Wood chip physical quality definition and measurement

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Abstract: For a TMP process, online chip quality measurement is very important because chip quality influences not only pulp and paper quality but also process control. In this paper, we will define and model chip quality based on an online measurement that can be used to pay suppliers, manage chip yards, monitor chip feeding, and achieve predictive and optimal refining control, etc.

The objective of TMP (Thermo Mechanical Pulping) process control is to have stable, optimal pulp quality with minimal energy consumption. Thus, a constant flow of chips into the refiners is an important parameter for maintaining good refining performance. As a raw material, wood chips are heterogeneous and when fed into a refiner can vary in terms of:

- Wood chip species;
- Chip size distribution;
- Moisture content;
- Bulk and basic density;
- Freshness;
- Bark, knot, and rot content;
- Impurity content, etc.

These variations disturb in turn TMP process control and influence pulp quality. Many studies have shown that wood species is the dominant factor in pulping performance and pulp quality. The spruce family is the most favorable species for TMP [1]. Homogeneity and low fines content of chip size distribution produce good pulp strength, while knot and bark contents decrease the strength and brightness of the pulp [2]. Continuous variations in wood basic density and moisture content occurring in chip flow tend to cause variations in refining consistency, which in turn affect pulp uniformity and energy consumption [3]. Rot should be avoided as it impairs the brightness and strength properties of paper [4]. Knots produce low strength pulp and are predominant among oversize chips. They also reduce pulp brightness [2, 5]. Fresh wood chips increase productivity, decrease hydrosulfite consumption, and stabilize the pulping process [6].

It is clear that if these chip properties can be measured online, then it will be possible to: 1) pay chip suppliers a reasonable price and better manage the chip yard; 2) achieve predictive and optimal refining control; 3) predict pulp and paper quality for a given pulp and paper manufacturing process.

The chip properties mentioned above can serve to sum up chip quality. A quantitative evaluation of pulpwood chip quality has been proposed for the chemical pulping process [7]. This evaluation is based on offline laboratory measurements. Accuracy depends on sampling method, frequency, and quantities. Because offline measurement cannot be used to stabilize, predict, and optimize processes, this evaluation can seldom be used in the industry. In this paper, chip quality will be defined on the basis of online measurement results, and thus should have a broad range of applications. In order to model this definition, a series of TMP experiments have been performed at CIPP’s TMP pilot plant.

EXPERIMENTAL

Two sets of trials were designed and performed at the UQTR’s CIPP. For the first set, black spruce and balsam fir, two species widely used in TMP, and jack pine and white birch, species that are expected to be used in the future, were chosen. After registering the pure chip species and its initial age, the

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pure chip species were stored outdoors separately for one year from autumn. Sampling frequency was about 3 weeks for the A, B, C, D, E, and F test groups. The interval between groups D and E was during the winter, and chip ageing had stopped \[8\]. For this reason, no tests were performed during this period. The sampled pure species were combined to form several mixtures as shown in Table 1.

The purpose of this experiment is to study the effects of mixtures of the four species and their characteristics such as ageing, size, impurity and moisture content etc. on final pulp and paper properties.

In the second set, the two main species-namely, black spruce and balsam fir, were used. The wood chips came directly from the sawmill and their ages were unknown. The freshest chips available were chosen. The main variables considered in the plan were: basic density, size distribution, and moisture content. A regular full factorial design was used for these three variables. The same high density species as those included in the first set were used. Thus, the second set of tests could also serve to check the results of the first set. These tests were performed in the summer, and the results were used to study fast chip-ageing conditions.

Chip physical properties were measured before refining using offline laboratory and online methods. The offline measurements followed PAPTAC standard methods; the online measurements were carried out using CRIQ’s CMS (Chip Management System), which measured a number of optical properties and moisture content etc. on final pulp and paper properties.

Before entering the Metso CD-300 TMP pilot plant, the chips were washed. The refining process was divided into two stages: the first stage was performed at 128°C and the second stage was atmospheric refining. Four freeness/energy levels were obtained by adjusting the plate gap during the second stage. Following PAPTAC standard methods, a full evaluation of pulp and paper properties was performed.

### ONLINE MEASUREMENT OF CHIP PROPERTIES

The importance of chip quality for the TMP process has long been recognized, but until now, a common definition has not been available due to the limitations of online measurement technologies. In order to develop an online measuring technology, some continuous non-contact technologies such as NIR (Near Infrared) and video camera, etc. may be considered.

