

Comparison of cooking technologies for production of softwood kraftliner pulp

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ABSTRACT: Kraftliner, used as the top and bottom layers in corrugated board, is one of the major paper products in the United States and worldwide and is a long-term growth business area for the pulp and paper industry. However, for many years pulping development for kraftliner has been limited. The lack of development may be because corrugated board standards in many countries have specified basis weight and not strength demands on the corrugated board. With the modifications of Item 222/Rule 41, the situation in the United States has changed. Recently, a new cooking technology has been developed enabling defibration of softwood pulps at considerably higher kappa number with low reject content. Pulp quality as a function of kappa number has been evaluated for this new cooking technology compared to pulp produced using a conventional kraftliner cooking technology. Lower H-factor demands and increased strength, measured as tensile energy absorption, were the most important differences found between the two cooking systems in this study.

Application: A new cooking technology may contribute to development of pulping for kraftliner.

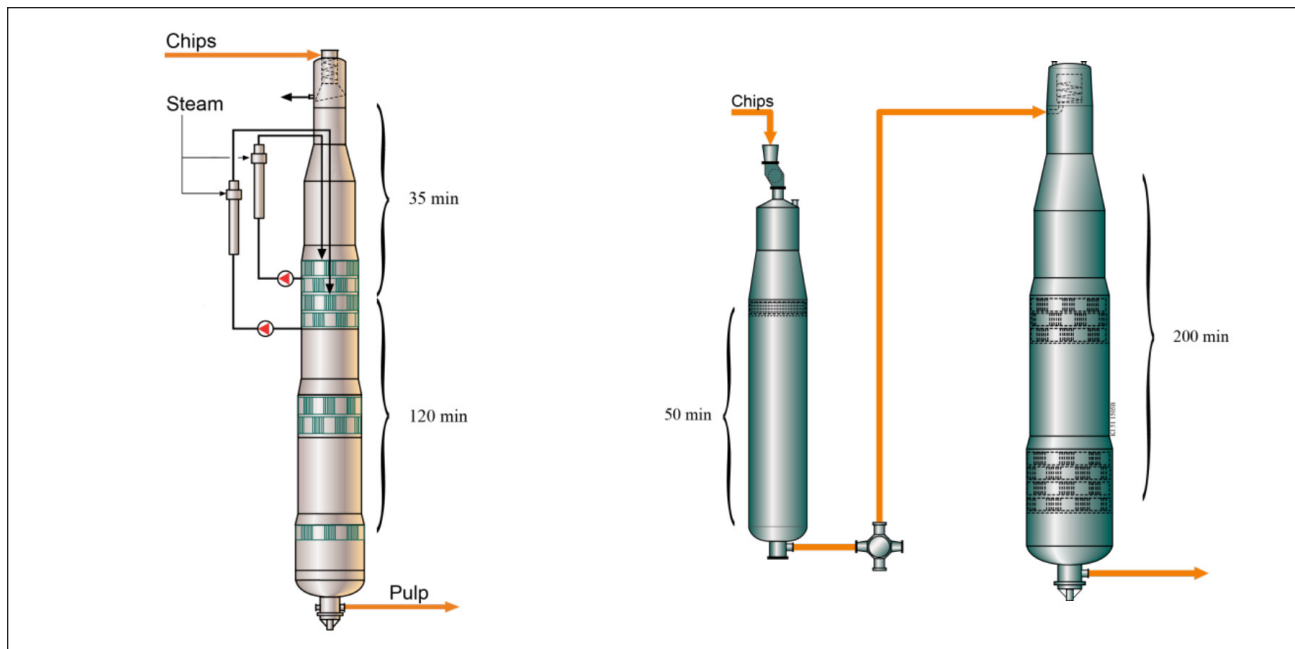
Corrugated board is a major packaging material that makes our everyday life less costly, simpler, and more environmentally friendly compared to other packaging materials. Kraftliner has been in use for a long time as the top and bottom layers for corrugated board [1]. To make corrugated board an even more competitive packaging material and increase profitability for the pulp, paper, and packing industry, continuous development is important. When corrugated boxes made out of corrugated board were first introduced, they were transported as individual parcels on trains and ships. Resistance to drops and puncture were among the most important parameters to consider. Since then, however, the ways corrugated boxes are used have shifted and today stacking performance, especially during variations in relative humidity, and appearance of the boxes have increased in importance. This is because boxes are now more often transported longer distances as stacked units and are expected to remain in a condition conducive to handling by modern package moving equipment. The package, in many cases, will also need to work as an advertisement for the highly branded valuable contents.

