Executive Summary

In order to produce pulp the chip column must be moving - this has become one of the most important tasks for the operator. The chip column movement in a two-vessel hydraulic digester can be improved by converting the digester to a two-vessel steam/liquor phase digester. This paper describes the factors important for chip column movement and presents the results from a digester conversion at BillerudKorsnäs, Gävle Mill, Sweden.

For many years pulping development for kraftliner has been limited. With the modifications of Item 222/Rule 41 the situation in the U.S. has changed. Recently a new cooking technology has been developed enabling defibration of softwood pulps at considerably higher kappa number with low reject content. 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.
Chip column movement in a continuous digester

Abstract
Most continuous digesters are between 30-50 years old and in many cases the production has been increased by 50-100%. In some cases, the kappa target and/or wood specie has been changed too. These digesters no longer operate under the conditions they originally were designed for. In order to produce pulp the chip column must be moving and this has become one of the most important tasks for the operator. The chip column movement in a two-vessel hydraulic digester can be improved by converting the digester to a two-vessel steam/liquor phase digester. This paper describes the factors important for chip column movement and presents the results from a digester conversion at BillerudKorsnäs, Gävle Mill, Sweden.

Introduction
The two most important design parameters for a traditional continuous digester are the cross sectional load, (typical design was 50 cubic feet of chips per square foot and hour), and the retention times (typically 40-60 minutes for impregnation, 75-90 minutes for cooking, 150-220 minutes for washing). In most mills the production has been increased to 50-100% above design and the kappa target and/or wood species may also have been changed. This has made running the digester, especially to keep the chip column moving, more difficult. The chip column movement can be improved by rebuilding the digester. In this paper, we describe what factors impact chip column movement and what impact the conversion of a two-vessel hydraulic digester to a two-vessel steam/liquor phase digester had on the chip column movement. But first, Figures 1-3 will give a short description of the most common continuous digester types.

The single-vessel hydraulic digester (Figure 1), is filled with liquor. Impregnation takes place in the upper part of the digester. Cooking temperature is reached by indirect heating in two circulations. The lower part of the digester is used for washing. It is suitable for all types of wood and kappa ranges.

In the two-vessel steam/liquor phase digester (Figure 2), impregnation takes place in the impregnation vessel (I.V.), which is filled with liquor. Cooking temperature is reached by direct heating in the steam filled digester top. A liquor level is maintained below the top separator. The chip level is controlled to 3-4 feet above the liquor level. The weight of the chips above the liquor level pushes the chip column downwards. The lower part of the digester is used for washing. Thanks to the top design, this
type of digester can handle variations in chip density better than other types of digesters. It is suitable for all types of wood and kappa ranges.

In the two-vessel hydraulic digester, Figure 3, the impregnation takes place in the I.V. The I.V. is liquor filled. Indirect heating in the circulation between the I.V. and the digester brings the chips to cooking temperature and the digester is filled with liquor. The lower part of the digester is used for washing. The fact that the digester’s top is almost as wide as the digester’s bottom makes it difficult to form a steady and well defined chip column.

What moves the chip column
The forces acting on a single chip are gravity, buoyancy, wall friction, liquor friction and the force on a given chip originating from the weight of the chips above it, as illustrated in Figure 4.

The only force we cannot influence is gravity. The other forces can to some extent be controlled and must be considered when designing new digesters or rebuilding old. The forces we can influence are:

- **The buoyancy.** An untreated chip with a moisture content of 50% is typically composed of 1/3 wood, 1/3 water and 1/3 air. As the wood density is about 1.5 times the density of water the chip will float if the air is not removed, i.e. steaming is important! The density of the free liquor is also a factor. The higher the dry solids content the bigger is the impact. This force is directed upwards.
- **The wall friction.** This force is acting on the chips closest to the digester wall. The wall conditions can have an impact. The biggest contribution to the wall friction comes from the horizontal forces trying to expand the chip column. The wall friction is a dynamic force directed upwards.
- **The weight from the chip column.** In a hydraulic digester, this force comes only from the weight of the submerged chip column above a given chip. In a steam/liquor phase digester this force is
increased by the weight of the chip column above the liquor level in the digester top. This is a downwards directed force.