### Wood Chip Optical Properties

In mills, visual evaluation of wood chip quality is widely used. From the chip colour, a specialist can determine the chip species and estimate freshness, bark, rot, and knot contents, etc. Knowing this, a RGB video camera was used to monitor chip colors. For a captured image, after some pre-processing, the following signals were extracted: the average of the red, green, and blue color bands (RGB) and the average of the HSL signal (Hue, Saturation, Luminance) that is computed from the RGB data. Hue is a pure color measure (green, red, etc.). Saturation indicates how much the color deviates from its pure form (an unsaturated color is a shade of gray). Luminance is the average of the three RGB color bands and indicates the degree of light reflected by the objects in the image. This information shows that spruce and balsam fir are brighter than jack pine and hardwood. Ageing and bark content decrease chip brightness, etc. This measurement has been used in mill chip yard management and process monitoring \[6\].

### Online Chip Size Measurement

Uniform chip size is very important for the production of high quality pulp. Changes in the distribution of sizes influences chip bulk density under a dynamic feeding condition, and therefore influence the applied specific energy; oversized chips require more energy and produce poor pulp quality; fines and pin chips decrease the pulp strength. Using a chip classifier (for example, Williams classifier) to classify chip size is frequently performed at...
chip reception sites of mills, but this offline measurement cannot be used to stabilize and control the TMP process.

In our research, a granulometry theory is applied. The process of computing a granulometry is similar to sifting sand through a screen. By gradually increasing the screen size, only the biggest sand grains will be left at the end of the sifting process. As a result, the number and weight of sand grains can be plotted as a function of screen size. The resulting curve is a granulometry and gives the size distribution of the particles visible in those images. Mathematical morphology offers tools that are very useful in this task. The process of sifting sand through screens of increasing size is similar to opening an image using a set size of structuring elements. An introduction to mathematical morphology is beyond the scope of this paper, and we refer the reader to these papers for an introduction to morphology and granulometry [9-12].

Each successive opening is performed using a bigger structuring element. As long as the smallest dimension of a wood chip is not contained by the structuring element, that wood chip will not contribute an accurate measurement. Comparing the results of this method with the Williams classifier, we found they followed well [8]. Figure 1 shows the measurement results of chip size distribution.

**Bark Content and Impurities Detection**

Bark content is a critical factor in the production of a high quality pulp. Excessive bark content will give rise to problems of pulp brightness, strength, and paper quality.

As bark color (except inner bark) is darker than chip color, it is possible to discriminate them in bark-chip mixtures. A variety of detection methods can be applied. For example, one can pick a color plane \((h, s, l, r, g, b, \text{or any linear combination of them})\) and select a bark specific intensity range. An image region will be classified as bark if the majority of its pixels fall inside the limits of this bark range. Another method would be to define one (or more) bark color reference point(s) with an admissible tolerance in the 3D RGB color plane. When the distance from the pixel being classified and the related reference is less than the allowable tolerance, it is classified as bark. These two methods need a lot of manual tuning to attain a reasonable confidence level. This tedious classifier setup can be avoided using a learning method. In this study, a Bayesian color classifier has been used. It is based on the well-known probability analysis methods in which the Gaussian statistical distribution for each class can be established. The advantages of this method are:

- A learning system does not require much manual tuning;
- The measurement accuracy can be calculated because the algorithm is based on a statistical theory;
- The classification step is easily made in real time.

In order to train the algorithm, chip, bark, and belt zone samples were selected from a series of chip images. During training, the algorithm uses them to define corresponding color classes. Finally, it is able to identify these three colors from a chip image, although noises (snow specks) are apparent in the classified image. These are filtered with morphological post-processing. Figure 2 illustrates an example of bark detection (part a is the original image and part b is the processed image; the dark color represents detected bark); the proportion of bark surface versus the total surface (bark and chip) is about 24.43%. Comparing the results with manual measurement, a good rate of correlation has obtained [8].

Impurities such as a plastic bag, etc. in chips can also be detected by a properly trained algorithm. The limitation of this method is that an adequate color difference between impurities and chips is required.

**Moisture Content Measurement**

In the TMP, chips are washed in hot running water and steamed at a high temperature, then they are softened and the moisture content is increased and homogenized. But when the moisture content is less than FSP (Fiber Saturation Point), the impact has been an observable decrease in tensile index. It is thought that greenwood makes better pulp than dry wood, thus an online moisture measurement would help avoid having a chip moisture content less than the FSP.