For many years development of kraftliner strength performance was not very critical because corrugated boxes were regulated by basis weight. There was very little incentive to increase performance and lower basis weight to increase profitability. With the modifications of Item 222/Rule 41, the situation in the United States has changed. As an alternative to minimum basis weight and burst strength, a minimum edge crush test (ECT) for corrugated board became an option [2]. In addition, there is greater need for kraftliner because of in-

creasing competition for suitable recycled fiber as box consumption grows steadily. This has renewed interest in developing kraftliner and the pulp to make it.

Recently, a new cooking concept using impregnation at low temperature for an extended time (extended impregnation cooking, or EIC) has been described in the literature [3]. In this type of impregnation, with longer retention times and lower temperatures to promote diffusion of the cooking chemicals over consumption, softwood can be chemically defibrated at kappa no. 90–95 with a low reject content. This might not only make it possible to eliminate the comparably small in-line refining energy and make a gain in yield but, more importantly, enhance the kraftliner strength properties [4].

Along with a well-impregnated chip, even distribution of cooking chemicals and heat in the cross section of the digester is important for lower cooking temperature and reduced steam consumption to be possible. These cross-sectional types of variation in industrial scale digesters are not possible to see when typical laboratory cooks are made and evaluated. An impregnation vessel before a digester usually makes even heat and chemical distribution much easier to achieve in the cross section of a digester. However, a typical digester presently producing kraftliner pulp was built in the 1960s or 1970s and is a one-vessel hydraulic type of digester. Since then, production has typically been increased by 50%–100% compared to design capacity and very little to no washing is done in the digester. The drawback with a single vessel system is that an even alkali and temperature profile during cooking is hard to achieve. Uniform cross-section temperature and alkali profiles rely on



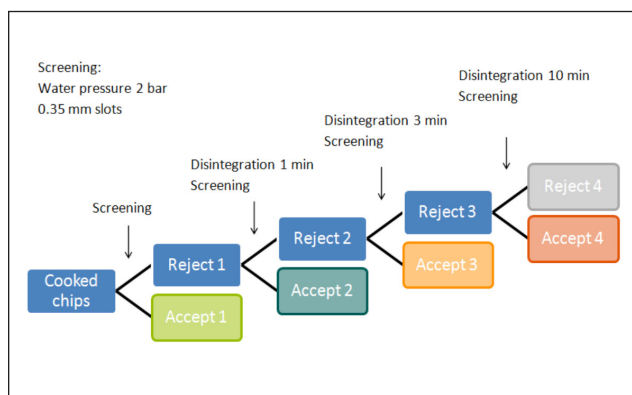
1. Schematic description of the continuous cooking simulated in laboratory. At left, a one-vessel hydraulic digester as is typically run today with 35-min impregnation and 120-min cooking. At right, a two-vessel steam/liquor phase digester system with 50-min impregnation time and 200-min cooking time. Both digesters are operated in a down-flow mode.

large circulation flows, which, especially in an overloaded digester, can have a negative impact on chip column movement

To investigate the effect of modern cooking concepts on kraftliner pulp properties, two different concepts were simulated in the laboratory. The first applies to a new, state-of-the-art digester system with impregnation at low temperature prior to cooking performed at relatively low temperatures in a steam/liquor-phase digester. The second method is a classic single vessel hydraulic digester as typically runs in many mills today for production of kraftliner pulp.

