

Biofilms, Porous Media and NMR

Sarah L Codd

College of Engineering and Center for Biofilm Engineering Montana State University Bozeman, USA

Magnetic Resonance



Down the Borehole 300 kHz

Superconducting Magnets 300 MHz





What can Magnetic Resonance do?

- NMR Spectroscopy
- MRI Imaging
- But we focus on transport measurements and relaxation....

Diffusion Measurement with PGSE NMR



Propagator Measurement with PGSE NMR



Diffusion through monodispersed Beadpeak

Diffraction

[Coy and Callaghan, J. Chem. Phys. (1994)]





Flow through monodispersed Beadpeak [Seymour and Callaghan, AlChe, (1996)]



Time dependent Diffusion

$$\frac{D(t)}{D_o} = 1 - \left(1 - \frac{1}{\alpha}\right) \left(\frac{\frac{4}{9\sqrt{\pi}} \frac{S}{V_p} (D_o t)^{\frac{1}{2}} + \left(1 - \frac{1}{\alpha}\right) \frac{D_o t}{D_o \theta}}{\left(1 - \frac{1}{\alpha}\right) + \frac{4}{9\sqrt{\pi}} \frac{S}{V_p} (D_o t)^{\frac{1}{2}} + \left(1 - \frac{1}{\alpha}\right) \frac{D_o t}{D_o \theta}}{D_o \theta}\right)$$



Mair, et al, Phys. Rev. Lett. (1999)



Latour et al, Proc.Natl. Acad. Sci. (1994)



Brown, Brox et al, J. Mag. Reson. (2012)

Application: Biofilms in Porous Media





Influence of Biofilm Growth on Dispersion in Porous Media

Clean Beadpack Gaussian Dispersion



Biofilm Fouled Beadpack Back bone flow



Velocity Maps and T₂ Maps



241 μm monodisperse beads in 5 mm ID cylinder

Bulk Dynamics Change Due to Biofilm Growth

[J.D. Seymour, J.P. Gage, S.L. Codd and R. Gerlach, PRL 93 198103 2004]



Bulk Dynamics Change Due to Biofilm Growth



T2 relaxation-Propagators



What else can we do with NMR in porous media?

- relaxation exchange
- Spectrally separate (oil) particles in water
- low field NMR

Relaxation Exchange



.... track oil in hard shell particles...



flow colloidal particles through foam...



Evidence of particle accumulation in foam...



Low Field NMR



Down the Borehole avelin, Vista Clara Inc, Seattle) 300 kHz



RCA, Magritek, NZ 2 MHz



Field Scale Subsurface NMR of Biofouling

Results – monitoring using T₂ Relaxation



Summary

 NMR has lots of tricks and tools to aid analysis of complex fluid in porous media including biofilms in the subsurface



• Funding Acknowledgements US DOE Office of Science

National Science Foundation Murdock Trust