Water States in Black Spruce During Drying Studied by Time-Domain Magnetic Resonance

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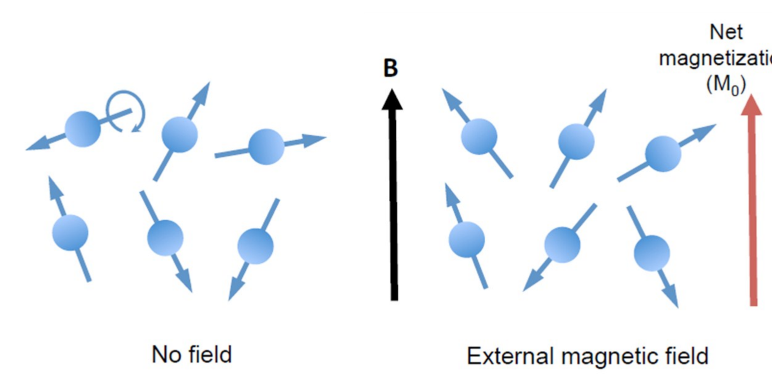
Abstract

In this study, water content in black spruce (*Picea mariana Mill.*) sapwood samples was investigated with time-domain magnetic resonance (MR). Time-domain MR measurements easily distinguish water in different environments in wood according to the spin-spin relaxation time and provide quantitative information on water content. The MR techniques employed can distinguish and quantify the individual signal components. Black spruce has two signal components at moisture contents above the fiber saturation point. These two signal components correspond to motionally restricted water, often referred to as bound water, and unrestricted, or free water. Bound water content is constant above 40% moisture content. No signal from free water was detected at or below 20% moisture content. We also demonstrated the use of a recently developed portable unilateral magnet that can be employed as a powerful tool in the study and measurement of water content in wood.

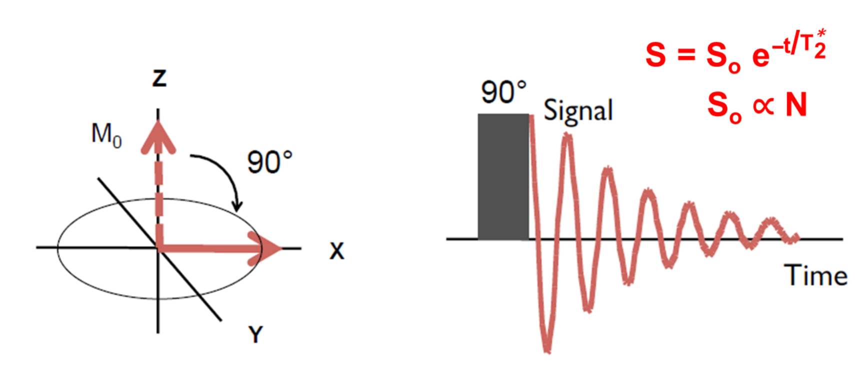
1. Theory

Magnetic resonance theory



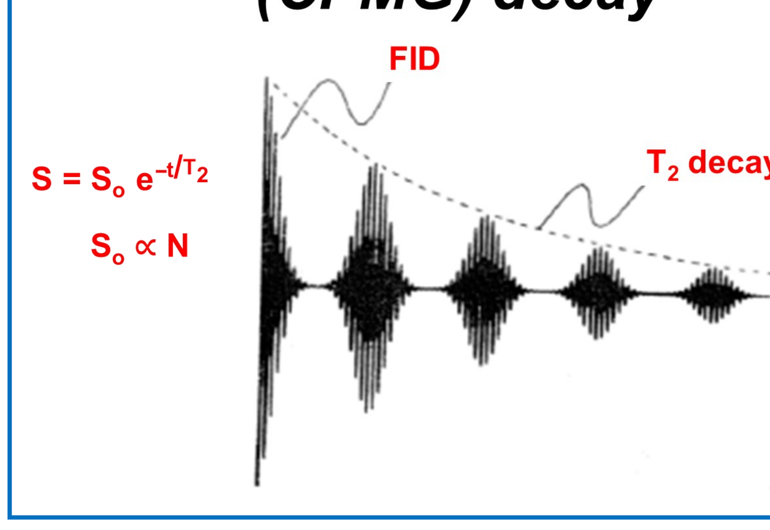
- $M_0 \propto N$
- N is the number of ^1H nuclei in H_2O

