# Improved Continuous Digester Controls using Wood Chip Analyzer at Zellstoff-Celgar

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## Abstract

Modern Pulp, Paper and Power mills have measurements installed for almost all inputs or key variables to their process. Yet wood chips that account for nearly 50% of the production cost are largely left unmeasured. Wood chip moisture is typically fixed at ~50% in the continuous Kraft digester control system. Depending upon the grade being pulped, dry bulk density is also fixed at an average of ~142.5 kg/m3 for softwood pulp. Yield is also set to a fixed value at ~46.5%; even though it is affected by blow line Kappa, wood species, size distribution and cooking conditions among other things as reported by MacLeod [1]. Digester revs, or chip meter speed in revolution per minute (rpm) sets the production rate on which white liquor addition is based. Blow line Kappa # is then used to correct the H factor control which adjusts the cooking temperature. The continuous digester residence time is typically between 4 to 6 hours. By then, the corrective feedback control action may not be effective due to ever changing wood chip conditions.

Modern Kraft mills have now become green energy power producers. Green power production is directly linked to pulp production. Stable power export requires stable digester operation. Improving the stability of digester operation helps to reduce blow line kappa # variability.

This paper discusses the uses on an on-line real-time wood chip analyzer to effectively control a continuous digester for stable operation.

## Understanding the impact of moisture on continuous digester operation

A desired dry mass of wood chips is continuously fed and cooked in a fixed volume digester in order to obtain a desired blow line Kappa # target.

The chip meter is the piece of equipment that takes the volume of wood chip and converts it to mass using a constant dry wood bulk density. If the wood chip moisture is known, then most believe liquor to wood can be assessed.

The reality is more complicated as moisture content affects dry bulk density. Naturally dried chips shrink while naturally wetted chips swell to retain water. Take the example of 1 ft3 of the same species wood chips with moisture content of 40% and 60%. When lab measurement of wood chip moisture is performed, the resulting moisture content is removed from the wet bulk density to provide dry bulk density. The same wood species will have two resulting and different dry bulk density values. The 40% moisture content sample will display a higher dry bulk density than the 60% moisture content sample.

Another way to help picture this phenomena is sliced green wood stacked up in a fixed support of let say 4ft * 8ft. At the end of the summer, the wood has cured and there could be up to several inches gap between the stacked wood and the frame. It is still the same amount of fully dried wood, but with reduced moisture content. The dry density is different.

Some other people equate this phenomenon to the space water takes within the wood chip.

This illustrates the complexity of what information is required to effectively control continuous digester feed. Moisture measurement, despite all its importance, cannot alone be used to reduce digester variability.

## Understanding dry bulk density

Saw mill wood chips have a higher dry bulk density than whole tree wood chips. Saw mill wood chips consist of more juvenile or outer wood while whole tree chips have more mature wood content.

In order to obtain an on-line real-time dry bulk density measurement, one has to rely on three different measurements: moisture, volume and mass. The errors in each of these measurements are summed up when dry bulk density is calculated. It is therefore imperative that each of the measurements be as accurate and precise as can be to minimize the resulting error in dry bulk density.

The accuracy in volumetric flow is a function of the chip belt speed. Measurement of mass should be performed with the highest available accuracy using double roll load cells equipped with a span calibration device. The accuracy in moisture content has to be equal or better than 1.5% moisture.

It is also important that all three measurements be performed in close proximity to facilitate data

reconciliation to obtain dry bulk density. In addition, the measurement should be made before the Kraft process treatment begins. This makes the ideal location of measurements after the screen room but before wood chips enter the chip bin.

## Understanding wood chip on-line moisture measurement

The real-time measurement of wood chip moisture is a difficult task as it is subjected to several variables. Color of the wood chips changes with species. Color is also affected by the aging of the chip. Ambient weather such as rain, snow, freezing and relative humidity affects surface and overall moisture. The impact can also be noticed in a change of color of the wood chips. On-line wood chip moisture measurement can therefore be qualified as a phenomenological measurement when using optical sensors.

## Wood Chip Analyzer

The Chip Management System (CMS) from Centre de Recherches Industrielles du Québec (CRIQ) has been undergoing development since 1994 for applications such as Kraft batch digesters filling control, TMP refiner motor load control using bulk density, and wood chip dumper to pile selection control.

CMS is comprised of several modules:

1. Chip Moisture Analyzer (CMA)
2. Chip Weighing System (CWS)
3. Chip Volumetric Measurement (CVM)
4. Chip Sizing System (CSS)

The Chip Moisture Analyzer (CMA) utilized a patented measuring principle [2,3,4] based upon non-intrusive NIR absorption complemented by a color LAB camera, an IR temperature and ambient air moisture. Wood chip moisture is typically 1.5% or better. Bark content, wood chip aging or freshness measurements are available as optional outputs. CMS has computing algorithms that can handle snow and frozen wood chips.

The Chip Weighing System (CWS) provides weight and belt speed from a double rolls load cell installed nearby the CMA.

The Chip Volumetric System provides real-time volume measurement at belt speed of up to 550 ft/min. Four (4) CVMs are installed at the discharge of each of the four (4) chip silos. A dedicated CVM signal concentrator and CVM computer using CRIQ proprietary computing algorithm provides each output on a 4-20mA signal to the Distributed Control System (DCS). Another CVM is located near the CMA and the CWS.

