DEVELOPMENT OF WOOD GRINDING
4. EVALUATION OF THE THEORETICAL GRINDING MODEL

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Spruce wood was ground under certain fixed conditions to achieve data for interpretation of the grinding mechanism. For this purpose, wood moisture content, wood feeding rate and grindstone peripheral speed were given five, three and two different levels, respectively. The data obtained by application of a laboratory grinder were accordingly most reliable, because the grinder was run under well controlled conditions, and the wood samples represented one and the same wood quality, but at five moisture content levels. The grinding zone temperature was measured at the outlet from the grinding zone, and accordingly it would indicate the average grinding zone temperature. The grinding model suggests that the energy specific fibre production ($\dot{G}w/Pt$) evaluated at various power friction levels (Pc/Pt) would help understanding the wood grinding mechanism.

The energy specific fibre production showed significant dispersion, when evaluated as a function of the power friction. However, detailed analysis of the data revealed that there could be two linears, one representing moisture saturated wood, and one representing fresh wood that also contains free water in the lumina. Surprisingly, this linear also included data representing air-dry wood. Increasing wood moisture ratio from 0.2 kg to 1.4 kg per kg o.d. wood decreased the average grinding zone temperature significantly from about 98° to 88 °C. Further, there was roughly a difference of 8–12° C in grinding zone temperature due to the wood moisture, when evaluated as a function of the force friction coefficient (Ft/Fc). The two highest moisture ratios resulted in a low-level linear, as the other moisture ratios produced a high-level linear.

The wood moisture content seems to affect the grinding process in different ways due to the moisture content level. Since moisture is absorbed in the fibre wall material and evidently linked to various lignin and cellulose components by hydrogen bonds, it will affect the grinding in a certain mode. However, the air-dry wood sample seemed to act as the fresh wood samples, which cannot be explained properly unless also considering fibrillation and fibre properties.

Keywords: balance, energy, evaluation, friction, grinding, heat, mechanism, power, spruce, temperature, wood

INTRODUCTION

Since the recently introduced energy balance of wood grinding did not consider the effect of shower water and grindstone – both cooling the wood and fibre slurry – the simplified energy balance must be interpreted with due care.[1-3] The moisture appearing as free liquid in the fibre lumina was earlier suggested to have the same temperature as the fibre wall, including its own moisture. However, it was thought that a step backwards would provide a stable basis for continuation of the studies.

The energy balance is dependent on the grindstone surface. It should also have space for shower water and separated fibres in the stone grooves that serve as channels for the slurry flow off as well. The groove edges take part in the grinding procedure as they produce low-frequency stresses to the wood surface. The grits again produce high-frequency stresses, which initially act as viscoelastic rather than as elastic stresses. The closer to the grindstone surface, the higher is the wood temperature, and accordingly, the higher the possibilities for wood softening, which means viscoelasticity and finally, fibre separation. Since most of the lignin is located around fibres and between them, there will apparently not be similar prerequisites for its softening, because some of it is located on the "shadow side" of the compressing forces.

EVALUATION OF THE THEORETICAL GRINDING MODEL
Development of model

A theoretical wood grinding model (1) was developed and it was based on an energy balance of the grinding zone.[3] Accordingly, the balance included the fibre slurry, the thin fibre separation layer and a comparatively thick wood layer, including viscoelastic and elastic sections, but not the grindstone surface layer. However, the grindstone grooving pattern, the grit size, and their sharpness/dullness, as well as their specific number, were all included in the grinding activity. Accordingly, the effects caused by the grindstone would be visible, for example, in the fibre length, pulp fines and fibrillation.

$$(P_c/P_t) + 1 \approx (c_w + X \cdot c_m) \cdot \Delta T_{p\text{-}w} \cdot (\dot{G}_w/P_t) \quad (1)$$

This model (1) tested with data obtained by Riissanen suggested that $(\dot{G}_w/P_t)$ *versus* (P_c/P_t) would appear as a linear function, but with considerable dispersion – see Figure 1.[4] The data varied from 15 to 65% moisture content, or as moisture ratio – correspondingly from 0.2 to 1.9 kg moisture per kg oven-dry wood. These data include the entire industrially used moisture contents of wood, *i.e.* air-dry wood (15%/0.2 kg), saturated wood (28–44%/0.4–0.8 kg) and fresh wood also containing free water in the lumina (58–65%/1.4–1.9 kg). Data by Schmidt obtained with lodgepole pine chips indicated that moisture

contents in the range between 20 and 45% would represent fibre saturation, as the data used now suggested 28 and 44% moisture contents being limits for fibre saturation.[5]