EXPERIMENTAL

Cooking was performed using industrial Scandinavian softwood chips (a mixture of *Pinus sylvestris* and *Picea abies*). The chips were air dried at ambient temperature and screened and only the accept fraction (2- to 8-mm thickness) of the chip batch was used. Laboratory kraftliner cooks were made to simulate continuous cooking (**Fig. 1**). The first concept simulated a digester system with an impregnation of 35 min at 125°C followed by cooking for 120 min at the temperature required to obtain the targeted kappa number. For the first concept the liquor-to-wood ratio was 3.0 in all stages; this simulation will be hereafter denoted as 35+120 min. The second concept was simulating a system with an impregnation of 50 min at 105°C followed by cooking for 200 min at the temperature required to obtain the targeted kappa number. The liquor-to-wood ratio was 5.0, 3.8, and 3.0 in the impregnation part, the first half of the cooking time, and the last half of the cooking time, respectively; this simulation will be here-



2. Description of the fractionated defibration.

after denoted as 50+200 min. The pulps were cooked using synthetic white liquor with sulfidity of 25% and causticizing degree of 80% (both calculated on an active alkali basis). A residual alkali of about 10 g/L (as effective alkali sodium hydroxide) was targeted by adjusting the initial charge. In the 50+200-min simulation, black liquor from previous cooks (then conducted with only white liquor) of the same chip batch was added.

Mechanical defibration of the pulps was performed in a laboratory refiner (Defibrator; Stockholm, Sweden), except when the uniformity of the pulp was investigated by fractionated defibration according to the principal presented in **Fig. 2**. The disintegration in the fractionated defibration was performed to the specifications in ISO 5263-1:2004 "Pulps—laboratory wet disintegration—part 1: disintegration

Property	Method Applied	Method Name
Kappa number	ISO 302:2004	"Pulps — Determination of Kappa number"
ISO brightness	ISO 2470:1999	"Paper, board and pulp — Measurement of diffuse blue reflectance factor (ISO brightness)"
Carbohydrate composition	SCAN CM 71:2009	"Pulps — Carbohydrate composition"
PFI beating	ISO 5264-2:2002	"Pulps—Laboratory beating—Part 2: PFI method"
Dewatering resistance, °SR	ISO 5267-1:1999	"Pulps—Determination of drainability—Part 1: Schopper-Riegler method"
Laboratory sheet preparation	ISO 5269-1:2004	"Pulps—Preparation of laboratory sheets for physical testing—Part 1: Conventional sheet-former method"
Sheet grammage	ISO 536:1996	"Paper and board — Determination of grammage"
Sheet thickness	ISO 534:2005	"Paper and board — Determination of thickness, density and specific volume"
Tensile properties	ISO 1924-3:2005	"Paper and board — Determination of tensile properties — Part 3: Constant rate of elongation method (100 mm/min)"

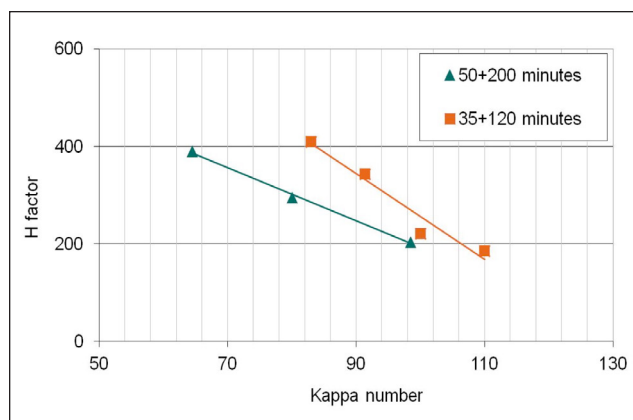
1. Standard methods used to determine properties.

of chemical pulp." Approximately 20–30 g (calculated as bone dry) of cooked chips at a time were put through the fractionation procedure and two runs were performed on each pulp. About 1 L of deionized water was used for each disintegration. Screening was performed using a water jet defibrator (Nordiska Armatur Fabriken; Linköping, Sweden) and a Wennberg screen with 0.35-mm slots. All fractions were collected and dried before weight fraction and chemical analysis were determined. Yield, reject content, kappa number, and strength analysis were performed according to the methods listed in **Table I**.