There are many non-contact moisture measurement tech-
CHIP QUALITY

nologies. The common problem with sensors of this kind of is that their calibrations depend on the wood species. In our study, a NIR sensor is used to measure chip surface moisture content for frozen and non-frozen chips. A phenomenological model has been developed to calculate the average moisture content from surface moisture content [6]. Chip optical properties can be used to adjust the calibration whenever wood species have varied. The experiment demonstrated that calibration adjustment would increase the measuring accuracy from ±5% to ±2% when black spruce contains unknown proportion of balsam fir (0-30%) and jack pine (0-10%). The calibration equation, which can be obtained by linear regression or PLS methods, is expressed as:

$$Q = b_1S + b_2F + b_3D + b_4B + b_5M + ...$$

• Moisture Content M.
• Bark Content B;
• Freshness F;
• Species Variation S;

... online measurement would be desirable.

Thus, chip quality may be expressed as:

$$Q = b_1S + b_2F + b_3D + b_4B + b_5M + ...$$

where:

- Q = chip quality
- S, F, D, B, and M = qualitative grades of each property;
- $b_1 - b_5$ = weighting factors.

CHIP QUALITY DEFINITION AND MODELING

In the mills, there is a chip reception standard illustrated in Table 2:

These physical properties are normally considered as the quality of chips and can be estimated by laboratory offline measurements. Unfortunately, it cannot be used to stabilize and control the TMP process due to the constraints of sampling size, frequency, and time delay. For this reason, a definition based on online measurement would be desirable.

WOOD CHIP QUALITY DEFINITION

As discussed above, online chip physical property measurement can be summarized as:

- Species Variation S;
- Freshness F;
- Size Distribution D;
- Bark Content B;
- Moisture Content M.

Thus, chip quality may be expressed as:

$$Q = b_1S + b_2F + b_3D + b_4B + b_5M + ...$$

The weighting factors represent the importance of related chip properties in the pulping process, which depends on the mill chip yard management, type of refiner, pulp and paper grade, and pulping process. This definition is flexible, with the development of measurement technology, the online measurement parameters (e.g., rot and knot content, etc.) can also be added to this equation.

Wood Chip Quality Modeling

Depending on pulp quality, refining requirements, and the experiences of a given mill, as exemplified in Table 2, some criteria have been set for chip properties. If the measured chip properties do not satisfy these criteria, the chips will be rejected so as to maintain process control, so this category of chip does not then need to be classified. Chips that satisfy the criteria are classified according to 10 different grades. As grades increase from 1 to 10, chip quality decreases accordingly. As mentioned in the quality definition, the final chip quality is based on the qualitative grade of each property. That is why it is imperative to perform qualitative grade modeling.

Chip Freshness and Species Qualitative Model

Our early studies demonstrated that chip optical properties correlate with chip ageing and species information [6, 8]. Thus, it should be possible to model them. Working from the trials at UQTR, in which chip freshness, ageing, and species are controlled, an FFNN (Feedforward Neural Networks) model is constructed. FFNN are known to have the empirically demonstrated ability to approximate complex functions. They are defined by the way they work and the way they are trained. The model thus constructed has 8 inputs, 1 hidden layer with 12 neurons, and 1 output layer with 2 neurons, as shown in Figure 3.

In the hidden layer, a log-sigmoid transfer function was used, and in the output layer a linear transfer function was used in order to obtain a broad range [1, 10]. The Levenberg-Marquardt algorithm was used to train the model. The inputs are R, G, B, H, S, L, M, and D; the outputs are the grades of freshness and purity of spruce.

According to the tests at UQTR, the freshness of group A is defined as grade 1, the group B is defined as grade 4, group C is defined as grade 7, group D is defined as grade 8 and groups E, and F are defined as grade 10.

With this definition, the ageing grade is used instead of the ageing time to determine chip freshness, since the chip ageing state not only depends on time but also on environmental conditions. As concerns species, 100% black spruce is defined as grade 1, 60% spruce with 40% jack pine is defined as grade 2, 60% spruce with 40% white birch is defined as grade 3, and 20% spruce with 40% jack pine and 40% white birch is defined as grade 4. A simulation result is illustrated in Table 3 and corresponds to the definition.