The Chip Sizing Systems is a patented laser based sensor that provides three dimensional (3D) chip sizing according to the mill's size and weigh based lab test. The first visible layers of wood chips are continuously measured according to width, length and height. The images of the wood chip dimensions are statistically correlated to lab results. Computation is performed real-time within the CSS computer via optic fiber to the CSS field cabinet.

The CMA, CWS and CVM provides the basic information regarding wood chips properties such as temperature, moisture, volumetric flow rate, mass flow rate. Dry bulk density is calculated in real time on a dedicated CMS computer connected via optic fiber to the field hub within the CMA.

The field installation shown in figure 1 conforms to the WorkSafeBC safety requirement.

**Figure 1:** CMS installation at Zellstoff-Celgar ahead of the chip bin

## Using CMS for Continuous Digester Control

The information from the CMS Chip Management System is utilized to improve several control functions of the digester control logics. Through a fully collaborative effort with Zellstoff-Celgar's digester operation personnel, several control algorithms were developed. The COOK-X advanced control solutions is composed of several modules:

1- CHIP-X: Volumetric control of silo discharge
2- BLEND: Chip Recipe
3- BIN LEVEL: Chip Bin Level
4- BIN TEMP: Pre-steaming
5- TON: Production Rate

6- FILL: Fill Factor
7- EA: Effective Alkali on wood
8- L2W: Liquor to Wood
9- LEVEL IV: Impregnation Vessel Level
10- LEVEL DIG: Digester Level
11- YIELD: Digester Yield

The information from CMS allows applying first principle on each of those control modules. First principle should always be the preferred choice. There was no need to resort to advanced process control (APC) tools such as Model Predictive Control (MPC or any variant) [5,6,7] or Fuzzy logics [8] to achieve improvement in digester control. The COOK-X technology is deployed under licence directly into the mill DCS which is an ABB Bailey Infi90. For this reason, the improvement in continuous dual vessel hydraulic digester control will show results, but will not enter into the details of how they were achieved.

## Zellstoff-Celgar's wood chip supply

The mill produces 1600 adMT/d of softwood pulp. It needs up to 8000 MT of green wood chip per day.

The wood species processed on site are SPF comprising of spruce, sub-alpine fir and white pine of mid-range density, western red cedar of lower density, and Douglas fir and western larch of higher density. The Zellstoff-Celgar mill has four chip silos that are typically identified as SPF, Cedar, Hemlock or Fir/Larch.

The mill receives saw mill chips from the next door sawmill by conveyor. It also receives wood chips from sawmills some 300km away delivered by trucks. Those wood chips are fed directly to the proper silo or stored on one of the 4 piles for future reclaim.

The mill has its own wood room and processes floated logs, mainly hemlock with cedar as well as whole tree chipping from logs stored on-site. The wood room operates 12 hours per day every day of the week. Wood room chips are typically fed directly to the silo, or stored on a pile for future reclaim.

## Volumetric control of silo discharges – CHIP-X

Two of the chip silos are old style turn tables while the other two are newer styles equipped with discharge screws. Speeds of discharge screws or turn tables are controlled to maintain the desired amount of chips required to maintain the chip bin level while respecting the proper species blend recipe.

The Chip Volumetric Measurements (CVM) were installed on each conveyor near the discharge of each silo to help stabilize the desired wood chip recipe. CVM needs to handle chip belt speed in excess of 500 ft/min with a minimum of 18 lines of scan per inch. This is important as silos equipped with screw for discharging chip leave a wave pattern of chips on the belt that reflects the pitch of the discharge screw. Improvement in chip supply delivery was noticeable as turn table and screw speeds have to continuously change to maintain their respective volume setpoints.

Chip screen operators can at any moment revert to speed control during upset or start up conditions. Switch between speed (figure 2) and volume control (figure 3) is transparent and bumpless. One of the many benefits of volume control is when there is a hang-up in one of the silo. Volumetric control will speed up the discharge to maintain the volume setpoint until the operator can resolve the issue. Once the chip flow resumes, the volume control automatically slows down the table or screw speed.

