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Abstract

As moisture is a major problem for the durability of construction materials, it must be considered in building design for extended life of the structures. A Nuclear Magnetic Resonance (NMR) spectrometer is one method of measuring the moisture content in building materials. In this study, different parameters of a low resolution NMR spectrometer were investigated. The longitudinal spatial resolution was found to be wide spread. The effect of that may be a large error in the measurements where a short steep moisture gradient or variation in moisture gradient in a short distance is present. The signal distribution in the radial direction of the NMR was also found to be unsymmetrical, which made the situation worse. It is suggested that to minimise error in the measurements a standard sample prepared maintaining a close tolerance should be used and should be placed in the same position in the measurement area every time. The NMR signals were found to decrease due to increase in the sample temperature. To overcome the problem it is suggested that the measurement should be carried out in a very short time or the temperature effect should be considered.

Key words: Moisture Measurement, Building Materials, Nuclear Magnetic Resonance.

1. Introduction

Moisture is an important factor in most of the processes that cause deterioration of building materials, playing a dominant role in accelerating the degradation process¹. The damage may be in several forms such as the decay of wood, swelling of materials leading to cracking, corrosion of metals, reduced frost resistance, freezing damage etc. Moisture also increases thermal conductivity of materials and hence increases the loss of energy from buildings. The cost of damage due to moisture is billions of pounds around the globe. Moisture can enter a structure by driving rain (which may be contaminated), flooding, condensation, run off from a roof and capillary rise of ground water. Water can transport contaminants such as soluble salts, which may remain in the structure on drying and cause structural damage, e.g. delamination, surface chipping or disintegration.

It has become generally accepted that the climate is changing due to greenhouse gas release and deforestation; besides increased temperatures and rising sea levels, both wind and rain are expected to increase in North west Europe, increasing the stress of driving rain on building facades².

Porous building materials are very vulnerable to moisture related damage since the pores allow water to enter into the structure. Many historical buildings and monuments in the UK are made of highly porous sandstone, where water can penetrate easily through the wall and make the building damp. If no measures are taken and the degradation continues then there is a possibility of collapse of the building structure and loss of lives.

Both the heat and moisture properties of the materials must be considered for effective building design. While the thermal properties of building materials have been determined by different researchers and considerable data are available, the equivalent moisture properties are absent. The data which are available are so scattered in different sources that any coherent conclusion cannot be made. An extensive study of moisture properties of different building materials, e.g. sandstone, mortar, brick, timber etc, is necessary to provide the relevant information.

There are a number of different methods to measure moisture in building materials including Nuclear Magnetic Resonance (NMR)^{3,4}, Neutron Radiography⁵, Gamma ray^{6,7} or X-ray absorption, as well as the traditional oven drying. It has been demonstrated³ that the moisture measurement using a NMR spectrometer is more effective than Neutron Radiography. This paper, part of a detailed study aimed at determining the different moisture properties of building materials investigates the importance of different parameters of the NMR spectrometer as a preliminary to the main investigation.

2. Description of Equipment

In this investigation a low resolution Nuclear Magnetic Resonance (NMR) spectrometer (manufactured by BRUKER ANALYTISCHE MESSTECHNIK, GMBH, Germany) was used to measure the moisture present in the specimens. The system is equipped with a permanent magnet with 125 mm pole-diameter, 50 mm airgap, the set frequency is 10 MHz (0.23 Tesla) with automatic field adjustment. No magnetic gradient is included to obtain a higher spatial resolution. The measurement position (situated in the airgap) is a cylindrical hole of diameter is 40 mm and the size of the probehead is 4 mm. The system operating temperature is 40 °C is maintained with a close tolerance.

The specimens are placed in the measurement position and the free induction decay (FID) signals from the hydrogen atoms present recorded. Since the investigation is aimed to determine the amount of moisture, i.e. the number of hydrogen atoms present in the specimen, the maximum intensity of the signals was taken. There are different settings in the spectrometer such as number of scans, recycled delay, analogue bandwidth, digital bandwidth, gain etc. Each of them was individually investigated to find out their effect on the signals (not shown here). The settings were optimised for the measurements and thereafter kept constant.

3. Experimental Procedure and Result

3.1 Investigation of Spatial Resolution in the Longitudinal Direction

The spatial distribution of the signals in the measurement position was determined using water samples or water saturated absorbent paper samples. To determine the spatial resolution in the longitudinal direction, a thin, absorbent paper sample 17 mm diameter and 0.912 mm thick, saturated with ~0.25 grams of water, was passed through the measurement position of the spectrometer held in a glass syringe. The experimental set-up for the investigation is shown in Figure 1.

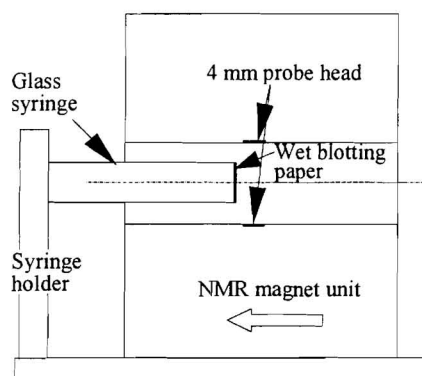


Figure 1 – Experimental set-up for determining the longitudinal sensitivity

The longitudinal spatial resolution was measured 4 times giving a similar pattern of signal distribution each time. One of the 4 measurements is presented here (Figure 2), where an exponential curve $y = \exp(-Ax^2)$ is fitted to the measured data.