This model was trained using laboratory test results. For application in mills, the qualitative grade may be defined according to each mill’s real conditions and measurements. The measured input-output must be registered in a database in order to prepare the training patterns.

Chip Size Distribution Qualitative Model

The quality of chips satisfying the criteria of Table 2 may be different because of variations in the size distribution. For example, when 100% of the chips are 15.9-28.6 (mm) in size, they can be

| TABLE IV. Chip Size Distribution Qualitative Grade Simulation Results |
|---|---|---|---|---|---|
| Size grade | >28.6 | 15.9–28.6 | 9.5-15.9 | 4.8-9.5 | <4.8 |
| 0 | 100 | 0 | 0 | 0 | 1 |
| 8.33 | 72.22 | 13.89 | 8.33 | 0.44 | 5.8 |
| 13.33 | 55.56 | 22.22 | 13.33 | 0.56 | 8.4 |
| 9 | 50 | 25 | 15 | 1 | 10 |

| TABLE V. Bark and Moisture Qualitative Grades |
|---|---|---|---|---|---|
| % | Qualitative Grade |
| B | 0 | 0.1 | 0.2 | 0.3 | 0.4 |
| M | >43 | 41 | 39 | 37 | 35 |

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| TABLE VI. Chip Measurement Values and Weighting Factors |
|---|---|---|---|---|---|
| Weighting Grade | 0.15 | 0.2 | 0.4 | 0.2 | 0.05 |
| Grade | 4.5 | 3 | 5.8 | 9 | 2 |

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considered as grade 1. 1% of fines, plus 15% of 4.8-9.5 (mm), plus 25% of 9.5-15.9 (mm), plus 50% of 15.9-28.6 (mm), plus 9% of oversize can be defined as grade 10. The other combinations may be regarded as grades 2-9.

An FFNN quantitative model has been constructed. This model has 5 inputs, 1 hidden layer with 7 neurons, and 1 output layer with 1 neuron, as shown in Figure 4. In the hidden layer, a log-sigmoid transfer function was used, and in the output layer, linear transfer function was used in order to obtain a wide range 

An efficient online measurement method is not available for use with knots and rot, but the proportion of such defects in wood chips is stable since they are natural part of the wood. The bark and moisture contents can be measured directly and a qualitative value to evaluate the chip distribution grade. A validation of fiber length \( lw \) prediction is illustrated in Figure 5, the validation squares correspond with the definition.

If the mill has special requirements regarding chip distribution, a training file can be reoriented. The advantage of this model is to use a qualitative value to evaluate the chip distribution grade.

**Bark and Moisture Content Qualitative Values**

The bark and moisture contents can be measured directly and the definition of qualitative grades is listed in Table 5.

Impurities were not considered in this simulation since chip washing and screening are carried out for their removal.

An efficient online measurement method is not available for use with knots and rot, but the proportion of such defects in wood chips is stable since they are natural part of the wood. The knot, rock, and metal etc. can be removed by an air density separation system before feeding to refiners. In the case of ageing, rot content may increase; thus the chip freshness is also an indicator of rot content. The experience of the mill has shown that these two parameters are not too critical to the TMP process. The definition of chip quality is also representative without them.

**Chip Quality Simulation**

Chip quality can be simulated using qualitative grade definition and modeling. The weighting factors and simulated parameters (according to tables 3, 4, and 5) are listed in Table 6.

As illustrated in the Table 6, chip size distribution is the most significant parameter, while moisture is the least significant. Using equation (2), we obtained chip quality grade \( Q = 5.5 \). It is clear that chip quality is a synthetic evolution involving the main physical properties of chips that can be measured online.

**DISCUSSION**

In this section, potential applications of chip quality are discussed.

**Pay Chip Suppliers According to Chip Quality**

Normally, a mill pays chip suppliers when the chips satisfy the “Chip Quality Criteria” listed in Table 2. The measurements are performed offline; they may not be representative for a truck of chips, as the sampling quantity is only about 6 kg. Using chip quality, the online sensor can measure a large quantity of chips. Before feeding the chips to pile or silo, one part of or full unloading chips will pass through under the sensor (e.x.: the CMS). The measurement results (chip quality grade) not only be used to apply a bonus or penalty to suppliers, but also be used to feed the chips to appropriate chip quality pile and silo.