- **The liquor friction.** The liquor friction is the force between the chips and the free liquor flowing in the void between chips. A liquor to wood ratio (L/W) between 2.5 and 3.5 ton/ton is normal. The L/W ratio has to be substantially higher than this before liquor starts to move downward faster than the chips. Figure 5 shows the chip/liquor velocity at the digester top for a high density SW and a low density SW as a function of the L/W ratio. At a Vchip/Vliquor > 1 the chips are moving faster than the liquor and the liquor friction force is directed upwards. The flow between the chips can also be restricted by air in the liquor and by the chip quality. Pins and dust tend to plug the void between the chips.

When summarizing the forces directed upwards and downwards the net force must be directed downwards for chip column movement to occur, as illustrated in Figure 6.

To make it possible to compare digesters of different sizes the "Net Force" is usually divided by the cross-sectional area and the driving force expressed as "Chip Pressure".

Chip compaction is illustrated in Figure 7. If a 1 ft³ box is filled with chips and no compaction takes place the compaction is 1. If, by compaction, the box can be filled with 2 ft³ of loose chips the compaction is 2.

Due to chip column weight, compaction increases towards the digester bottom. The compaction is also a function of kappa number. As the kappa is reduced the void volume between the chips is reduced. As a consequence, high kappa digesters can be taller than low kappa digesters without developing too high a compaction.
factor. Figure 8 shows softwood chips before and after laboratory cooking, with no external compaction applied. The chip column height was reduced by ¾” (out of 17” total) during the cook. The size of each individual chip did not change much.

Simulation of the chip column movement

The simulation program used in this paper is a proprietary Valmet tool. The actual digester dimensions together with chip density, liquor to wood ratio, dilution factor, etc., are fed into the simulator. The simulator divides the digester vertically into a couple of hundred slices. Each slice is divided into ten concentric circles, each representing 10% of the chip flow. Material, heat and liquor balances are made between the rings and the slices with results presented graphically.

Simulations were run on a digester before and after a 2011 conversion from a two-vessel hydraulic digester to a two-vessel steam/liquor phase digester. The difference in top design before and after the conversion is shown in Figure 9.

Figure 8. Chips before cooking (left) and after cooking to kappa 75 (right)

Figure 9. The digester top in a two-vessel hydraulic digester to the left and the digester top after conversion to a steam/liquor phase digester to the right
The simulation results for chip pressure and compaction factor before and after the conversion are shown in Figure 10. The red lines represent the digester before the conversion, the blue lines after the conversion and all units are metric.

The digester height is in meters on the x-axis with the digester top to the right and digester bottom to the left. The brown bands represent digester screens. The upper graph’s y-axis shows the driving force expressed as chip pressure in kPa and the lower graph’s y-axis shows the compaction factor. The simulated conditions are: 1060 ADMT/d, softwood at kappa 24.5, dilution factor 1.0 m³/ADMT.

In order to get a smooth moving chip column, the compaction at the bottom of the digester should be between 1.8-2 and the chip pressure safely above 6 kPa, i.e. the blue curves in both graphs are close to ideal.

![Figure 10](image)

Figure 10. The upper diagram shows the driving force expressed as Chip Pressure. The lower diagram shows the Chip Compaction. Red lines before the conversion, blue lines after the conversion to a two-vessel steam/liquor phase digester. Chip pressure is the "Net Force" on the chip column divided by the digester's cross sectional area.

The red curves show a digester with runnability problems due to a too low compaction and a marginally low chip pressure (driving force). In a steam/liquor phase digester the downwards "push" can be increased by increasing the chip level above the liquor level in the top of the digester.
Figure 11 shows how the chip compaction and driving force (expressed as chip pressure) are influenced by a plus/minus 1½ foot change in chip level at a constant liquor level. The conditions simulated are the same as in the simulation shown in Figure 10.

While a net downwards force is needed for column movement, a balance must be kept between compaction and driving force. Chip column movement is explained in Figure 12.
If the chip level above the liquor level is too high, compaction can become too great and increase liquor flow resistance in the chip column and as a consequence, increase the upward force acting on the chips.