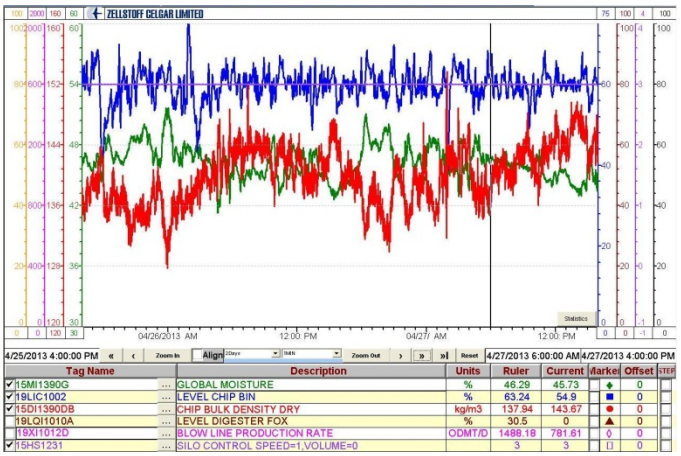


**Figure 2 :** Chip bin level under speed control

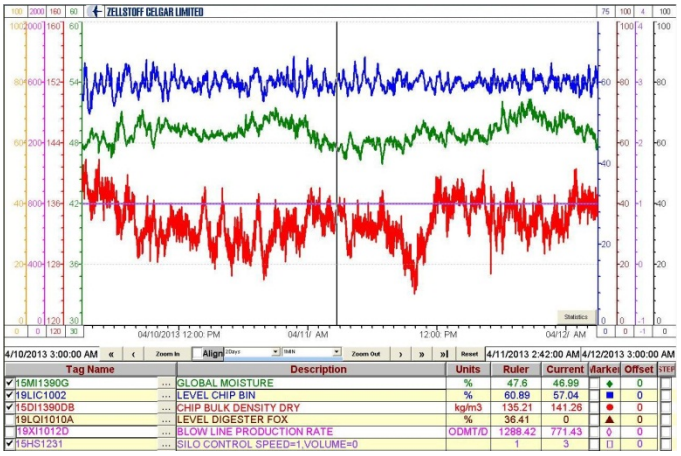


**Figure 3:** Chip bin level under volume control

## Wood chip blend recipe – BLEND

In normal condition, 60% of the chip supply comes from silos #3 and $4 equipped with screws while the remaining 40% are supplied by the silos #1 and #2 equipped with turn table as shown in figure 4.

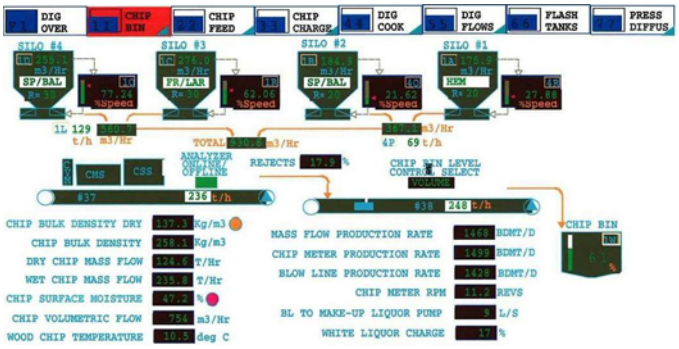


**Figure 4:** Digester operator overview of the CVM at the screen room and of the CMS results

The wood chip ratio control was redesigned to always add up to 100% as shown in figure 5. All of the volume controls were adjusted to operate with the same dynamic to maintain desired ratio as well as being able to deliver the total chip supply with only 3 silos in operation.

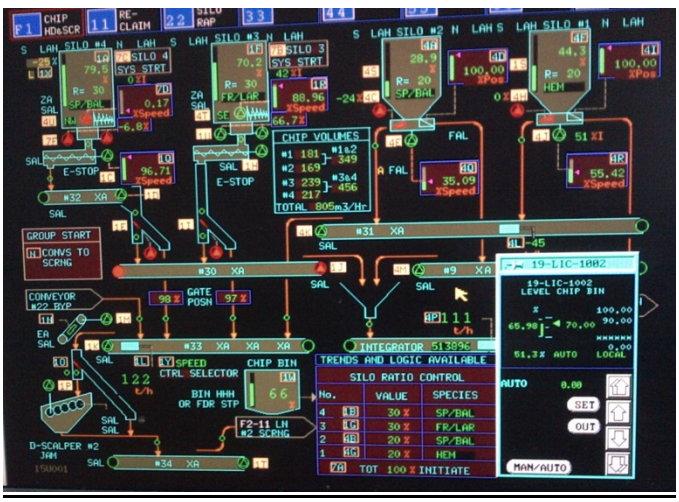


**Figure 5:** Screen room operator display

## Chip bin level – BIN LEVEL

The chip bin level setpoint is set as high as possible to maximize chip pre-streaming, but low enough to allow emptying the conveyor should the digester feed system stop. As the digester was designed for 1314 bdMT/d, but currently producing 1600 bdMT/d, the retention time in the chip bin is reduced to 16min at current production. There is some 5 minutes of deadtime between a level demand and wood chip to the chip bin. Output of the level controller has a feedforward from chip meter speed to maximize chip bin level stability. The volume control at the chip silos has reduced variability on chip bin level by some 20% as displayed in figure 6 and 7.