RESULTS AND DISCUSSION

The yield at a given kappa number was similar for the 35+120-min and 50+200-min pulps, as well as for the total alkali consumptions (i.e., the alkali addition needed in the two systems are similar). The H-factor demand to yield a certain kappa number is presented in **Fig. 3**. The H-factor demand is considerably lower for the 50+200-min pulps, probably because more complete impregnation before cooking takes place. It has been shown in literature that low alkalinity results in more lignin reacting as residual-phase lignin and hence requires a higher H-factor [5]. In practice, a shorter cooking time also requires higher temperatures, and hence a higher steam consumption, to obtain the same H-factor as it is defined [6].

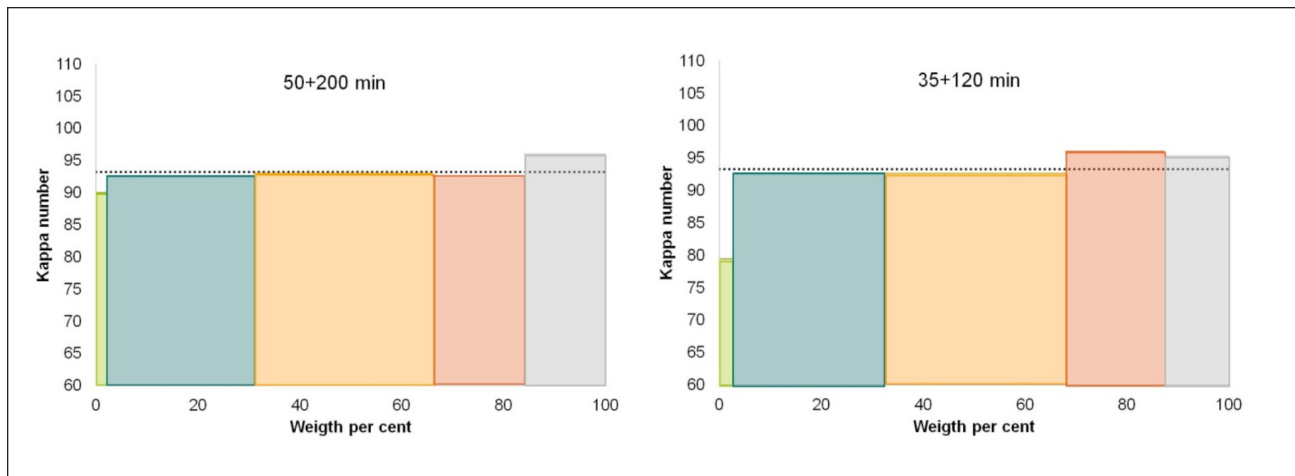
The cooking uniformity of high kappa number pulps is not easy to evaluate. One way of looking at uniformity is by fractionated defibration (i.e., using a laboratory disintegrator together with screening equipment to get different fractions of