Free induction decay (FID)



- RF pulse excites and rotates magnetization
- FID is collected after a 90° pulse
- Larmor equation, $\omega_o = \gamma B_o$

Carr Purcell Meiboom Gill (CPMG) decay



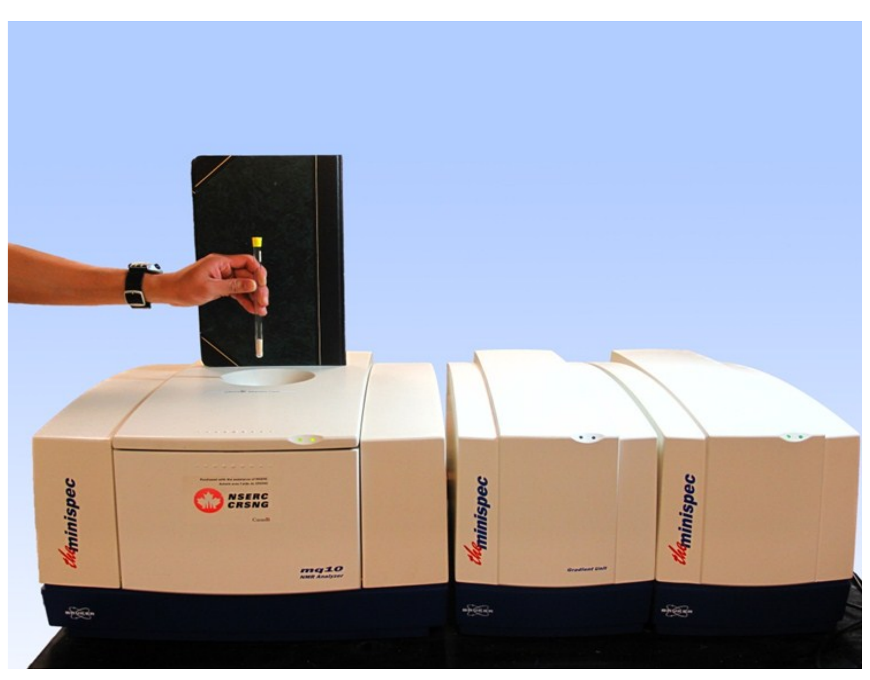
Signal equation for multi-exponential decay