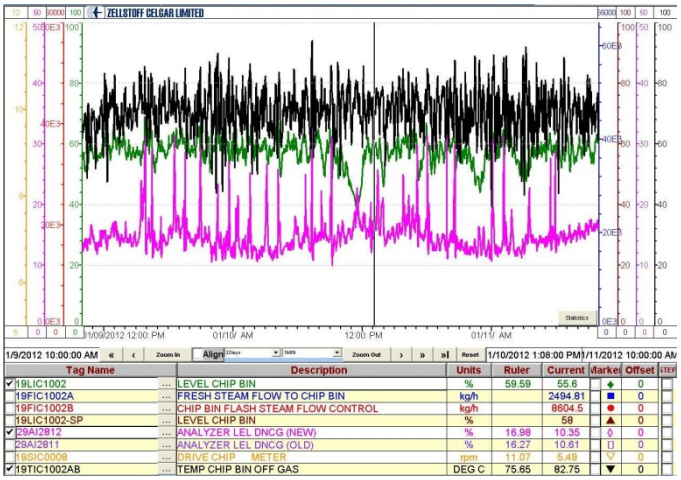


**Figure 6:** Before – Chip bin level control in winter

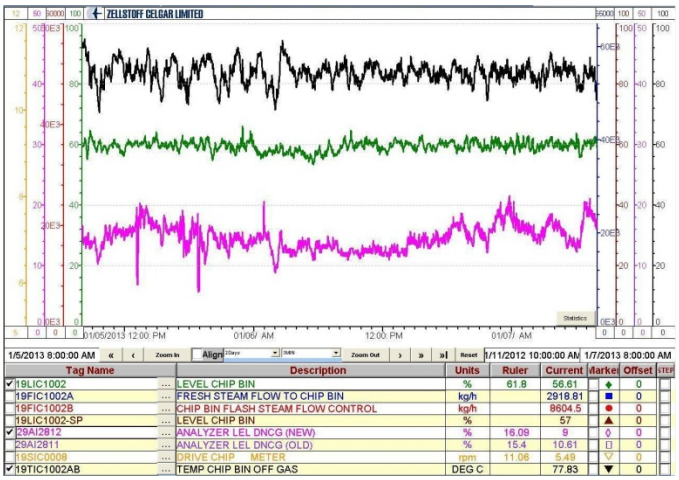


**Figure 7:** After - Chip bin level control in winter

## Chip bin temperature – BIN TEMP

The purpose of the chip bin is first to ensure a constant supply of wood chips to the digester. It secondary purpose is to ensure optimum pre-steaming of the wood chips. Air removal is particularly important for hydraulic digesters to avoid floating of the chips leading to poor digester level control and column compaction. Due to the reduced retention time and higher wood chip flow in the chip bin, it has become difficult to use flash steam to pre-steam the wood chips without venting on Lower Explosion Limit (LEL). LEL triggers atmospheric venting below 35$^{o}$C at the chip bin off-gas temperature or when LEL exceeds 35%. This was particularly true in winter with wet, cold or frozen chips.

Existing control was an off-gas temperature controller that controls the 500 kPa fresh steam valve. The digester operator manually adjusted the flash steam valve opening so the LEL would remain in a comfortable zone.

Soft-sensors for steam flows were installed on both fresh and flash steam to the chip bin and to the steaming vessel. The CMS information (temperature, moisture, mass) allows maximizing the flash steam usage, if available, to a maximum of 20000 kg/hr. Since Zellstoff-Celgar exports electric power, this is equivalent to 2.5 MW of extra green power produced from the displaced fresh steam as shown on figure 8. In winter time, flash steam represents approximately 70% of the total steam demand while during summer time, pre-steaming utilizes strictly flash steam when available. Figures 9 and 10 shows the result before and after implementation during summer, while figures 11 and 12 display similar results during winter.

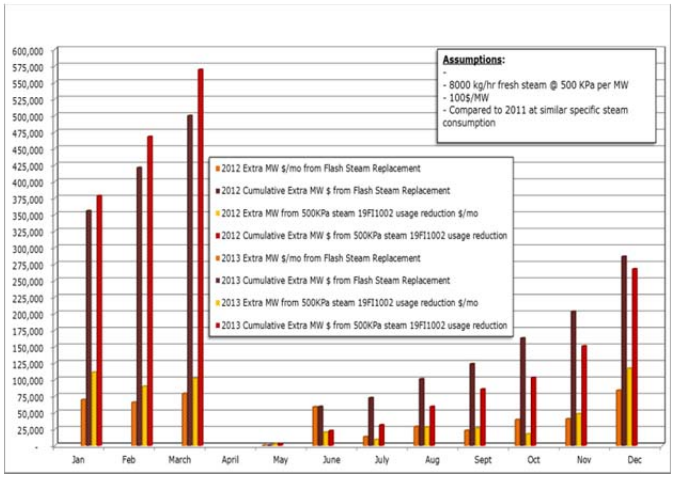


**Figure 8**: Extra power production from utilizing maximum available flash steam.

The above design production rate means higher steam flow is required. As both flash and fresh steams are injected in a common header at the bottom of the chip bin, any sudden steam flow change affects the chip column and disturbs the chip bin level. Thus the chip bin off-gas temperature control and the chip bin level control have to be properly decoupled.

