Chip moisture testing: How often is often enough?

By D. Olson

Abstract: The prevailing wisdom in the chip supply business is that chip sampling and testing can be reduced with no detrimental effect to the purchaser. However, the statistics used to justify this conclusion do not take into account the systematic bias created because chip moisture content and wet chip weight are not independent variables. Stochastic modeling showed that purchasers who practice either composite testing or skip sampling will always pay for more chips than they receive.

Chip purchasers weigh wet chips, but pay chip suppliers based on dry chips delivered. To calculate the bone dry tonnage (BDt) delivered, a representative chip moisture content is applied to the wet weight of chips delivered to the mill.

A number of chip supply consultants have suggested that, based on statistics, chip samples can either be composited for testing, or chip sampling and testing can be reduced significantly via skip sampling with no penalty to the pulp mill. Many chip purchasers have modified their sampling and testing procedures based on these consultant reports.

There are three main methods of determining a representative chip moisture content:

1. Sample and test chips from every truck
2. Skip sampling — sample every second, third, fifth, etc, truck, then apply the tested moisture to those trucks.
3. Composite testing — sample every truck, combine two, three, five or ten samples, then apply the tested moisture of the composite to all the sampled trucks.

Cariboo Pulp and Paper (CPP) purchases wood chips to produce 1000 AD tpd of northern bleached softwood kraft pulp. About 140 chip truck loads are delivered each day. Every truck is sampled and tested for chip moisture so that chip suppliers can be accurately paid based on the dry weight of chips they supplied.

MODELING OF CHIP MOISTURE

An analysis of actual chip deliveries to CPP was performed to determine if reducing the number of chip moisture samples would detrimentally affect chip purchase cost. The surprising result was that reducing chip moisture sampling and testing always resulted in an increased cost to the mill.

Figure 1 shows an example of the systematic unfavorable bias generated by not sampling and testing every truck for moisture. The example is admittedly extreme for purposes of clarity, but the unfavorable bias is true for any two trucks containing chips with different moisture content which are skip sampled. Two trucks of the same size are loaded with wood chips to capacity. During air drying of chips the free moisture is removed from the lumen of the fibre, so there is no significant difference in bulk density of the air dry chips compared to wet chips.

Therefore, since both trucks are the same volume, both trucks will hold the same bone dry tonnes (BDt) of chips. However, the truck hauling chips with lower moisture content will be considerably lighter than the truck hauling chips with higher moisture content. Although both trucks in the example would haul the same dry weight, one truck would haul a wet load of 25 wet tonnes, while the other would haul 40 wet tonnes.

The actual dry tonnes of chips delivered by the two trucks is 40 BDt (20 BDt from truck #1 and 20 BDt from truck #2). If the mill used the chip moisture from truck #1 (80% OD) to calculate total BDt, then the mill would pay for (25 + 40) * 80% = 52 BDt chips. This would be an overpayment of 12 BDt.

Alternatively, if the mill used the chip moisture from truck #2 (50% OD), then the mill would pay for (25 + 40) * 50% = 32.5 BDt chips, for an underpayment of 7.5 BDt.

Prevailing wisdom is that these under and overpayments will balance out in the end. However, this example and the analysis in this paper prove that prevailing wisdom is incorrect.

A little probability theory will point out the problem. Each truck is equally likely to be sampled. Since the sampling is random, the probability of using the moisture test from either truck #1 or truck #2 is exactly one half. Therefore, the expected value of the dry chip weight that the mill will pay for can be calculated as follows:

\[
\text{Dry Weight} = \left(\frac{1}{2}\right) \times (\text{dry weight if 80\% OD}) + \left(\frac{1}{2}\right) \times (\text{dry weight if 50\% OD})
\]

\[
= \left(\frac{1}{2}\right) \times (52) + \left(\frac{1}{2}\right) \times (32.5)
\]

\[
= 42.25 \text{ BDt}
\]

In other words, for this example the mill can expect to pay almost 6% too much for their wood chips. This is an unfavorable bias due to reduced chip moisture sampling.

Although this is an extreme example, the rest of this paper will show that the systematic unfavorable bias in the weight of dry chips is true for all chip purchasers that practice skip sampling or composite testing of their chip deliveries.
Stochastic Model of Moisture and Weight
A spreadsheet model was developed that used 229 paired truck weight and moisture samples from one chip supplier over 12 days. The order of each paired sample series was changed using random number sorting. The model calculated bone dry tonnes chips for five different skip sampling scenarios:
1. Sampling every truck for chip moisture
2. Sampling every second truck
3. Sampling every third truck
4. Sampling every fifth truck
5. Sampling every tenth truck

Figure 2 is a portion of the spreadsheet model showing how random numbers were used to re-sort the data. The percent error was defined as the difference between the actual BDt purchased based on sampling and testing chips from every truck, and the total BDt calculated by the model for each of the four skip sampling scenarios.