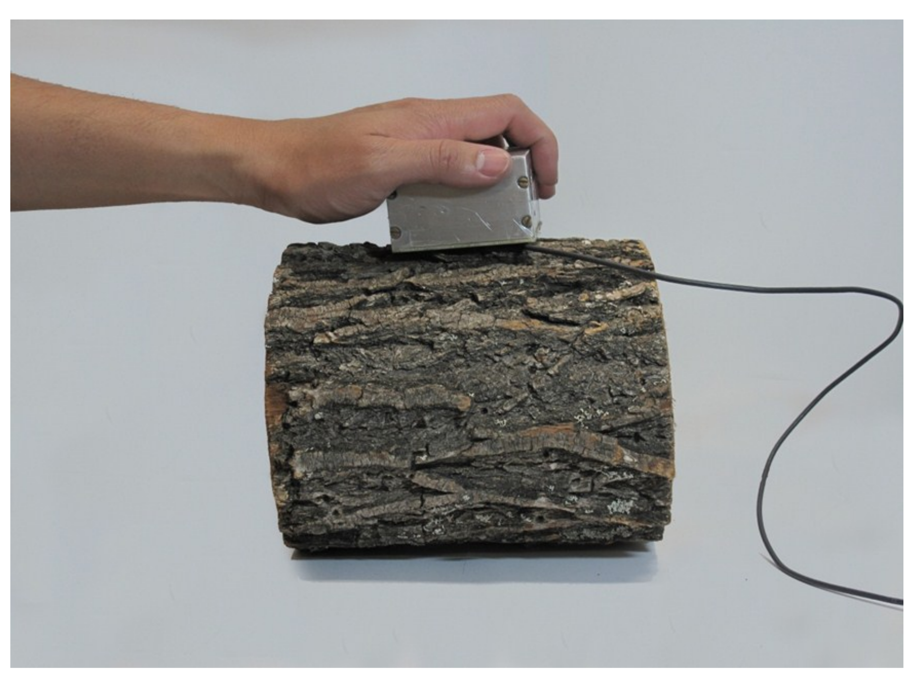
$$S(t) = \sum_i S_{0i} e^{-t/T_{2i}}$$

In the case of 2 hydrogen environments,

$$S = S_{01} e^{-t/T_{21}} + S_{02} e^{-t/T_{22}}$$

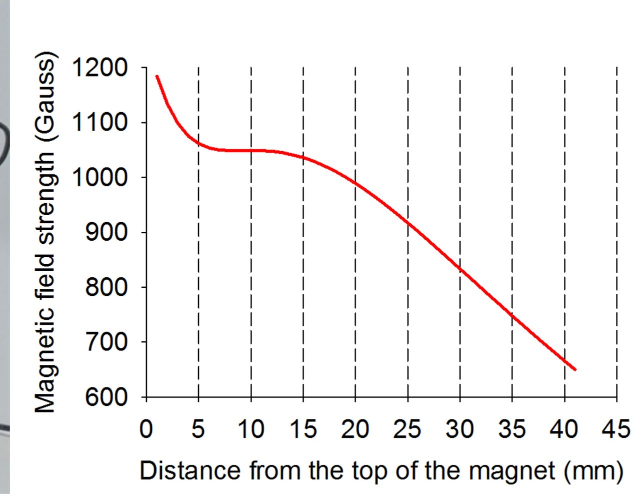
2. MR instruments





10 MHz *Bruker Minispec* **4.46 MHz Unilateral Magnet [1]**

Magnetic field along central vertical line of the 4.46 MHz Unilateral Magnet



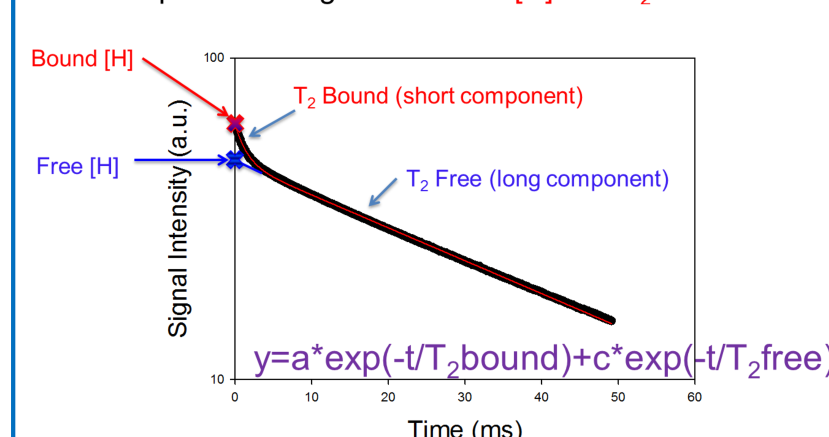
- Center of homogeneous spot is 13 mm from the surface of the magnet [1].
- This permits measurement of signal within a finite volume inside the sample.