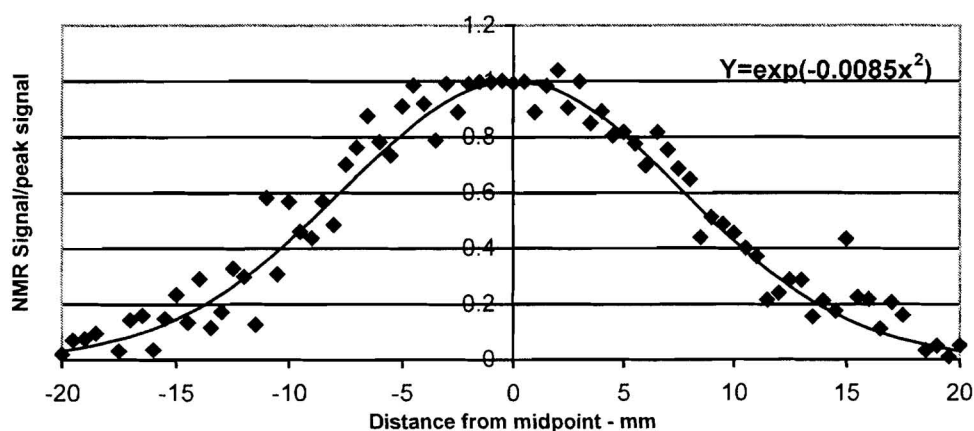


Figure 2 – Longitudinal resolution curve of the NMR spectrometer

The effective length of the NMR measurements were calculated by integrating the area under the fitted exponential curve and dividing the area by the maximum height. The effective lengths of the four different tests were 19.43mm, 19.34 mm, 19.89 mm, and 18.49 mm giving an average of 19.3 mm.

3.2 Investigation of Spatial Resolution in the Radial Direction

To determine the horizontal and vertical spatial resolution, a water filled glass tube, of 4 mm ID and 5 mm OD, was moved through the measured position vertically and horizontally as shown in the experimental set-up in Figures 3 and 4. The NMR signals were measured from two perpendicular radial lines: a horizontal line and a vertical line (shown in Figures 3 and 4).

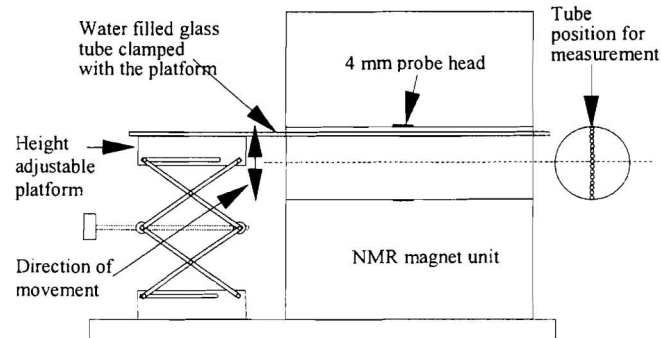


Figure 3 - Experimental set-up to determine radial distribution of NMR signals

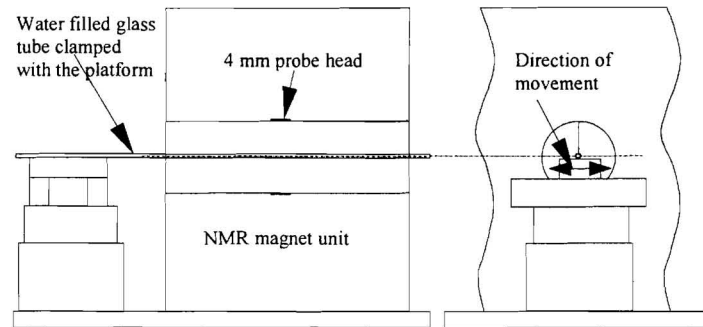


Figure 4 – Experimental set-up for horizontal sensitivity measurement

The signals were measured twice, in both measurements a similar pattern of signal distribution was found. The signals were plotted against the distance from the centre of the hole of the NMR (shown in Figure 5).