If the compaction is too low chips will be pulled from the chip column into the screens, eventually plugging them. Maintaining chip level above the liquor level for optimum chip pressure and compaction factor can assure good column movement that will help sweep the digester screens clean.

**Improving chip column movement by converting a two-vessel hydraulic digester to a two-vessel steam liquor phase digester**

BillerudKorsnäs in Gävle, shown in Figure 13, is located 170 km north of Stockholm. It is an integrated mill producing liquid packaging board and white top kraftliner. Strength and cleanliness are the most important pulp quality parameters. The pulp production is 680,000 tons per year of which 360,000 are bleached.

The bleached pulp line that started up in 1988 is producing softwood and hardwood pulps in campaigns with a length of 20-40 hours. The digester, D3, was originally a two-vessel hydraulic. In 1994 the digester was rebuilt to isothermal cooking (ITCTM). The current production is 20% above design.

Due to frequent disturbances in chip column movement the digester had problems achieving stable operation. This resulted in channeling in the washing zone, variations in kappa, blow line consistency variations and problems with the chip level control. In order to minimize the impact from these disturbances the upwards directed force from the liquor was often reduced by a reduction of the dilution factor. When this did not help the circulation flows in the counter current cooking circulation and the ITC™ had to be reduced or shut down. As a last option, the chip feed to the digester was reduced.

Several trials were made in order to improve digester runnability, among them were down flow cooking and controlling the packing degree by changing the liquor to wood ratio. None of these resulted in improving digester stability. In light of this and after several reference visits the advantages of a two-vessel steam/liquor phase digester compared to a two-vessel hydraulic digester became obvious.

A decision was made to convert the digester to steam/liquor phase during the October 2011 outage. Another part of the new strategy was to abandon counter current cooking and implement conventional concurrent cooking. The screens that were used for modified cooking became the new extraction screens. The digester, before and after the conversion to steam/liquor phase plus the new digester top are shown in Figure 14 (next page).

The main parameters before and after the conversion are presented in Table 1 (next page).

A considerable amount of effort in planning the project was done to minimize the length of the shut down without reducing work place safety and the quality of the workmanship. The key was the onsite prefabrication of the new digester top. The prefabrication started three months before the outage and included platforms, a drive for the top separator, chip level indicators and cable racks.

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*Figure 13. The BillerudKorsnäs Mill in Gävle*
The digester top was built up next to the digester, as shown in Figure 15 (next page). Figure 16 (next page) shows the new top being lifted into position with the old hydraulic top removed and set on the ground. The installation was completed in 12 days in the middle of October, 2011 (Figure 17, next page). The scheduled 11 days were increased by 1 day as strong winds prevented the critical lift. The digester startup was initially problematic. The problem was frequent top separator plugging and the time to get back in operation could be from a few hours up to 12 hours. The cause of the problem was found to be sudden increases in the chip transfer from the impregnation vessel to the digester. The problem was solved by increasing the top separator speed from 10 to 14 rpm.

Table 1. Main digester parameters before and after the conversion

<table>
<thead>
<tr>
<th></th>
<th>Before conversion</th>
<th>After conversion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Softwood</td>
<td>Hardwood</td>
</tr>
<tr>
<td>Digester height, ft</td>
<td>180</td>
<td>200</td>
</tr>
<tr>
<td>Digester diameter, ft</td>
<td>21 1/2</td>
<td>21 1/2</td>
</tr>
<tr>
<td>Capacity, ADMT/d</td>
<td>1130</td>
<td>1260</td>
</tr>
<tr>
<td>Chip weight, lb/ft³</td>
<td>8.9</td>
<td>10.9</td>
</tr>
<tr>
<td>Impregnation, minutes</td>
<td>33</td>
<td>38</td>
</tr>
<tr>
<td>Cooking concurrent, minutes</td>
<td>70</td>
<td>89</td>
</tr>
<tr>
<td>Cooking counter current, minutes</td>
<td>47</td>
<td>59</td>
</tr>
<tr>
<td>Wash zone (HiHeat), minutes</td>
<td>133</td>
<td>169</td>
</tr>
<tr>
<td>Kappa</td>
<td>25</td>
<td>16</td>
</tr>
</tbody>
</table>