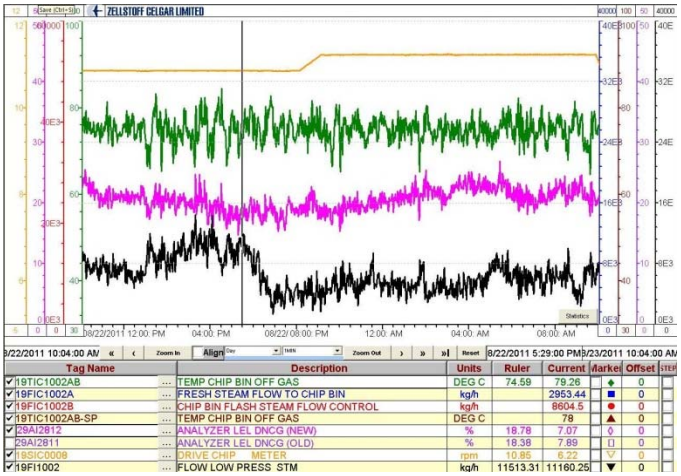


**Figure 9:** Before – Chip bin off-gas temperature control during summer

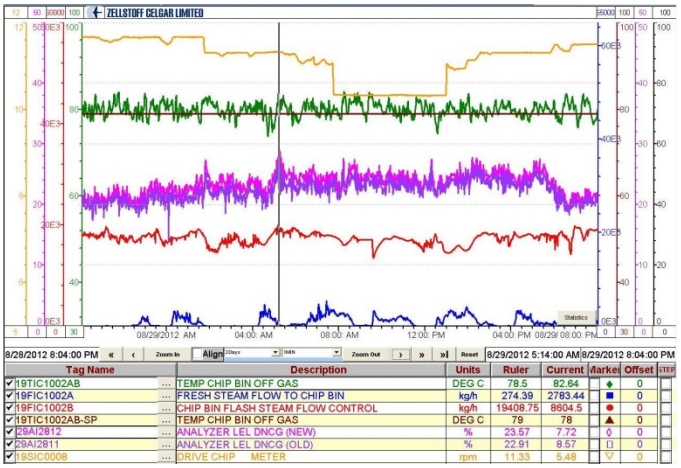


**Figure 10:** After – Chip bin off-gas temperature control during summer

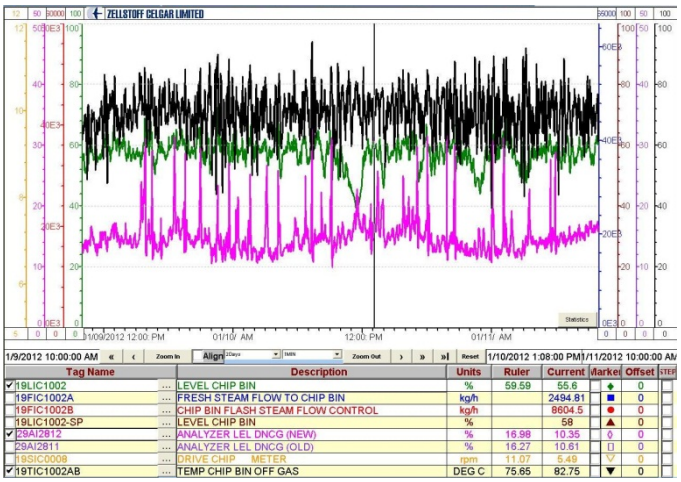


**Figure 11:** Before – Chip Bin Off-gas temperature control during winter

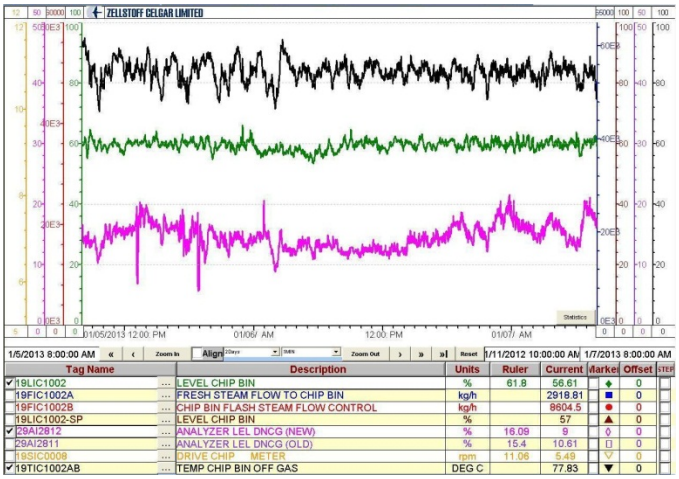


**Figure 12:** After – Chip Bin Off-gas Temperature Control during winter

It is interesting to observe the difficulty to pre-steam dry wood chips or pine beetle wood chips as they have a limited ability to absorb steam because of low total mass, rendering pre-steaming even more difficult.

The most noticeable benefit achieved with the new control scheme was the 55% reduction in atmospheric venting of diluted non-condensable gases (DNCG) as displayed in figure 13, making Zellstoff-Celgar a better corporate citizen. Given the proximity of the city of Castlegar and the narrow valley of the area, it is a welcome outcome.

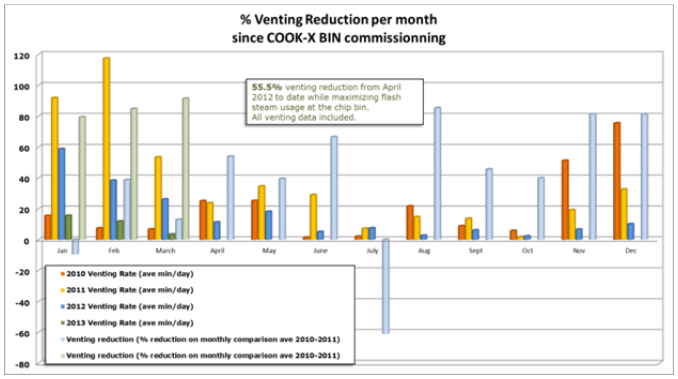


**Figure 13:** Chip bin venting before and after.

Extra benefit is the increase of the off-gas temperature setpoint to maximize chip pre-steaming under reduced retention time. As a result, LEL average is higher, but a lot more stable rendering a smoother operation of the overloaded DNCG handling system. This is especially true in winter conditions were wood chips retain most of the LEL precursors.

## Production rate - TON

The conventional method of assessing the production rate of the digester is to set the chip meter speed. Digester production rate in bdMT/d is assessed by looking at the monthly average production rate at the pulp machines in adMT/d assuming a 10% loss equivalent to the air dry and bleach plant yield loss. The relationship between the chip meter speed and the pulp machines production converts chip meter speed to tonnage, allowing the digester operator to fix production rate target in bdMT/d.

The CMS information allows calculating the estimated production rate and then modulating the chip meter speed to maintain the desired production rate target.

In order to alleviate the dry mass flow rate of chip caused by the chip bin level, dry bulk density is utilized in conjunction with the chip meter specific volume, the chip meter fill factor and the digester expected yield. The chip meter is allowed to vary +1.2 and -0.8 rpm from conventional fixed speed operation in order to maintain the production target. Figures 14 shows conventional fixed chip meter speed operation while figure 15 displays the new production rate control. The difference in blow tonnage is noticeable.