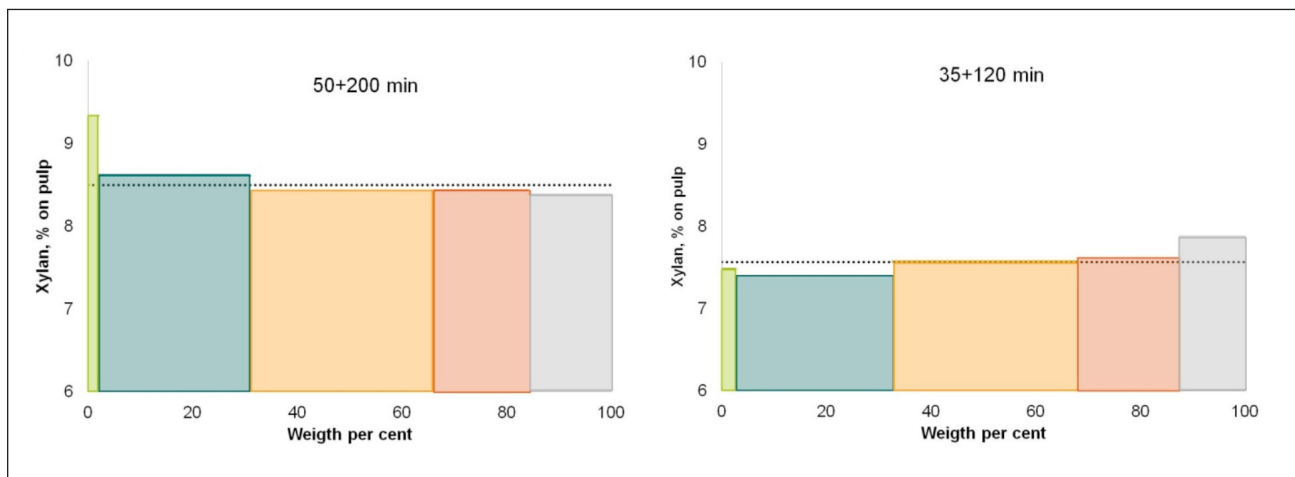
3. The H-factor demand to reach a certain kappa number is lower for the 50+200-min retention time pulps.

the pulp). That method was applied on 50+200-min and 35+120-min pulps, both having a kappa number close to 90 (**Fig. 4**). With this method, significant differences in kappa number distribution were not possible to see between the laboratory pulps. The reason may be that the 35+120-min pulp still has a fairly good impregnation time of 35 min.

When analyzing the chemical composition of the different fractions obtained by the fractionated defibration (**Fig. 5**), it is possible to see that the xylan has greater potential to reprecipitate on the 50+200-min pulp. This can be due to addition of black liquor, although the amount of dissolved xylan in softwood liquors is usually rather small [7]. Longer cooking times, which can increase the amount of xylan reprecipitated



4. The cumulative weight percentage of pulp after fractionated defibration (according to method described in Fig. 2) is on the x-axis and the kappa number of the fractions is on the y-axis. Kappa number distribution of the 50+200-min pulp (left) and the 35+120-min pulp (right) is shown. The dashed line represents the average value of the whole pulp sample.