3. Data processing

Data Processing

For the Bruker Minispec and Unilateral Magnet data:

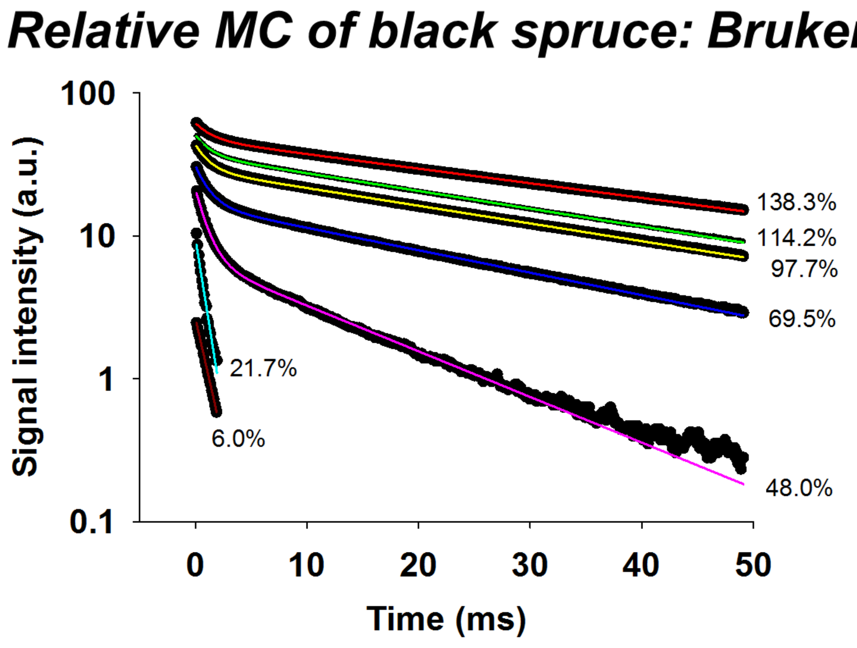
1. Bi-exponential regression fit → [H] and T_2



