Editorial

Editorial on Special Issue "Applications of Low Field Magnetic Resonance"

Robert H. Morris * and Michael I. Newton (ORCID)

School of Science and Technology, Nottingham Trent University, Clifton Lane, Nottingham NG11 8NS, UK; michael.newton@ntu.ac.uk

*   Correspondence: rob.morris@ntu.ac.uk; Tel.: +44-115-848-3123

1. Referees for the Special Issue

This Special Issue presents the latest advances in the applications of low field magnetic resonance. Magnetic resonance already has well established applications, from medical imaging to chemical spectroscopy. It is, however, also becoming more common for use in so called sensor applications, in which the measurement of the effective transverse (T_2^{eff}) relaxation times, longitudinal (T_1) relaxation times, self-diffusion coefficients (D_0), or a mixture of the three, are used in process control or quality management for manufacturing and environmental monitoring. This Special Issue contains 15 papers covering a wide range of applications and reviews which highlight the broad range and ongoing advancements in the field of low field magnetic resonance, and the importance of several future research directions.

2. Introduction

The phenomenon of magnetic resonance is most commonly known for chemical finger printing of NMR or the medical applications of MRI. For MRI, images with tissue contrast arising from natural variations of the transverse relaxation time, longitudinal relaxation time or self-diffusion coefficients of different tissues are used to inform medical diagnostics. It is, however, possible to measure these relaxation times without imaging using so called sensors that determine the average value over a sample volume. Such measurements can be made at much lower magnetic fields than are routinely used for NMR or clinical MRI to provide information about a sample. The continual improvement in permanent magnet technology and measurement electronics means that such measurements are now becoming viable for a range of industrial applications, such as process monitoring. In this Special Issue, we have contributions that cover a range of such applications, as well as progress in the measurement process.

3. Applications of Low Field Magnetic Resonance

The first set of articles describe the characterization of industrially relevant materials with low field NMR. In [1], the amount of bound water and free water in heat-treated and untreated Chinese Fir heartwood were investigated using various NMR methods. Their results indicated that the heat treatment made it more difficult for the wood to be accessed by moisture, providing a scientific basis for assessing the application of heat-treated wood, especially for outdoor applications. In [2], the authors use low field relaxometry to monitor the change of the evaporable water content in the early hydration process of cement paste, with different water-to-cement ratios. Their results demonstrated that the first derivative curves of the transverse magnetization were in agreement with the known five stages of cement hydration process. In [3], the time-domain nuclear magnetic resonance (TD-NMR) technique was applied to determine the solid content of black liquor which is a by-product of paper pulp production and is used for the recovery of chemicals and serves as an energy source for pulp mills. Before entering the recovery unit, black liquor runs through several

stages of evaporation, wherein the solids content can be used to control the evaporation effectiveness. In [4], changes in wettability with the TD-NMR T_2 distribution and diffusion coefficient have been used, starting with a well-controlled glass bead based porous system and then a model rock (Berea), in the presence of one phase, either oil or brine exclusively to investigate the influence of wettability on oil recovery. Another porous media application is presented in [5], where a simplified method for predicting permeability coefficients of clay-quartz mixtures based on NMR technology without centrifugal and evaporation experiments was proposed following the NMR testing of eight clay-quartz mixtures with different mineral compositions.

The second set of articles cover more fundamental aspects of the development of low field techniques including image quality improvement and memory-saving in a Permanent-Magnet-Array-Based MRI Systems by approaches of compensating the uneven point population by increasing the numbers of sampling points or rotation angles [6]. In [7], a mini-review summarizes the progress that has been achieved in the coupling between TD-NMR (using low-field spectrometers) and electrochemistry and how the challenges that this coupling poses have been overcome over the years. In [8], advances in the development of a Field Programmable Gate Array (FPGA) based spectrometers for NMR relaxation is described along with applications in NMR cryoporometry. Performing the NMR measurement in the strong heteronuclear J-coupling regime is described in [9] and shows promise for the chemical analysis of small molecules. The results demonstrate that high resolution J-coupled spectra are quantitative, and the common NMR observables, including Larmor frequency, heteronuclear and homonuclear J-couplings, relative signs of the J-coupling, chemical shift and relaxation times, are all measurable and are differentiable between molecules at low magnetic fields. The mini-review in [10] discusses the theory and applications of the Continuous Wave Free Precession (CWFP) sequence in low-field, TD-NMR. CWFP is a special case of the often used Steady State Free Precession (SSFP) sequences and, unlike regular pulsed experiments, in the CWFP regime the amplitude is not dependent on T_1. In [11], TD-NMR is reviewed as a candidate for assisting product and process development in several applications throughout the rubber, plastics, composites, and adhesives industry. Several examples illustrate measurements such as crosslink density in vulcanized rubber and the monitoring of crystallization kinetics. In [12], the authors use hyperpolarized $^{13}C\{^1H\}$ NMR to overcome the challenges of low sensitivity and significant peak overlap in ^1H NMR spectra associated with low magnetic fields. They demonstrate the Signal Amplification By Reversible Exchange (SABRE) parahydrogen-based hyperpolarization technique to enhance the sensitivity of natural abundance 1D and 2D $^{13}C\{^1H\}$ benchtop NMR spectra.

Magnetic resonance is most well-known to the public through medical applications in closed bore Magnetic Resonance Imaging (MRI). In [13], a potential medical application of low field magnetic resonance is suggested with the demonstration of a unilateral system operating at only 18mT that can measure transverse relaxation time at a distance from its surface equivalent to the positioning of an anterior human placenta and over a range of values shown in the literature to be the full range relevant for the developing placenta.

Finally, we see application from the production and processing of food and drink in two papers. This topic has spawned regular conferences as the measurement of relaxation times are ideally placed to probe the amount and nature of the water in food and the production process. The work in [14] identifies drought as the main abiotic stress worldwide affecting harvest quality and quantity of numerous crops. Their results also showed that T_2 NMR relaxation spectra allow the detection of mild water stress through the characterization of the leaf water status. In [15], low field NMR is applied to monitor deterioration and allow for prediction of shelf life in fish fillets during refrigerated storage.

4. Conclusions

This Special Issue presents some significant advancements in the application of low field magnetic resonance. With the continual rising speed and falling cost of modern

electronics and the advances in permanent magnet technology, such applications will be commercially viable for an increasing range of new applications.

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