Fig. 11). The more water that was in the bale, the faster OCC disintegration occurred. In batch pulping with constant process conditions, energy consumption can depend solely on pulping time [14]. Therefore, energy consumption could be reduced by about 30% when using forced wetting, whereas soaking alone only reduced energy consumption by 10%. Prior studies have shown that this would mean 6 kWh/t savings [15]. Indeed, pressings require energy so the savings are slightly lower than 6 kWh/t. Of note, with lower consistency pulpings the amount of saved energy is larger.

The study was performed at the laboratory scale but results are also applicable in industrial scale pulping. Forced wetting could be an interesting means to reduce the energy consumption of pulping. Development and engineering are needed, however, to implement a forced wetting method in industrial operations.

CONCLUSIONS

Proper wetting of OCC material is essential for energy efficient pulping. The amount of water in the bale is a good indicator of pulping kinetics and energy consumption needed for the disintegration of OCC. The use of full saturation is not achieved solely by soaking; forced wetting (e.g., hydraulic pressing of soaked bales) is also needed. This could possibly lead to about 30% savings in the energy consumption of pulping. **TJ**

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We chose this topic because pulping is one of the most energy consuming unit operations in OCC recycling processes and wetting is the first phenomenon that occurs for the raw material. Disintegration must overcome the strength of the material during pulping; therefore, it is advantageous to reduce that strength by wetting. Previous pre-wetting studies by other research groups have shown promising results in terms of energy consumption in pulping.

The most difficult aspect of this study was the search for a way to wet baled OCC that could be implemented at the industrial scale and meet production capacity demand. We did some preliminary experiments with three different wetting methods: spraying, steaming, and submerging. Spraying and steaming were found to be inefficient; therefore, we chose submerging and pressing for the study. The most interesting part of this study was to see the method work in practice as was planned.

These results may encourage mills to rethink their processes and consider adding a specific unit operation for wetting. Of course, larger scale experiments are needed before we can see pre-wetting unit operations in OCC recycling processes.

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