Figure 14. From left to right, the hydraulic digester before the rebuild, the digester after the conversion to steam/liquor phase and the new digester top
During the first year of operation, problems with plugging of the heat exchangers in the bottom circulation were experienced. This made it difficult to handle the quick temperature increase needed when switching from hardwood to softwood. What was found in the heat exchangers was a mixture of chips and inorganic material. When the digester was inspected during the maintenance stop in October 2012, one year after start-up, several of the ring girders in the top separator screen basket were broken. This had made it possible for chips to pass the separator screen and end up in the bottom circulation heat exchanger. The initial start-up problem with the top separator was probably what caused the ring girders to break.

**Mill results of the digester top conversion**

The main difference before and after the conversion can be seen in the higher "push" (down force) the steam/liquor phase digester is applying to the chip column. This has been used to increase the dilution factor, reduce liquor bypass flow and improve the control of the blow line consistency. A steady blow line consistency is important for the performance of the pressure diffuser after this digester.

**Figure 18** shows that the conversion of the digester to steam/liquor phase resulted in an increased dilution factor from 0.4 to 0.8 m³/ADMT.
At the same time, as shown in Figure 19, the variations in the dilution factor have decreased.

Another benefit from the conversion is the reduced steam consumption. Typical steam consumptions, before and after the conversion, are presented in Table 2 for softwood and Table 3 for hardwood.

![Figure 19. Dilution factor daily average duration curve for the period Jan-Apr 2011 (hydraulic) and Jan-Apr 2013 (steam-liquor phase)](image)

<table>
<thead>
<tr>
<th>SW (Pine and Spruce)</th>
<th>Before</th>
<th>After</th>
<th>Saving</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooking temperature</td>
<td>317 °F</td>
<td>311 °F</td>
<td>6 °F</td>
</tr>
<tr>
<td>Consumption of 50# steam</td>
<td>1080 lb/BDST</td>
<td>790 lb/BDST</td>
<td>290 lb/BDST</td>
</tr>
<tr>
<td>Consumption of 150# steam</td>
<td>2140 lb/BDST</td>
<td>1500 lb/BDST</td>
<td>640 lb/BDST</td>
</tr>
<tr>
<td>Total steam saving softwood</td>
<td></td>
<td></td>
<td>930 lb/BDST</td>
</tr>
</tbody>
</table>

*Table 2. Steam consumption before and after the conversion, softwood*

<table>
<thead>
<tr>
<th>HW (Birch)</th>
<th>Before</th>
<th>After</th>
<th>Saving</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooking temperature</td>
<td>308 °F</td>
<td>302 °F</td>
<td>6 °F</td>
</tr>
<tr>
<td>Consumption of 50# steam</td>
<td>770 lb/BDST</td>
<td>550 lb/BDST</td>
<td>220 lb/BDST</td>
</tr>
<tr>
<td>Consumption of 150# steam</td>
<td>1300 lb/BDST</td>
<td>790 lb/BDST</td>
<td>510 lb/BDST</td>
</tr>
<tr>
<td>Total steam saving hardwood</td>
<td></td>
<td></td>
<td>730 lb/BDST</td>
</tr>
</tbody>
</table>

*Table 3. Steam consumption before and after the conversion, hardwood*

The benefits shown in Tables 2 and 3 are primarily due to four factors:

1. There was not much upflow (i.e. dilution factor) before the conversion. This reduced the efficiency of the countercurrent cooking in the lower part of the digester.
2. Thanks to the increased chip compaction, the retention time in the cooking zone has increased and as time can replace temperature, a reduction of the cooking temperature has been possible.
3. The concurrent cooking time was increased when the extraction zone was moved to the old countercurrent cooking screens. This added to the cooking temperature reduction.
4. The wash (dilution factor) has increased. This means less cooling and more heat displacement in the bottom of the digester and an increased extraction flow that will generate more flash steam for the chip bin and steaming vessel, replacing fresh steam used for chip steaming.
Conclusions of chip column movement in a continuous digester

It is possible to improve the chip column movement in a continuous digester by converting from a two-vessel hydraulic type to a two-vessel steam/liquor phase type. The benefits are mainly due to:

- Better chip column formation as the digester top is narrower.
- A gradual increase of the column compaction and a higher end compaction as the chips above the liquor level generates a better “push”.
- Better control of the forces acting on the chip column. This can be used to increase the dilution factor.

