Absolute Moisture Determination in Building Materials with Single-Sided NMR

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Kurzfassung

Moisture and moisture related processes are a main damage cause to building materials and infrastructure. In Germany alone, the annual damage due to moisture exceeds several 10 billion €/a. However, common non-destructive measurement devices cannot reliably determine the absolute moisture content due to surface effects, cross influences and complex material dependences. Although Nuclear Magnetic Resonance (NMR) measurements are commonly used to investigate the moisture content, distribution and transport in building materials, it is usually treated as a laboratory method only. With the development of unilateral devices, which allow to investigate extended samples, NMR becomes increasingly interesting for field application.

The biggest challenge concerning building materials are the very fast T2 relaxation times (10µs-100ms) and a complex T2 distribution. Additionally, unilateral NMR devices usually suffer from poor SNR. This in combination with the demand to detect moisture contents down to 0.5% of dry mass, makes the estimation of the initial amplitude very inaccurate. Therefore, we are left to use the attenuated signals with moisture dependent relaxation times resulting in non-linear and material dependent correlation curves between the NMR signal and moisture content. We present a method to determine such correlation curves based on a single T2 measurement close to saturation. This yields a substantial saving of time (upto several weeks) compared to a manual, empiric determination.

When using a capillary bundle model and the Young-Laplace equation to describe the drying behavior of porous media, larger pores are emptied before smaller ones. Since the T2 distribution reflects the pore size distribution of the material, we introduce a moisture dependent cut-off radius, respectively relaxation time. Subsequently, the expected relaxation decay at a certain moisture content can be reconstructed.

Our results show a good agreement between the predicted and experimentally determined correlation curves for different building materials. Our method is easy to use and allows a fast build-up of a material database. Together with the technology of single-sided NMR this could be a vital step towards a reliable and consumer suitable moisture measuring tool.

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Moisture Measurement today

Measuring system should be
- Sensitive at low moisture
- Non-destructive
- Independent of thickness/ environment
- Easy or no calibration
- Robust and cheap

Common technologies
- Calcium Carbide
- Oven Drying
- Corresponding Relative Humidity
- Resistance, Conductivity
- Dielectric (Radar, TDR, Capacity)

What is NMR?

NMR = **N**uclear **M**agnetic **R**esonance

Ordinary NMR

MRT

Spectroscopy

- Large
- Expensive
- Complicated
- Only Laboratory
- Limited sample size

Single-Sided NMR

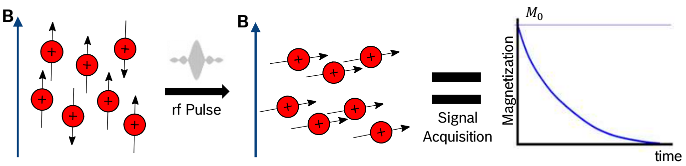
NMR MOUSE

NMR Prototype

- Investigation of extended samples
- portable
- Spatially resolved measurement

- Poor signal-to-noise ratio
- Limited penetration depth

NMR Principle



Hydrogen nuclei polarized by static magnetic field

Radio frequency pulse flips the spins 90 degrees

Relaxation signal measured via electro-magnetic induction

NMR in Building Materials

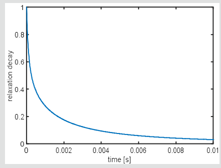
Relaxation time τ $\propto$ Pore diameter r

- Relaxation time distribution $\leftrightarrow$ Pore size distribution
- Very short relaxation times ($10\mu s - 100$ms)
- Low moisture → low signal

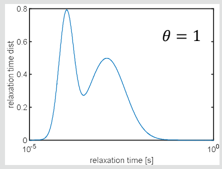
[1] G. Eidmann, R. Savelsberg, P. Blümler, and B. Blümich, The nmr mouse, a mobile universal surface explorer, Journal of Magnetic Resonance 122 (0185) (1996) 104–109

NMR-Moisture Calibration

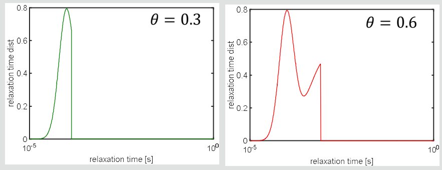
1. Step
NMR measurement close to saturation ($\theta = 1$) for good signal-to-noise



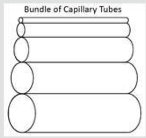
2. Step
Extract relaxation time distribution, respectively pore volume distribution



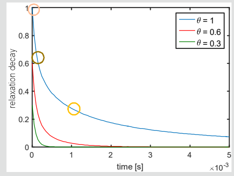
3. Step
Calculate relaxation time distribution for arbitrary moisture values θ according to capillary bundle model



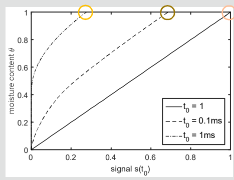
<u>Capillary Bundle:</u>
According to capillary suction forces, pores are successively filled with increasing moisture content beginning with small radii



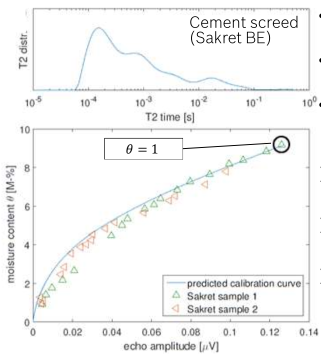
4. Step
Back calculation of NMR signals which are expected at different moisture values



5. Step
Extraction of desired signal $s(t_0)$ at times t_0 (e.g. 0, 0.1, 1ms) and correlation with moisture content



Experiment



- Relaxation time distr. measured at 22MHz and τ_e=$50\mu s$
- Signal was taken at $t_0 = 90\mu s$ (minimum echo time)using the NMR-MOUSE[1]
- Moisture content from oven drying (105°C)

- Good agreement between calculation and experiment!
- Overestimation of moisture due to inhomogeneous moisture distribution
- Similar results for other screeds (cement and anhydrite)

Conclusion

Opportunities
- High precision (< 1 M-%)
- Robust to surface and surrounding
- Measurement place/volume well defined
- Moisture distribution
- Additional material information (pore volume distribution)

Challenges
- Still too expensive
- Limited penetration depth
- Sensitive to ferromagnetic materials

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