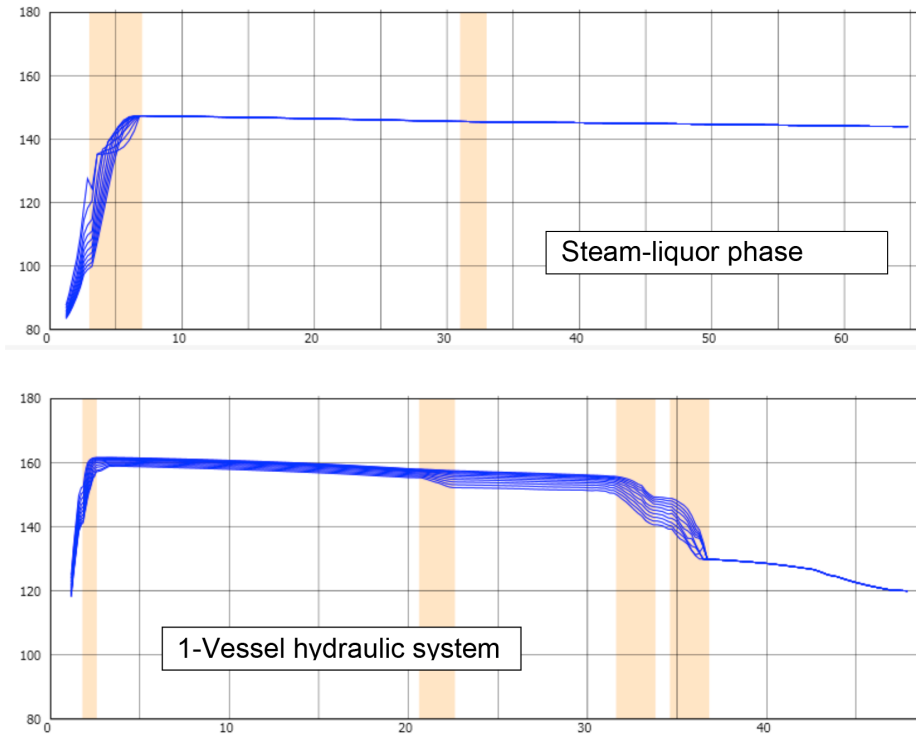


5. The cumulative weight percentage of pulp after fractionated defibration (according to method described in Fig. 2) is on the x-axis and the xylan content of the fractions is on the y-axis. Xylan distribution of the 50+200-min pulp (left) and the 35+120-min pulp (right), both at kappa no. close to 90, is shown. The dashed line represents the average value of the whole pulp sample.

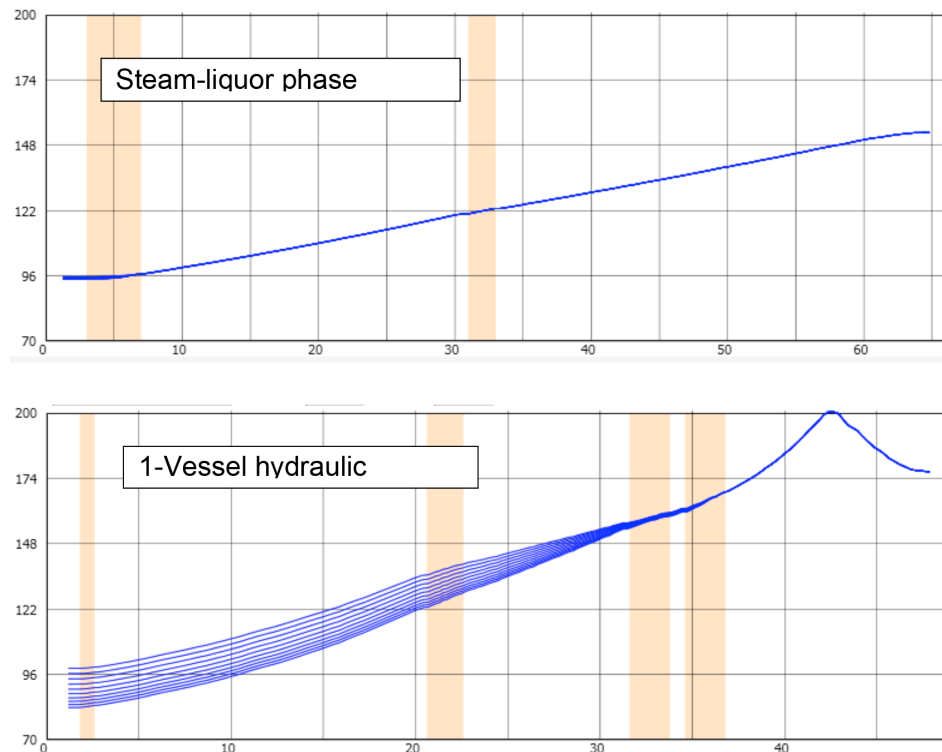
on the pulp, also can be an explanation [8]. The fractions of the chips easiest to defibrate (i.e., the first fractions obtained from the fractionated defibration) consist predominantly of the surface layers of the chips. It is noteworthy that these fractions of the 50+200-min pulp are enriched in xylan compared to the average content of that pulp. This indicates that xylan reprecipitation is taking place to a larger extent on the surfaces of the chips.