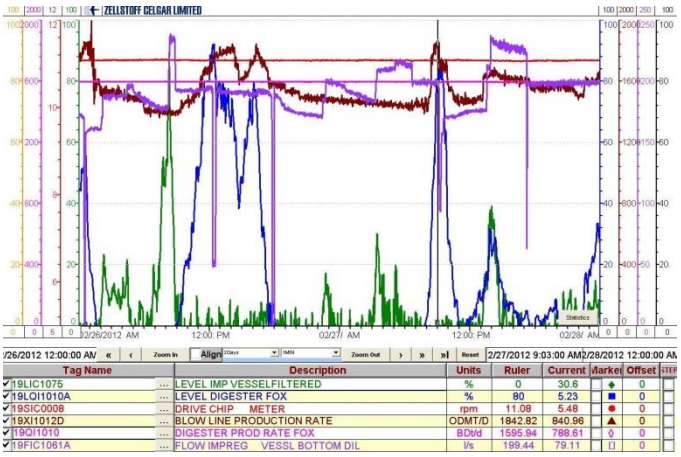

**Figure 14:** Before - Production rate results at fixed chip meter speed.

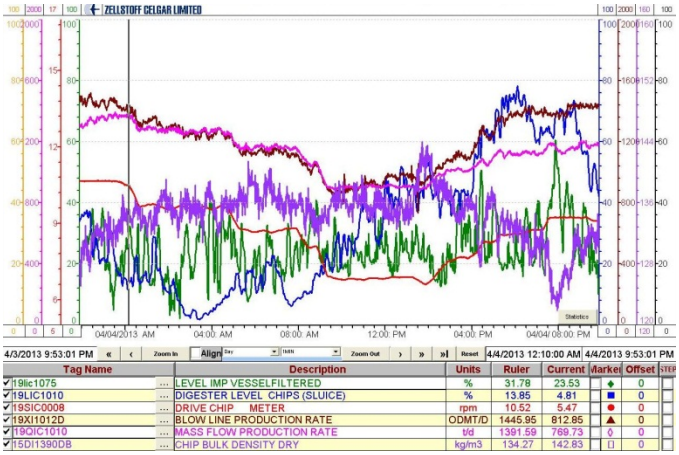


**Figure 15:** After - Production rate results during slow down then speed-up under control.

## Fill factor – FILL

The CMS information allows calculating the fill factor and monitoring of the low pressure feeder. The volumetric flow of wood chip entering the chip bin together with accumulation/depletion in the chip bin level compared with the theoretical chip meter volumetric flow provides accurate fill factor. The live fill factor is used in the production rate calculation.

The real-time fill factor calculation is presented to the digester operator and decision upon the adjustment of the low pressure feeder is based upon objective information instead of the weekly scheduled adjustment.

The opportunity to validate that the fill factor drops at higher chip meter speed has been confirmed. It is not unusual to observe fill factor of 1.00-0.98 at low chip meter speed while lower fill factor 0.986 of is observed at higher rate, as illustrated in figure 16.

The fill factor information was used as part of the justification to replace the low pressure feeder during the last mill wide shutdown.

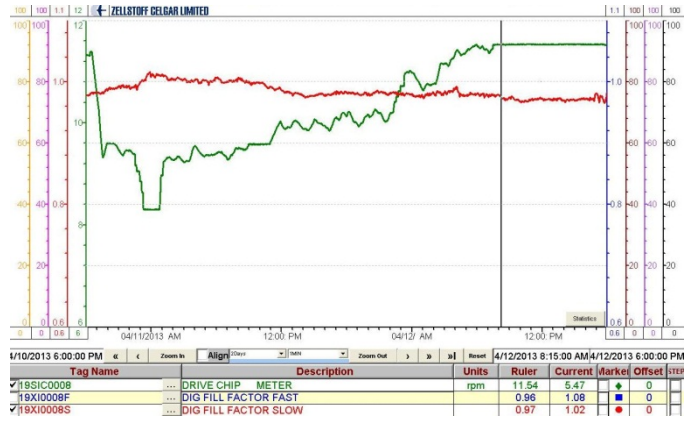


**Figure 16:** Fill factor at different chip meter speed

## Effective alkali on wood – EA

The amount of dry wood fed to the digester is used to adjust the dosage of white liquor to the make-up liquor pump (MULP). Accurate wood information allows proper dosage of the % alkali on wood, resulting in more stable extraction residuals as tested by operation every two hours. The alkali is added primarily at the MULP with only a smaller volume at the lower cook zone (LCZ) addition point.

## Liquor to wood ratio – L2W

One of the most important parameter in hydraulic digester is the liquor to wood ratio. Higher liquor to wood ratio improves compaction, which in turn improves the ability to increase washing in the wash zone. The digester wash zone is the most effective washer to recover weak black liquor.

The liquor to wood ratio calculation starts with the wood chip moisture entering the chip bin, hence the critical location of the CMS. Pre-steaming of the wood chips in the chip bin and steaming vessel adds between 3 to 5% moisture content. White liquor flow rate as set by the EA dosage and black liquor reject filtrate completes the initial assessment of the liquor to wood ratio. Cold blow filtrate added to the feed system is used to reach the liquor wood ratio target.

Work is currently under way to find a hotter source of weak black liquor to adjust the liquor to wood ratio. Volumetric flow of cold blow filtrate is limited when dry wood chips or pine beetle wood chips are present. Initial study around the digester hydraulic balance suggests that an external source of liquid to digester hydraulic system should be utilized to absorb the wood chip moisture variability.