2. Relationship between [H] and MC: $MC = \frac{[H]}{[H]_{ref}} \times MCref$

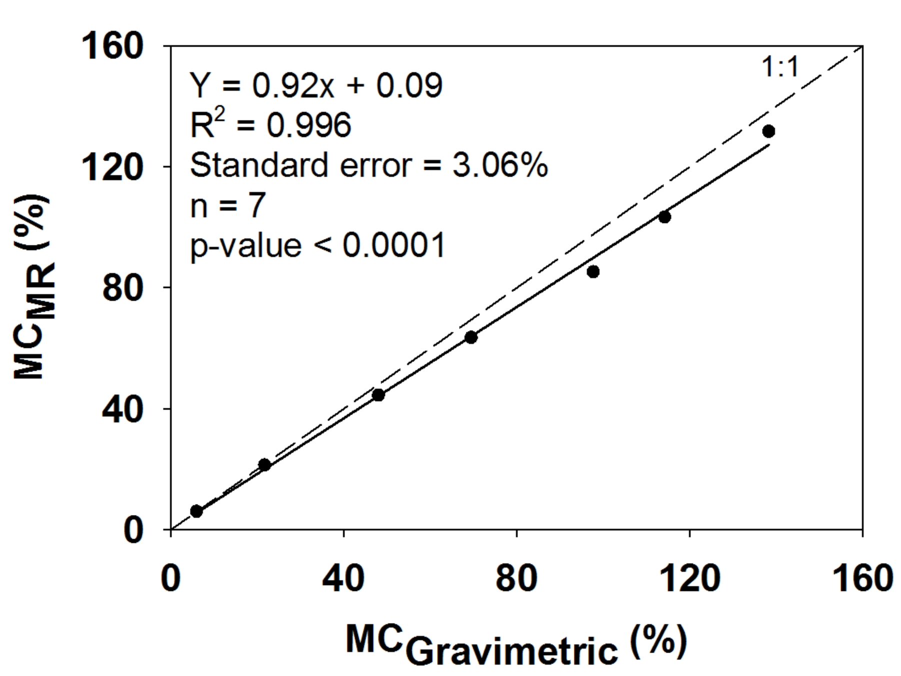
4. Results

Relative MC of black spruce: Bruker Minispec



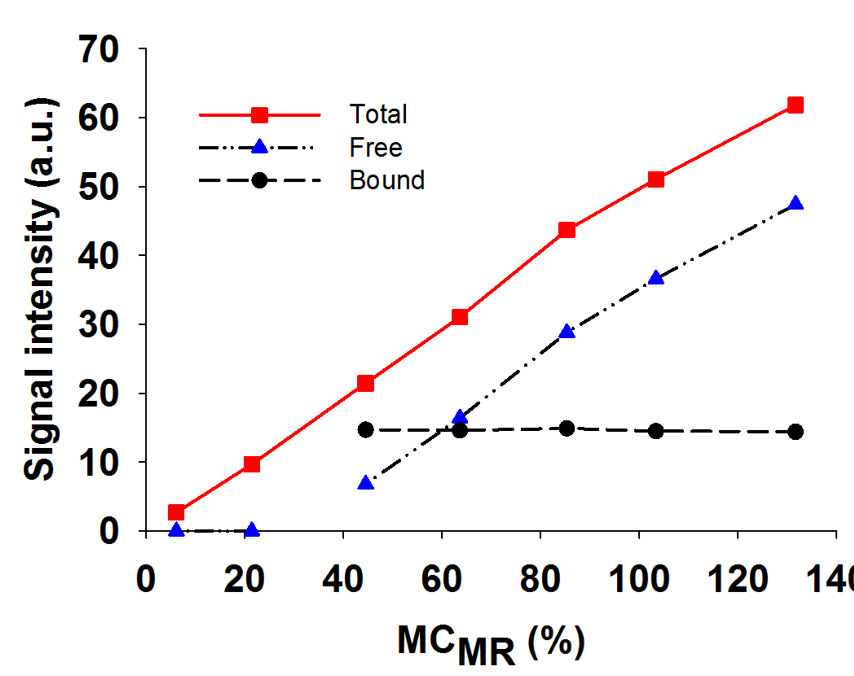
- Above the *fiber saturation point (FSP)*, both short (bound water) and long (free water) lifetime components are present.
- Below FSP, only the short lifetime component is present.
- Overall signal decreases as MC decreases.
- At 138.3% MC, the T_2 values of water in the cell wall and lumen ranged from 1.45 to 0.90 ms and 42.5 to 13.6 ms, respectively. These values are in accordance with T_2 values published in the literature for short and long lifetime signals of water in wood [2], [3], [4].

Gravimetric vs. MR: Bruker Minispec (black spruce)



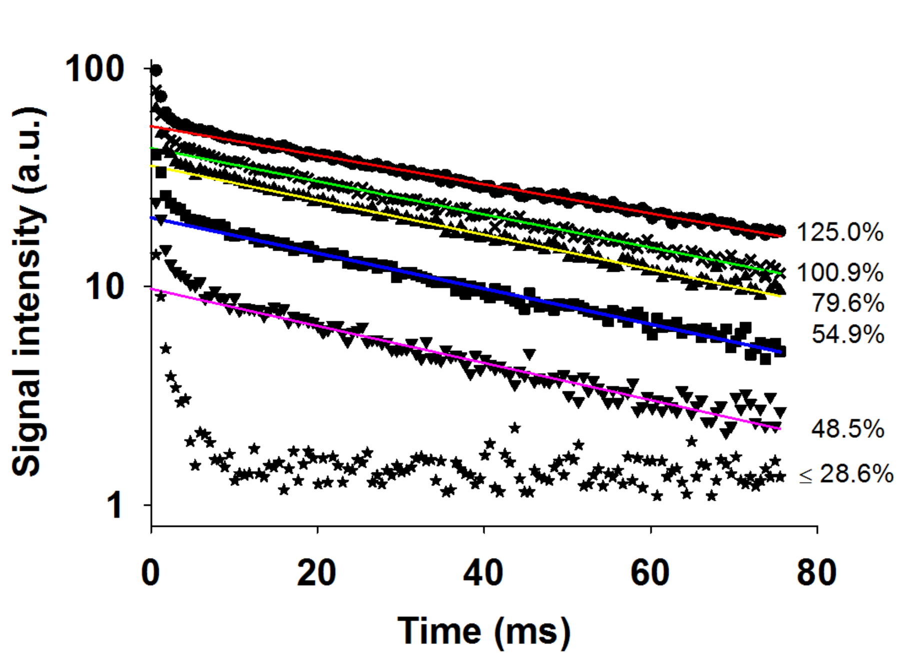
- Magnetic resonance estimation of MC agrees with the gravimetric method.

