Let it flow - tracking fluid flows through porous materials with NMR spectroscopy

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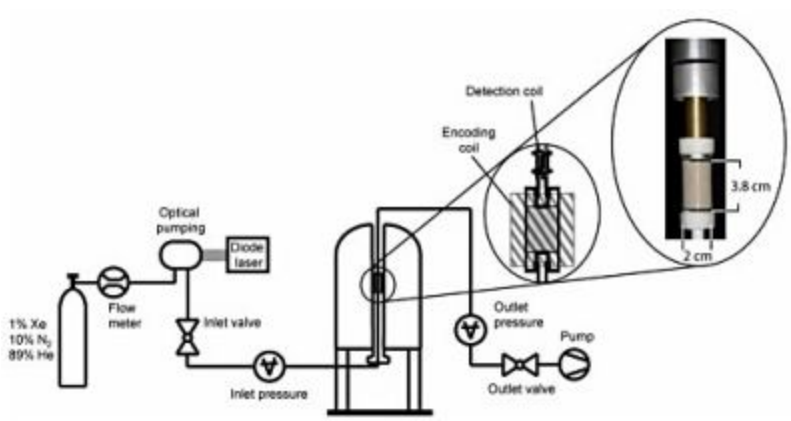
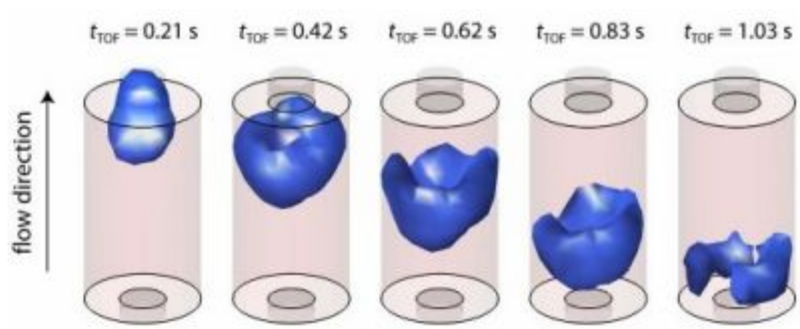
The ability to follow the flow of a fluid through a porous material would be of great utility for oil exploration, in monitoring natural and synthetic structures, and in tracking industrial flow processes. Now, thanks to US researchers who had the clever idea of using two NMR radio coils instead of one, it is possible to study fluid flow using remote magnetic resonance imaging with time-of-flight detection.



The setup and a photo of the rock.



Isosurfaces of the gas as it flows through the cylindrical rock.

MRI seems an endlessly important technique for studying details below the surface of soft objects such as biological tissues and moist solid objects like rice grains. Now, Josef Granwehr and co-workers in the group of Alex Pines at the Lawrence Berkeley National Laboratory and UC Berkeley working with colleagues led by Yi-Qiao Song at Schlumberger-Doll Research have developed a novel twist on MRI that allows them to watch fluid flow through opaque materials. They have demonstrated their technique by visualizing gases flowing through porous rocks.

Granwehr, Song and their colleagues used two coils separated in space for their experiment. One coil surrounds the porous sample and in conjunction with a tuneable magnetic field gradient, selectively disturbs the nuclei in a voxel (the volume equivalent of a pixel) anywhere in the sample. The second, independent, coil, is positioned at the exit of the sample and detects fluid as it emerges. The first coil essentially "tags" certain nuclei at a given point in time, and the second coil records the journey time from initial tagging to the exit point.

With location and velocity information in hand, the researchers can in effect look inside the rock and watch the fluid flow. The researchers emphasise that they can trade off the minimum detectable partial pressure of the target nuclei (tens of millibar up to one bar) against time resolution (tens of microseconds to milliseconds) or vice versa and so view different aspects of the fluid flow.

"In principle experiments would be possible where fluid nuclei in only one voxel are addressed by the encoding step," Granwehr told Resonants, "Then the position of this encoding location could be moved across the whole sample in subsequent encoding steps." To obtain three-dimensional data, the team performed the experiments in the Fourier space, or k-space (phase encoding). This is done by repeating a large number of encoding steps, thereby varying the strength of the field gradients in all three spatial dimensions independently. The real spatial information is thus obtained after Fourier transform of the k-space data, and then it is equivalent to think of the data as being obtained from manipulating spins in individual voxels. The flow information is obtained by monitoring the magnetization of the encoded nuclear spins stroboscopically at fixed time intervals after the encoding step as they leave the sample - as soon as the atoms or molecules from the encoded region pass the detector coil, the signal changes proportional to the number of encoded nuclei.

Alex Pines

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