Testing the energy balance model

Careful analysis of the data in Figure 1 indicated that two different linears appeared, as shown in Figure 2, which linears both showed satisfactory regression coefficients of 0.93. The upper linear is valid for moisture contents close to fibre saturation: 28 and 44%. The lower linear represents fresh wood samples: 58 and 65%, and unexpectedly also the air-dry wood sample: 15%. It seems logical that moisture saturated wood samples produce more groundwood than fresh wood samples, because water in the lumina decreases the wood fibre temperature and, accordingly, delays proper fibre softening. However, some relevant explanation might be delivered, when also considering the fibre properties.

The average grinding zone temperature, measured at the pulp outlet from the grinding zone, decreased significantly as a function of the wood moisture ratio – see Figure 3 (basic data by Riissanen).[4] The air-dry wood (15% moisture content) showed the highest grinding temperature, but it behaved in grinding like the fresh wood samples.
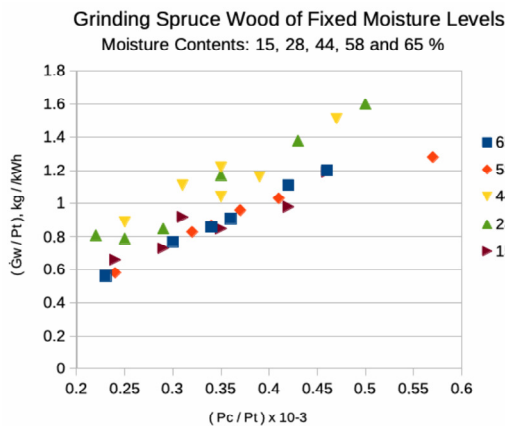

Figure 1: Energy specific fibre production $(\dot{G}_w/P_t)$ *versus* power friction coefficient (P_c/P_t) valid for grinding data obtained for wood with 15, 28, 44, 58 and 65% moisture contents; wood feeding rate: 0, 7, 1 and 1.3 mm/s; grindstone peripheral speed: 20 and 30 m/s
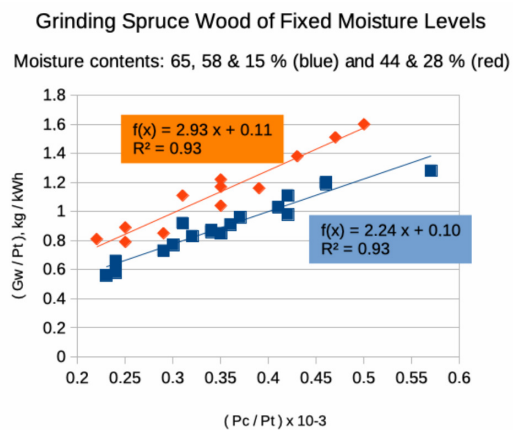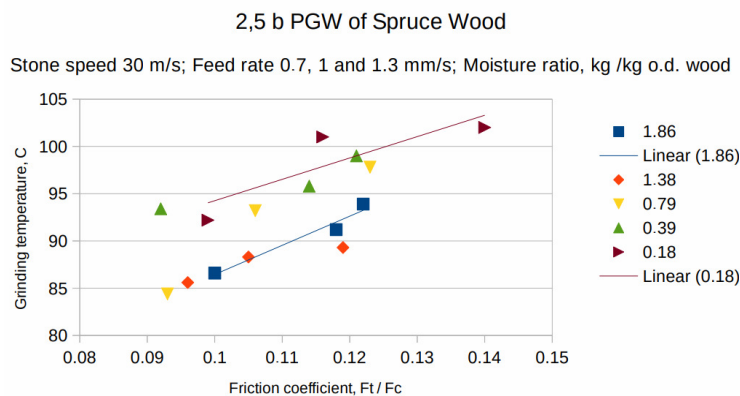

Figure 2: Energy specific fibre production *versus* power friction coefficient. Upper linear valid for wood fibre saturation, and the lower – for fresh wood (also containing free water in fibre lumina) and an air-dry wood sample; wood feeding rate: 0, 7, 1 and 1.3 mm/s; grindstone peripheral speed: 20 and 30 m/s