A side benefit in the described case is the reduced cooking temperature which has resulted in a substantial steam saving. This is due to higher compaction increasing cooking zone retention time along with the change in the length of the cooking zone.

Comparison of cooking technologies for production of softwood kraftliner pulp

Abstract

Kraftliner, used as the top and bottom layer in corrugated board, is one of the major paper products in the U.S. and worldwide, as well as a long-term growing business area for the pulp and paper industry. However, for many years pulping development for kraftliner has been limited. The lack of pulping development may be due to 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 U.S. 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.

Introduction

Corrugated board is a major packaging material that makes our everyday life less costly, simpler and more environmental friendly compared to other packaging materials. Kraftliner has been in use for a long time as the top and bottom layer for corrugated board [1]. In order to make corrugated board an even more competitive packaging material and, furthermore, increase profitability for the pulp, paper and packing industry, continuous development is important.

As corrugated boxes made out of the 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. However, since then, 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 due to the fact that the 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. In addition, 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 since corrugated boxes were regulated by basis weight. There was very little incentive for increasing the performance and
lowering basis weight to increase profitability. With the modifications of Item 222/Rule 41 the situation in the U.S. has changed. As an alternative to minimum basis weight and burst strength, a minimum ECT, edge compression test, of the corrugated board became an option [2]. This change as well as increasing competition for suitable recycled fiber due to steadily growing box consumption have renewed interest in developing kraftliner and the pulp to make it.

Recently a new cooking concept utilizing 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 a kappa number as high as 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, an 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 an 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 60's or 70's and is a 1-vessel hydraulic type of digester. Since then the 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 large circulation flows, which, especially in an overloaded digester, can have a negative impact on chip column movement.

In order 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 an 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 run 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 prior to use and only the accept fraction (2-8 mm thickness) of the chip batch was used. Laboratory kraftliner cooks were made to simulate continuous cooking as illustrated in Figure 20 (next page).

The first concept simulated a digester system with an impregnation of 35 minutes at 125 °C followed by cooking for 120 minutes at the temperature required to obtain the targeted kappa number. This simulation will be hereafter denoted as 35+120 minutes. The second concept was simulating a system with an impregnation of 50 minutes at 105 °C followed by cooking for 200 minutes at the temperature required to obtain the targeted kappa number. This simulation will be hereafter denoted as 50+200 minutes. The pulps were cooked using synthetic white liquor with a sulfidity of 25% and a causticizing degree of 80% (both calculated on an AA basis). A residual alkali of about 10 g/l (as EA NaOH) was targeted. In the 50+200 minutes simulation, black liquor from previous cooks of the same chip batch was added.
Mechanical defibration of the pulps was performed in a lab refiner (Defibrator, Stockholm, Sweden), except when the uniformity of the pulp was investigated by fractionated defibration. The fractionated defibration was done according to the principal presented in Figure 21. The disintegration in the fractionated defibration was performed to the specifications in ISO 5263-1:2004. Approximately 20-30 gram (as B.D.) of cooked chips at a time were put through the fractionation.
procedure and 2 runs where performed on each pulp. About one liter of de-ionized water was used for each disintegration. Screening was performed using a water jet defibrator (NAF) 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 method described in Table 4.

**Results and discussion**

The yield at a given kappa number were similar for the 35+120 minutes and 50+200 minutes pulps. The H-factor demand to yield a certain kappa number is presented in Figure 22. The H-factor demand is considerable lower for the 50+200 minutes pulps. This is probably due to a more complete impregnation before cooking takes place. It has been shown in literature that low alkalinites result 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].