Results
The stochastic model calculations were repeated 30,000 times to determine asymptotic values. Figure 3 shows that initially there was some uncertainty whether the bias would result in a favorable or unfavorable BDt error. However, the results after the first 2,500 trials trend towards an asymptotic value unfavorable to the chip purchaser.

Table 1 shows the results of all 30,000 trial sets. Skip testing every second truck will result in a 0.11% unfavorable error. Increasing the skip testing to every tenth truck will increase the error to 0.21%. For a typical 1000 AD tpd pulp mill, this would result in a $100,000 overpayment for chips.

**Why Does This Systematic Bias Exist?**
Trucks are loaded by volume, not weight, so chip loads with higher average moisture content will tend to be heavier. This means that chip moisture content and wet chip weight are not independent variables.

**Composite Testing vs. Skip Sampling**
The analysis so far has discussed “skip sampling”, where every second, third, fifth or tenth truck was sampled for moisture determination, and the moisture was applied to the rest of the trucks. The analysis has shown that this type of sampling and testing always results in increased chip costs to the pulp mill.

But what about “composite testing” of chip moisture for samples from every truck - would changing to this test method eliminate this unfavorable bias in dry chip weight? For the purpose of this study, “composite testing” was defined as sampling every chip truck, mixing equal volume samples, extracting a representative sample from the composite, testing that sample for moisture, then applying that moisture to all the trucks that were sampled for the original composite.

Since chip moisture and delivered chip weights are not independent variables, calculating bone dry weight using skip sampled moisture content will always result in a non-weighted average dry weight.
data used for this analysis was the same 229 paired data from one supplier taken over 12 days. The model was run 2,500 times to reach steady state.

The results were very similar to the results from skip sampling. Figure 6 shows that the percent error due to composite sampling quickly reached an asymptotic value, always in the unfavorable (to the purchaser) direction. However, as the number of samples per composite increased, the percent error also increased. Presumably the error would be even higher for those mills that composite more than 10 chip samples.

There may be ways to alter the sampling scheme so that composite testing would result in a true weighted average dry weight, thus eliminating the unfavorable bias. We are actively developing those sampling schemes in conjunction with Paprican.

CONCLUSIONS
To accurately calculate dry weight of chips delivered to a mill, every truck must be sampled and tested. Otherwise a systematic and unfavorable error will always result in overpayment for the chips.

Analysis of delivered chip loads using a stochastic model showed that the systematic error is introduced to chip purchases if either skip sampling or composite testing is practiced. At Cariboo Pulp and Paper, chip cost would increase up to $100,000 annually if skip sampling or composite testing were practiced.

The unfavorable systematic bias occurs because wet delivered chip weight is not independent from the chip moisture content. Therefore, calculating bone dry weight using skip sampled or composite tested moisture content will always result in a non-weighted average dry weight.

Subsequent to the work reported in this paper, Paprican was contacted to determine whether this unfavorable chip bias had been previously reported in the literature. No mention of chip moisture bias was found in the literature. However, in 1969 Forte Engineering reported a similar bias caused by composite moisture testing of pulp bales [2]. They concluded that the bias was always in the direction of the wetter bales, resulting in a loss in revenue to the mill.

The extent of the error caused by skip sampling or composite testing of moisture needs to be put in perspective. Skip sampling or composite testing could result in an annual $100,000 chip overpayment. However, this additional chip cost is much less than the additional cost caused by testing a non-representative chip sample taken from the wrong location. An internal CPP mill analysis of fifty chip truck loads showed that samples taken from the chip truck tailgate were, on average, 1.4% drier than chips sampled throughout the chip load [3]. The magnitude of this error due to testing a non-representative chip sample could reach $1.3 million annually.

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LITERATURE

Résumé: La sagesse populaire veut que, lorsqu’on s’approvisionne en copeaux, on peut réduire l’échantillonnage et les essais des copeaux sans effet adverse pour le client. Toutefois, les statistiques employées pour justifier cette conclusion ne tiennent pas compte du biais systématique créé parce que la teneur en eau et le poids humide des copeaux ne sont pas des variables indépendantes. La modélisation stochastique a indiqué que les acheteurs qui procèdent à l’essai composite ou qui ne se préoccupent pas de l’échantillonnage paieront pour plus de copeaux qu’ils n’en reçoivent.


Keywords: MOISTURE CONTENT, CHIPS, TESTING, TEST METHODS, SAMPLING