2.5 b PGW of Spruce Wood

Stone speed 30 m/s; Feed rate 0.7, 1 and 1.3 mm/s

$f(x) = -8.91 x + 99.6$
$R^2 = 0.99$
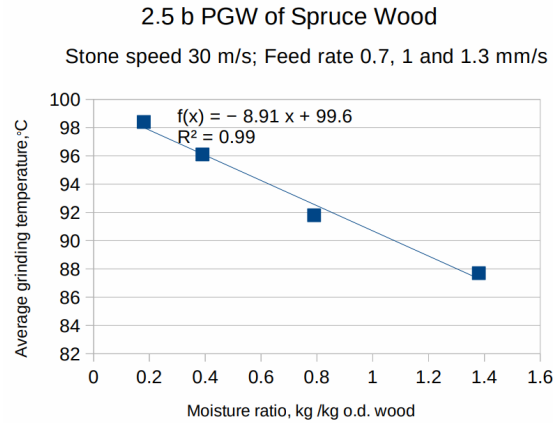
Figure 3: Average grinding temperature *versus* wood moisture ratio

2,5 b PGW of Spruce Wood

Stone speed 30 m/s; Feed rate 0.7, 1 and 1.3 mm/s; Moisture ratio, kg /kg o.d. wood

Figure 4: Grinding zone temperature *versus* force friction coefficient (F_t/F_c). Upper linear valid for grinding of air-dry and moisture saturated wood samples, and lower linear for fresh wood samples; wood feeding rate: 0, 7, 1 and 1.3 mm/s; grindstone peripheral speed: 20 and 30 m/s

The average grinding temperature *versus* the force friction coefficient (F_t/F_c) – see Figure 4 – indicated that fresh wood containing 58 and 65% moisture (1.4 and 1.9 kg per kg o.d. wood) resulted in a lower temperature that increased from 85 to 95 °C for force friction coefficients between about 0.10 and 0.12. On the other hand, the moisture saturated wood samples containing 28% and 44% moisture content (0.4 and 0.8 kg per kg o.d. wood) provided a correspondingly increasing level from 95 to 100 °C, but with slightly lower elevation.

CONCLUSION

It seems that the active grinding interface between wood and grindstone is more complicated than considered so far. The energy balance model suggested the evaluation of the interrelationship of the energy specific fibre production ($\dot{G}w/Pt$) and the power friction coefficient (Pc/Pt). The graph showed two distinct linears: one representing fibre saturated wood, *i.e.* having moisture contents from roughly 25 to 45%, which produced more pulp than fresh wood samples also containing free water in the lumina. It is supposed to depend on the moisture and its location as absorbed moisture or partly free water. If bound to the fibre carbohydrates by hydrogen bonds, the energy formed in frictional movements of the fibre wall heats effectively the fibre moisture and, accordingly, promotes fibre softening. On the other hand, free water in the lumina represents excess water, which also absorbs heat, although slowly due to heat transmission.

To confirm the results, the grinding zone temperature was evaluated as a function of the force friction coefficient (F_t/F_c). Based on the graph, it seems that air-dry and saturated wood samples would provide higher temperatures, while fresh wood samples containing free water provide lower temperatures. These data behave

BRUNO LÖNNBERG

mainly in the same way as the ($\dot{G}$w/Pt) *vs* (Pc/Pt) data, namely that fibre saturated samples produce higher temperatures and fresh ones containing free water produce lower temperature levels.

REFERENCES
[1] B. Lönnberg, *Cellulose Chem. Technol.*, **54**, 49 (2020), https://doi.org/10.35812/CelluloseChemTechnol.2020.54.90
[2] B. Lönnberg, *Cellulose Chem. Technol.*, **55**, 113 (2021), https://doi.org/10.35812/CelluloseChemTechnol.2021.55.11
[3] B. Lönnberg, *Cellulose Chem. Technol.*, **55**, 795 (2021), https://doi.org/10.35812/CelluloseChemTechnol.2021.55.66
[4] M. Riissanen, PGW-slipning av fuktkonditionerad ved (Pressure Groundwood Made of Moisture-Conditioned Wood), M. Tech. Thesis, Åbo Akademi University, Faculty of Chemical Technology, Åbo 2002, 70 p., conducted by Prof. B. Lönnberg, Laboratory of Pulping Technology
[5] R. E. Schmidt, *Tappi J.*, **51**, 164 (1968)