It is important to remember that laboratory cooking conditions are more perfect than reality and that nonuniformity in laboratory cooks are usually very small. This is due to several reasons. Oversized chips are removed to ensure the reproducibility of the cooks, all chips are well presteamed, the chemical is applied at the same temperature and concentrations, and all chips are perfectly washed. In the mill, heating and chemical distribution in different digester systems can be considerably different. Software developed by Valmet to simulate di-

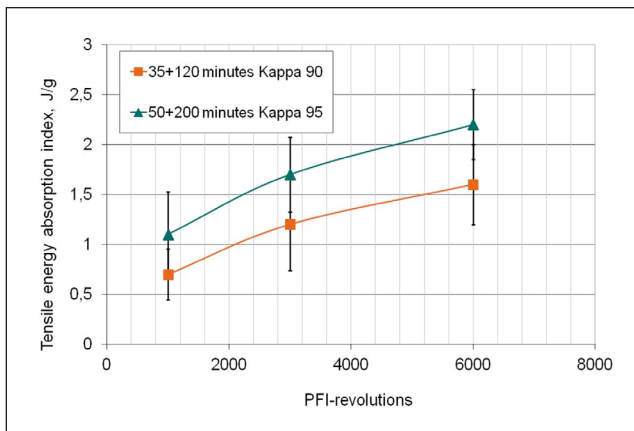
gester operations has been used to illustrate what the temperature gradients in a digester can look like (**Fig. 6**). The heating from impregnation temperature to cooking temperature in the steam/liquor-phase system is accomplished by direct steam in the top of the digester, resulting in even heating of all chips in the cross section of the digester. On the other hand, the single vessel hydraulic digester has a temperature gradient due to the heated liquor being recirculated back to the center of the digester, which heats up the center more than the periphery. The gradient in chemical composition will not be as great in this case because all the cooking chemicals are added as white liquor to the feed system. If white liquor is added in the heating circulation, the cross-section gradients will of course be larger. However, in this case there are mainly temperature gradients in the single vessel hydraulic digester that will result in different kappa numbers from the digester (**Fig. 7**). As a digester becomes more overloaded, it is



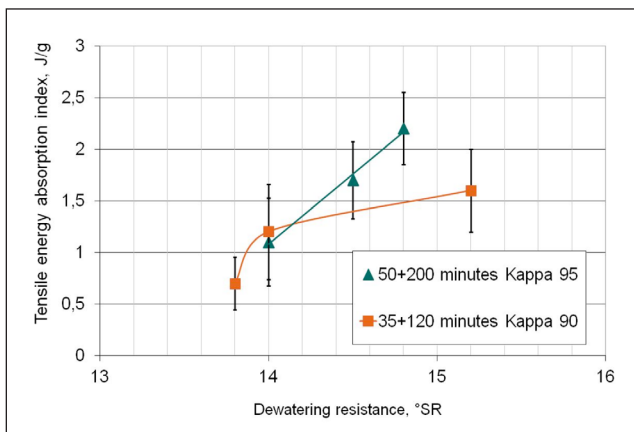
6. Valmet Crossim v5.06 software simulations of temperature profile in the different concepts with typical conditions for a 95-kappa pulp. Temperature in °C is shown on the y-axis and the digester height on the x-axis.



7. Valmet Crossim v5.06 software simulations of kappa number gradients in the cross section of the digester at typical conditions for a 95-kappa pulp. Kappa number is shown on the y-axis and the digester height on the x-axis.



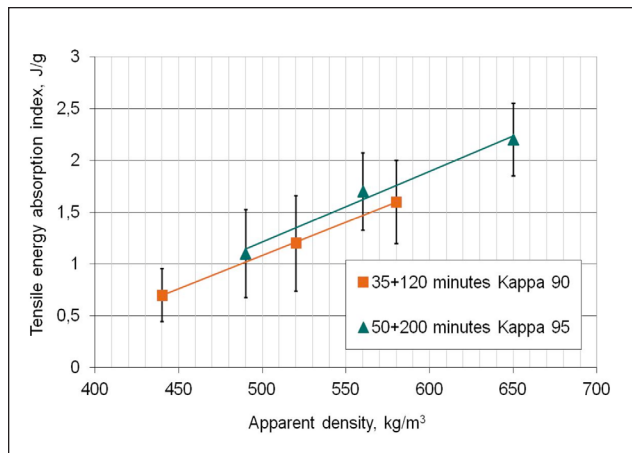
8. Strength is developed faster for the 50+200-min pulp compared to the 35+120-min pulp. The defibrated but unbeaten pulps had °SR 13.4 (35+120 min) and °SR 13.0 (50+200 min). The error bars represent a 95% confidence interval.