<table>
<thead>
<tr>
<th>Property</th>
<th>Method applied</th>
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<tbody>
<tr>
<td>Kappa number</td>
<td>ISO 302:2004</td>
</tr>
<tr>
<td>ISO-brightness</td>
<td>ISO 2470:1999</td>
</tr>
<tr>
<td>Carbohydrate composition</td>
<td>SCAN CM 71:2009</td>
</tr>
<tr>
<td>PFI-beating</td>
<td>ISO 5264-2:2002</td>
</tr>
<tr>
<td>Dewatering resistance, °SR</td>
<td>ISO 5267-1:1999</td>
</tr>
<tr>
<td>Laboratory sheet preparation</td>
<td>ISO 5269-1:2004</td>
</tr>
<tr>
<td>Sheet grammage</td>
<td>ISO 536:1996</td>
</tr>
<tr>
<td>Sheet thickness</td>
<td>ISO 534:2005</td>
</tr>
<tr>
<td>Tensile properties</td>
<td>ISO 1924-3:2005</td>
</tr>
</tbody>
</table>

*Table 4. Standard methods used*

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

In Figure 23 (next page) that method was applied on a 50+200 minutes pulp and a 35+120 minutes pulp, both having a kappa number close to 90. With this method, significant differences in kappa number distribution was not possible to see between the laboratory pulps. The reason for this can be that the 35+120 minutes pulp still has a fairly good impregnation time of 35 minutes.
When analyzing the chemical composition of the different fractions obtained by the fractionated defibration (Figure 24), it is possible to see that the xylan has a greater potential to re-precipitate on the 50+200 minutes pulp. This can be due to addition of black liquor, although the amount of dissolved xylan in softwood liquors is usually rather small [7], and longer cooking times, which can increase the amount of xylan re-precipitated on the pulp [8]. The fractions of the chips easiest to defibrate, i.e., the first fractions obtained from the fractionated defibration, are more likely to consist predominantly of the surface layers of the chips. It is noteworthy that these fractions of the 50+200 minutes pulp are enriched in xylan compared to the average content of that pulp. This indicates that xylan re-precipitation 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 non-uniformity 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 pre-steamed, the chemical is applied at the same temperature and concentrations and all are perfectly washed. In the mill, it has to be considered that heating and chemical distribution in different digester systems can be considerably different.
In **Figure 25**, software developed by Valmet to simulate digester operations has been used to illustrate what the temperature gradients in a digester can look like.

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 recirculated back to the center of the digester which will heat up the center more than the periphery. The gradient in chemical composition will not be as great in this case as 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 as illustrated by the software in **Figure 26**. As a digester becomes more overloaded, it is likely that the performance of the screens and circulations will deteriorate, exaggerating the problem even further.

Any distribution in kappa number or other pulp non-uniformity 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.
When comparing the tensile energy absorption versus the refining degree, measured as PFI-revolution, shown in Figure 27, it can be seen that strength is developing faster for the 50+200 minutes pulp compared to the 35+120 minutes pulp. This means that less refining energy is needed to obtain the same tensile energy absorption. This can also be seen in an increase in dewatering resistance, measured as °SR, obtained at smaller increases in tensile energy absorption for the 35+120 minutes pulp, shown in Figure 28.

As the tensile energy absorption is compared versus density it is also possible to see that less refining is needed to obtain a certain strength. This means that it is possible to increase the bulk, i.e., the inverted density, at a certain strength with less refining. Figure 29 (next page). An increased bulk at the same tensile stiffness gives increased bending stiffness to the pulp sheet.

**Conclusions of comparison of cooking technologies for production of softwood kraftliner pulp**

Lab cook simulations of two cooking systems were compared. A single-vessel hydraulic digester with a 35-minute typical impregnation and a two-vessel steam/liquor phase digester with a low temperature impregnation for 50 minutes. Without the practical problems, like non-uniformity due to circulations in a single-vessel hydraulic system, the difference between the cooking concepts is still significant. Lower H-factor demand and increased strength, measured as tensile energy absorption, are the most important benefits of utilizing a low temperature, extended time impregnation cooking system. The results show the potential for improved kraftliner properties utilizing a modern two-vessel steam/liquor phase digester.

**References**


This white paper combines technical information obtained from Valmet personnel and published Valmet articles and papers. The first section of this white paper was co-authored by Peter Sävelin, BillerudKorsnäs, Gävle, Sweden

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