

Preface

This book summarizes 23 years of work in Pulsed Field Gradient Nuclear Magnetic Resonance (PFG NMR). When starting up as a Ph.D. student in 1991, I was working on a 4.7 Tesla Bruker DMX system with a homemade diffusion probe (except for the actively shielded gradient coil built by Prof. Paul Callaghan's group at Massey University, New Zealand). This Ph.D. work, including the development of the unequal bipolar Pulsed Field Gradient Stimulated Echo method, ended up in a defense in 1998 where I had the pleasure of having Prof. Ken Packer as the opponent. Since then I have worked on various tasks where PFG NMR have been extensively used, as in quantification of fat content in biological systems, characterization of rock core plugs saturated with different fluids, and characterization of emulsions, being either stable or unstable. Besides being a post doc in work with the PFG NMR method, a company called Anvendt Teknologi AS was founded in 1998, aiming at producing and implementing PFG NMR applications for commercial purposes. In this latter work, I have come to realize that there does not exist a better referee than a demanding quality control manager who wants a method and instrumentation to work properly. The bottom line is that if you do not solve an issue that may occur with respect to, for example, an implemented PFG NMR quality control method and/or an instrumentation that does not work as prescribed, you lose goodwill, which is essential for running a business. Fortunately, the company has been up and running since 1998, and I have made a living out of it the past 15 years. The applications presented in this book are mainly a consequence of the research and development work done in Anvendt Teknologi AS, either as internal development work or contract work for the industry, universities, and research institutions.

During the past 15 years I have also been cooperating with different companies working in the field of NMR, such as Bruker GmbH, Resonance Instruments Ltd.(no longer in operation), and Oxford Instruments. The past 5 years I have had the pleasure of cooperating with Advanced Magnetic Resonance Ltd. and its founder Dr. Tim Benson. He has played a crucial role in the construction of the low field permanent magnet system for the characterization of emulsions, comprising shaped pulsed field gradient as well as the latest within RF-technology and

spectrometer utilities. He has also provided valuable feedback in the production of this book, for which I am very grateful. In particular, Chap. 4 in this book is his piece of work entirely.

I have also had the pleasure of working with Dr. Klaus Zick at Bruker GmbH on various issues, mostly related to PFG NMR sequence development and implementation on high-resolution systems. He also kindly supplied me with the gradient field plots from the actively shielded gradients (Chap. 3).

Without the dedicated work done by Prof. Johan Sjøblom and his co-workers at the Ugelstad Laboratory, NTNU (University of Trondheim), there would not have been a chapter on emulsion characterization. In addition, the spoiler recovery approach was developed due to their requirements for a robust PFG NMR method for characterizing unstable emulsions. In particular, I would like to thank Sebastien Simon for helping me out on emulsion sample preparation, and for his efforts in explaining to me what emulsion science is all about.

Dr. Hege C. Widerøe at Statoil Research Centre in Trondheim has made a significant contribution to Chap. 8, and kindly let me use the data we have acquired together on rock core plugs over the past 13 years.

I would also like to thank Frank Lundby at Nofima (former Matforsk) for his dedicated work within quantification of lipid content in biological systems using our PFG NMR methods, and consequently his faith in me.

Finally, thanks to Prof. Jostein Krane, who contributed to the founding of Anvendt Teknologi AS, also by initiating contact with hardware manufacturers of PFG NMR instrumentation.

Regarding the content of this book, it is divided into nine chapters as follows:

Chapter 1: Pulsed Field Gradient—NMR Sequences: Here the expected signal attenuation from a variety of PFG sequences combined with or without relaxation time measurements are evaluated. In addition, the concept of coherence transfer pathways is discussed.

Chapter 2: Observation Time-Dependent Diffusion Measurements in Heterogeneous Media by PFG NMR: Here the Fick's law is solved for the case of short observation times in restricting geometries. In particular, it is shown that the short observation time expansion of the diffusion propagator resolves the surface to volume ratio from the surface relaxivity, an important finding that enables the possibility of measuring physical properties as pore sizes. Comments for the diffusion propagator at longer timescales are also given.

Chapter 3: Experimental, Pitfalls and Suggested Solutions: The most important distortions that may affect the PFG NMR measurements in a destructive way are discussed in this chapter; unwanted coherence transfer pathways, eddy current transients, internal magnetic field gradients, convection, vibration, and the effect of finite gradient pulse lengths. Ways to circumvent or suppress the effect from the above-mentioned artifacts will also be discussed, as the application of phase sequences, crusher gradients, preemphasis adjustment, bipolar pulsed field gradients, convection compensated PFG NMR sequences, the second cumulant approximation, and corrected effective diffusion times.

Chapter 4: *PFG NMR Spectrometer*: This chapter provides an overview of the hardware required in order to conduct PFG NMR applications. Author: Dr. Tim Benson.

Chapter 5: *Analysis of Dynamic NMR Data*: An analysis of one- and two-dimensional datasets, both real and synthetic, using the Laplace transforms (ILT) and a discrete approach called Anahess is presented. Dr. Åsmund Ukkelberg developed the Anahess approach due to the need for a more robust and reliable method for analysis for PFG NMR data, and consequently he is an important contributor to this chapter.

Chapter 6: *The Spoiler Recovery Approach (SR)*: The spoiler recovery approach is presented with examples of applications, both at low and high external magnetic fields. In addition, a method for fast Fourier-Transformed-Inverse-Laplace-Transform is presented, which was developed by Dr. Henrik W. Anthonsen.

Chapter 7: *Emulsion Characterization*: Fast and accurate methods for emulsion characterization are presented. Especially, the characterization of unstable emulsions is innovative.

Chapter 8: *SCAL (Special Core AnaLysis)*: A variety of applications dedicated to the characterization of rock core plugs at different fluid saturations is described with examples. Most of the results are made on core material supplied by Statoil, but some of the data were acquired together with Center of Integrated Petroleum Research at the University of Bergen.

Chapter 9: *PFG NMR Applied to Biological Systems*: A variety of applications dedicated to the characterization of biological systems is described with examples.

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