**Chip Management According to Chip Quality**

In chip receiving areas, chips are unloaded onto a pile or into a silo immediately after sampling. Even if the test results show the quality of unloaded chips does not satisfy the criteria of the Table 2, any recuperation can be done due to time delay of the offline measurement. Using the online measurement, chips can be refused or accepted before they are unloaded from the truck. They can also be sent to a related pile or silo, where they will be combined with chips of a similar quality.

**Chip Quality Monitoring in the Process**

Chip quality online measurement is very useful for stabilizing chip input. Feedback information will control chip-feeding screws so as to take suitable proportions of chips from different piles or silos. Currently, we are unable to find any report of this kind of control being used, due to the lack of online quality measurement.

**Using Chip Quality to Predict Pulp and Paper Qualities**

Using PLS (Projections to Latent Structures) model, pulp quality can be predicted using online chip physical property measurement [8]. Thus, online measured chip quality can also predict pulp quality. A validation of fiber length \( lw \) has been performed using the second trial set [13]. The results are plotted in Figure 5.

The PLS model was constructed using test results from the first set, in which four pure wood species and their six mixtures were used. Pulp properties strongly depend on wood species. A major variation in any of the species entering into a mixture will cause problems of prediction accuracy, so this variable must be considered in the model. It is possible to obtain an accurate model for a specific mill where the variation range of wood species is known or restricted. In Figure 5, the validation squares consist of black spruce and balsam fir that were included in the
first set, and thus the prediction is good.

A prediction of some paper qualities was also modeled using the PLS method [13]. With the prediction of fiber length, the second test set was also used to validate the model built on the basis of test results from the first set. An example of tensile index prediction and validation is shown in Figure 6.

These predictions are very important for improving pulp and paper qualities by using chip quality control.

Refining Process Predictive and Optimal Control
As shown in Figure 7, it is supposed that the refining process can be modeled and the pulp quality (target) is given, the refining parameters can be decided using online measured chip quality. It is clear that this measurement is a necessary condition for MPC (Model Predictive Control) of TMP.

For optimal control, the choice of wood chips and refiner control parameters depends on a performance index. As shown in Figure 7, assuming that the performance index is focused on minimizing the production cost, an optimal chip quality and related refining parameters can be determined. Where chip quality is higher, it is also possible to produce pulp and paper whose qualities correspond to the target, but at an increased cost. For this reason, the online chip quality measurement will help to select optimal quality of chips and to select refiner control parameters.

CONCLUSIONS
In this paper, we proposed a new concept regarding wood chip quality definition. This definition is based on an online chip physical parameter measurement. Chip quality is classified into 10 different grades and achieved by three layer identification. In the first layer, the chips that cannot produce suitable qualities of pulp and paper must be rejected. In the second layer, FFNN, etc. methods were used to define qualitative grades for each measured physical property. In the last layer, related weighting factors were determined according to the significance of the physical properties for pulp and paper production, with chip quality grade being subsequently determined.

This model is very flexible and can be continuously improved by the development of new online measurement technologies. Different mills can train the model according to their conditions and use it satisfactorily. Chip quality is not only used to pay chip suppliers and manage the chip yard, but also to achieve MPC or optimal control of the TMP process.

In future research, a validation of the model will be performed in the mills, and new online measuring technologies will also be developed in order to increase model accuracy.

ACKNOWLEDGEMENTS
The authors gratefully acknowledge the financial support for this research provided by the MRNQ (Department of Natural Resources of Quebec) through the center of excellence for wood chip valorization and Precarn Canada. Thanks are also given to pulp and paper industry personnel, especially from our direct partners: Abitibi Consolidated - Division Belgo, Shawinigan; Kruger Inc., Trois-Rivières; and Bowater Inc., Gatineau.

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Résumé: Il est important de réaliser une mesure en temps réel de la qualité des copeaux plus spécifiquement dans les procédés de PTM. La qualité des copeaux affecte, en effet, celle des pâtes et papiers produits mais elle influence aussi directement la commande de raffinage. Dans cet article, nous tenterons de définir un facteur de qualité des copeaux et de donner un modèle qui pourrait être utilisé pour payer les fournisseurs, gérer les cours de copeaux, surveiller l’alimentation des raffineurs puis réaliser des commandes prédictives et optimales des procédés de raffinage.


Keywords: CHIPS, DIMENSIONS, QUALITY, ON LINE MEASUREMENT, PROCESS CONTROL, THERMOMECHANICAL PULPING.