Total water in black spruce: Bruker Minispec



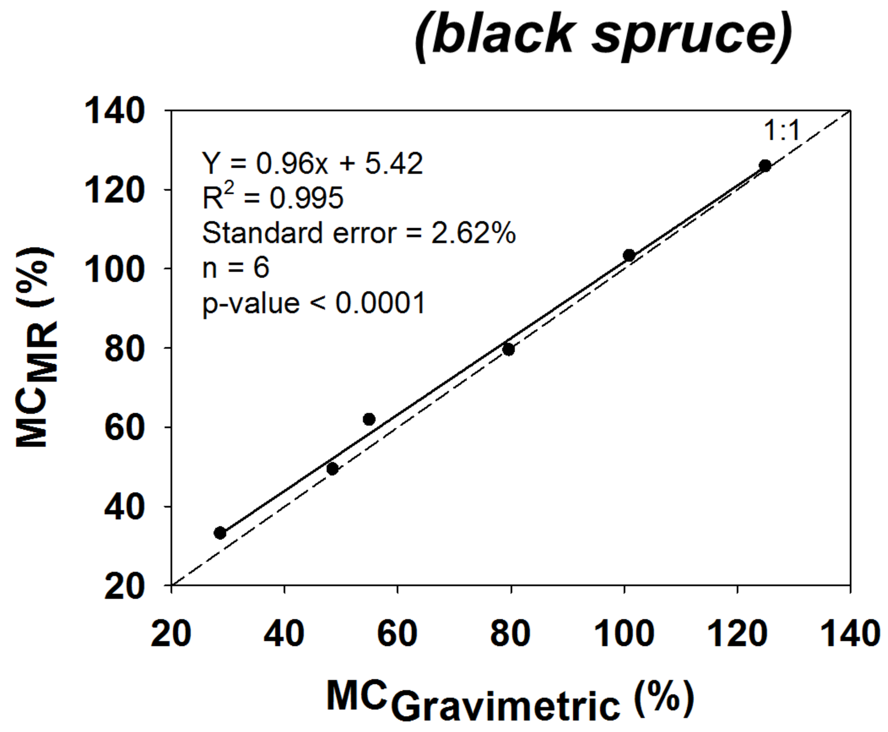
- Total water is cell wall water plus lumen water.
- Cell wall water does not change with MC above 40%.
- No signal is detected from the lumen water below 20% MC.

Relative MC of black spruce: Unilateral Magnet



- Signal decreases as MC decreases.
- Further refinements are needed to detect short lifetime component.

Gravimetric vs. MR: Unilateral Magnet (black spruce)



- Magnetic resonance estimation of MC agrees with the gravimetric method.

5. Conclusions

- Free and bound water were observed from green samples.
- MR estimation of MC agrees with the gravimetric method.
- The amount of bound water does not change significantly above 40% MC.
- The unilateral MR technique allows measurement of water in samples that are not debarked as it measures a volume located 1.3 cm from the surface.

References:
[1] Marble et al., J. Magn. Reson. 2007. 186(1):100-104.
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[3] Araujo et al., Wood Sci. Technol. 1992. 26(2):101-113.
[4] Zhang et al., Wood Fiber Sci. 2013. 45(4):1-6

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