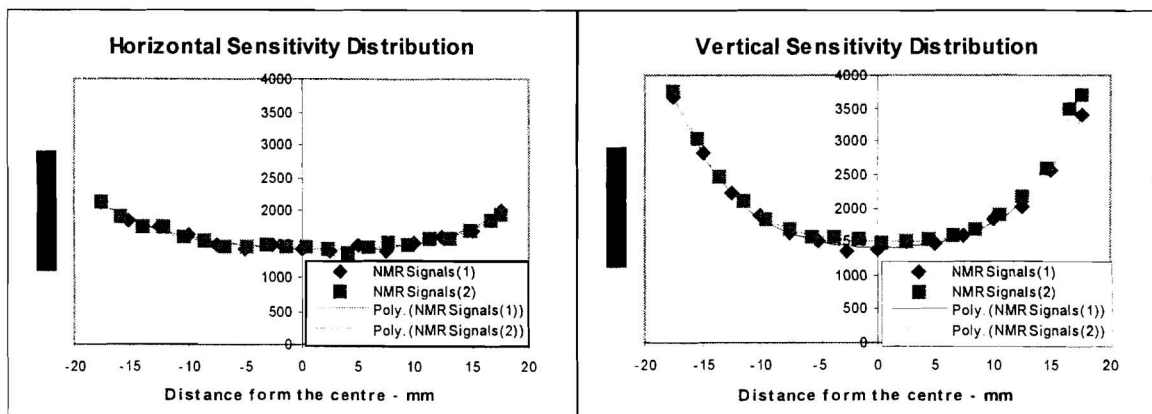


Figure 5 – Distribution of NMR signals in two perpendicular radial directions.

The signals were found to be a minimum at the centre of the measurement position increasing towards the wall. The distribution of the signals was symmetrical in both the horizontal direction and vertical directions but the variation was much higher in the vertical.

3.3 Investigation of Temperature Effect on the NMR Signals

The effect of sample temperature on the NMR measurements was also investigated. Samples of sandstone were crushed, saturated in water and placed in a sealed glass tube, heated to constant temperature in a water bath as shown in Figure 6.

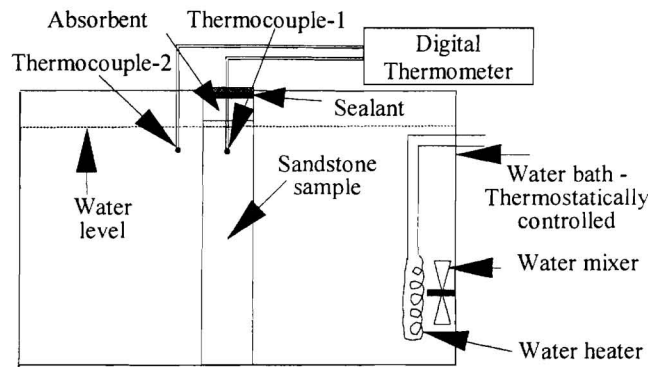


Figure 6 - Set-up for heating the sample at different levels of temperatures.

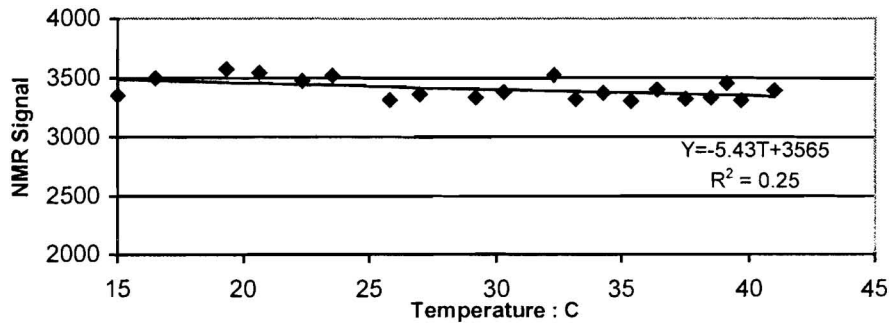


Figure 7 - NMR signals of wet crushed sandstone

The temperatures of the sample and water were measured and when the difference between the two temperatures was $0.1\text{ }^{\circ}\text{C}$ or less the sample was taken out and the maximum NMR signal measured. The experiment was repeated giving similar results on each occasion. Figure 7 shows the result of one run.

Although there was a considerable amount of scatter the signals decreased as the temperature increased, with a gradient of $-5.43\text{ }^{\circ}\text{C}^{-1}$. In contrast, a similar test with pure water gave a gradient of $-22\text{ }^{\circ}\text{C}^{-1}$. This implies that there must be a relationship between the moisture content and decrease in signals due to temperature increase. However, when these changes are compared to NMR signal changes of about 1000 for a 1% (by mass) change in water content in sandstone samples observed previously⁸, temperature effects can be considered negligible.

4. Conclusion

The longitudinal sensitivity of the machine is widespread (~38 mm), making it difficult to measure the distribution of moisture in a material with a gradient is present. A companion paper investigates the effect of this on the calculated liquid water diffusivity of typical building materials⁹.

The sensitivity in the radial direction was found to be non-isotropic, with a much larger variation in the vertical compared to the horizontal direction. While this distribution does not cause any problems with samples that fill the measuring area, for the measurement of building materials where the specimens may be cut from a large sample, it may be difficult to prepare a sample of standard geometry. To minimise error the specimens should be prepared to certain geometry maintaining a very close tolerance.

The investigation of the temperature effect showed that signals from moisture decreases as the temperature of the sample increases. This does not cause any problem to the samples where very low moisture is present and measurement can be carried out in a very short period (2 to 3 minutes). For specimens with larger moisture content or if the measurement takes bit longer time the temperature effect may need to be considered. The solution of this problem is may be modifying the machine to operate at a lower constant temperature of say 20 °C and placing the system in an environmentally controlled chamber.

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