Wood chip moisture entering the chip bin was observed to change up to more than 10% in 30-45 minutes at the time of the wood room start-up, with the processing of river logs. Since the digester retention time is around 6 hours, by the time the digester dynamic absorbs the change in moisture, the cycle starts again shortly after the wood room shuts down at the end of day. The ability to correctly adjust the liquor to wood ratio has largely attenuated the wood room operating schedule on the digester operation.

## Impregnation level – IV LEVEL

The function of the impregnation vessel is to allow proper impregnation of the white liquor into the wood chip prior to entering the digester. Pre-steaming is therefore paramount to air removal to ensure white liquor penetration within the wood chip.

Under constant feed to the digester, the conventional level control of the impregnation vessel adjusts the sluice flow as shown in figure 17.

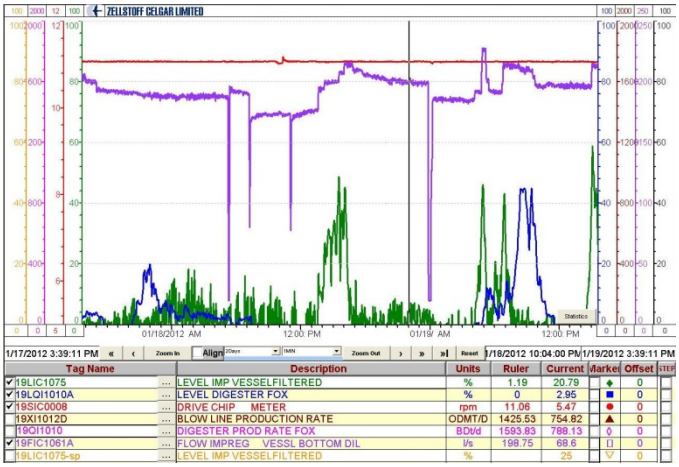


**Figure 17:** Before – Impregnation Vessel and Digester level controls

It has always been a struggle to maintain both impregnation and digester level since both level controls are dynamically coupled. The impregnation vessel level was often sacrificed, with no or low level indication most of the time. The digester operator often utilized the available residence time in the impregnation vessel as a safety option when the digester level reaches uncomfortably high value.

Using the CMS information, a breakthrough was made that allows the level of the impregnation vessel to be maintained at target all the time. Along with optimal available pre-steaming, residence time in the impregnation vessel is maximized. This is illustrated in figure 18.

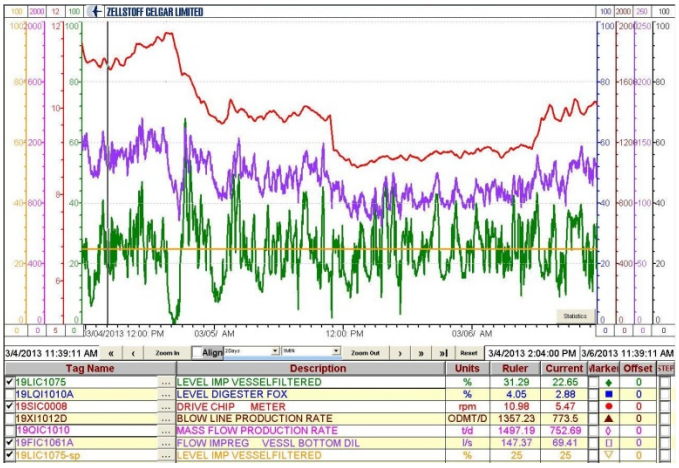


**Figure 18:** After – Impregnation Vessel and digester level controls

## Digester level – LEVEL DIG

Under constant feed to the digester, the digester level is maintained by modulating the blow flow valve. Conventional digester level gets feedforward ininformation from the chip meter. Typical results are shown in figure 19.

A stable digester level control is a good indication of the digester column stability. The less the blow valve has to move to maintain the digester level, the most likely the chip column is to remain compact and stable.

There is typically close to 60 minutes of deadtime between an action on the blow valve and response on level. Any piece of usable information to optimize level with the least amount of blow valve movement is an important addition.

A given dry mass of wood chip is continuously cooked in a fixed volume. Since dry bulk density changes for a given dry mass feed of wood chips, change in volume has to be dealt within the digester.

Chip meter alone provides theoretical volume entering the continuous digester. Add the fill factor and better information about real volume is available.

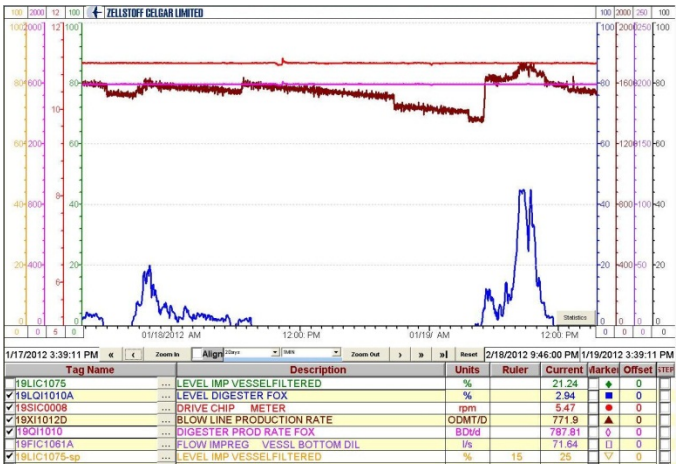


**Figure 19:** Before – Digester level control

Novel way of handling digester level control is allowing the digester level to be maintained in range. Large variations of 10-15 kg/m3 in dry bulk density are now being dealt within the digester. Under constant chip meter speed, this could be +/-150 bdMT/d at 1500 bdMT/D target production. By the time digester level control modulates the blow valve, +/-200 bdMT/d would exist the blow valve. Under previous fixed chip meter operation, the maximum allowable production rate was curtailed to avoid excessive production rate when dry bulk density ran high, resulting in Kappa # range of 35-40+. Results of the newer digester level control can be seen on figure 20.