9. The increase in tensile energy absorption vs. the increase in dewatering resistance is smaller for the 35+120-min pulp compared to the 50+200-min pulp. The defibrated but unbeaten pulps had °SR 13.4 (35+123 min) and °SR 13.0 (50+200 min). The error bars represent a 95% confidence interval.

likely that the performance of the screens and circulations will deteriorate, exaggerating the problem even further.

Any distribution in kappa number or other pulp nonuniformity resulting from the circulations in a mill digester are, however, obviously not easy to simulate in the laboratory and do not show up in evaluation of laboratory pulp properties. For strength testing comparison between the two cooking methods, 90-kappa pulps were used. Generally the strength differences are small and not statistically significant within a 95% confidence interval. However, when comparing the tensile energy absorption versus the refining degree, measured as PFI-revolution (performed according to ISO 5264-2:2002 “Pulps—laboratory beating—part 2: PFI method”) and shown in **Fig. 8**, it can be seen that strength is developing faster for the 50+200-min pulp compared to the 35+120-min pulp. This means less refining energy is needed to obtain the same tensile energy absorption. This can also be seen in an



10. Tensile energy absorption vs. pulp sheet density. Less refining is needed to obtain a given strength for 50+200-min pulp. The error bars represent a 95% confidence interval.

increase in dewatering resistance, measured as °SR (performed according to ISO 5267-1:1999 “Pulps—determination of drainability—part 1: Schopper-Riegler method”), obtained at smaller increases in tensile energy absorption for the 35+120-min pulp and shown in **Fig. 9**. The differences are, however, relatively small but can be due to different locations of the hemicelluloses in the pulp fibers (on the surface or in the bulk), resulting in different relationships between dewatering resistance and strength development. As the tensile energy absorption is compared against density, it is also possible to see that less refining is needed to obtain certain strength. Thus, it is possible to increase the bulk (i.e., the inverted density) at certain strength by less refining (**Fig. 10**). Increased bulk at the same tensile stiffness gives increased bending stiffness to the pulp sheet.

CONCLUSIONS

Laboratory cook simulations of two cooking systems were compared: (1) a single vessel hydraulic digester with 35-min typical impregnation and (2) a two-vessel steam/liquor-phase digester with a low temperature impregnation for 50 min. Without the practical problems, such as nonuniformity due to circulations in a single vessel hydraulic system, the difference between the cooking concepts is still notable. Lower H-factor demand and increased strength, measured as tensile energy absorption, are the most important benefits of using a low-temperature, extended-time impregnation cooking system. The results show the potential for improved kraftliner properties using a modern two-vessel steam/liquor-phase digester. **TJ**

ACKNOWLEDGMENTS

The authors gratefully acknowledge the laboratory personnel at Valmet R&D Center in Karlstad, Sweden, for skillful laboratory work and Philip Anderson of Valmet North America for the linguistic revision of the manuscript.

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ABOUT THE AUTHORS

Kraftliner is a significant product for the pulp and paper industry and deserves more attention. This research connects laboratory results with knowledge of how digesters perform. The major challenge in doing laboratory experiments of kraftliner pulping is getting a relevant defibration of the pulp and studying the refining energy required in the defibration. Hence, data on that are lacking in this paper.

The significantly higher amount of xylan in the pulp produced with black liquor impregnation and longer cooking time was interesting to see. Mills can make more xylan reprecipitate on the fibers by recycling more black liquor in the cooking system and prolonging cooking times (at a lower temperature).

The next step is to do more research on the link between mill pulping conditions and kraftliner properties seen on the board machine.

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