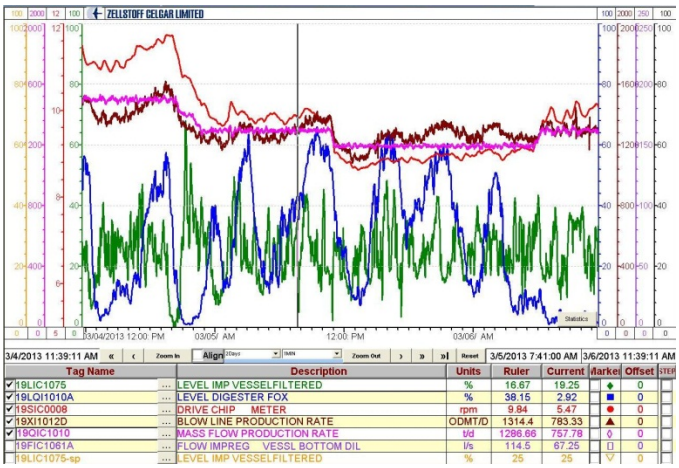


**Figure 20:** After – Digester Level control

## Digester yield – YIELD

The blow line consistency was configured in engineering unit using a soft-sensor based upon delta-P across the digester outlet device. The delta-P is affected by the Kappa # level, blow line temperature and blow flow. The blow line production is now known and has proven to be reliable.

Dynamic yield across the digester now provides valuable information to optimize digester operation.

## H factor control and Kappa #

H factor control is the relationship between time and temperature. Time is function of the volumetric flow rate. Little has been done to the existing digester H factor control since it was found to perform adequately at this time.

Initial average Kappa # was 25.6 with a standard deviation of 3.27 Kappa # as illustrated in figure 21.

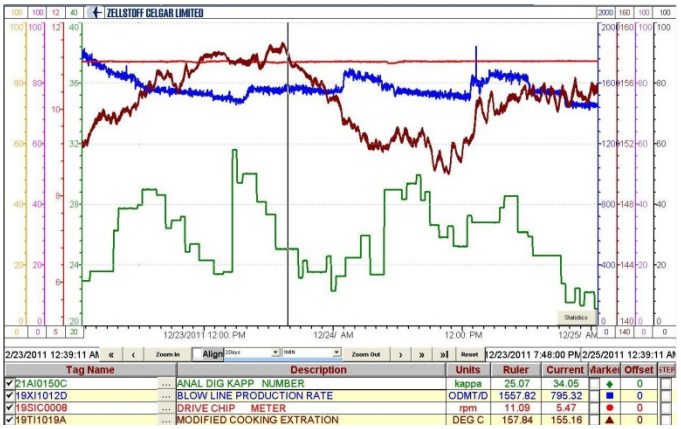


**Figure 21**: Before – Kappa # variation

Preliminary Kappa # under the COOK-X solutions is now 29.0 Kappa # with a standard deviation of 1.75 Kappa #, as shown in figure 22.

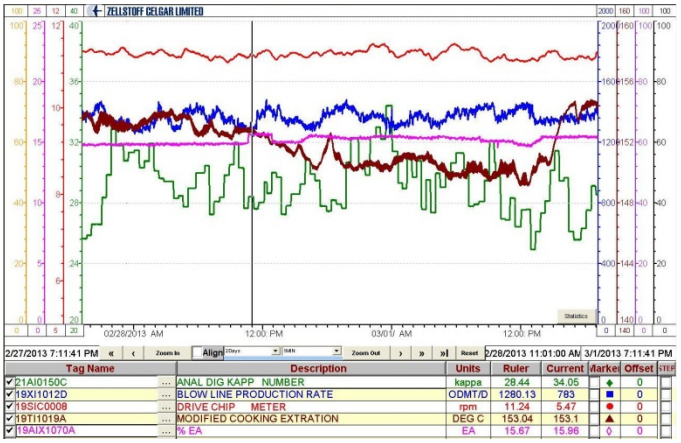


**Figure 22:** After – Kappa # variation

## Conclusion

The novel COOK-X control solution together with the CMS has allowed stabilizing the continuous digester operation. Most of the variation in wood chip moisture and dry bulk density can now be attenuated as can be observed in the stability of the blow line Kappa #. Those improvements would not have been possible without the CMS. However, there is too much variation in dry bulk density to be completely eliminated by the control system alone.

The new control system together with the wood chip analyzer allows Zellstoff-Celgar an increased flexibility of their fiber supply.

Despite previous effort to stabilize chip supply, the mill will be undergoing studies and corrective actions to stabilize the wood chip supply and the dry bulk density.

## Future work

Now that the fundamentals of wood chips measurements to the continuous dual vessel hydraulic Kraft digester have been tackled, future work will address the real-time chip sizing distribution impact on the Kraft cooking process.

Plans are for an FT-NIR analyzer skid to be installed on the digester liquor streams to further stabilize the digester operator.


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