Compact NMR tool for underground soil contaminants monitoring

Sihui Luo[1], *Zhihao Long*[1], *Guangzhi Liao*[1], *Huabing Liu*[2], *Tingting Lin*[3], *Lizhi Xiao*[1,*]
China University of Petroleum, Beijing, China
Beijing Limecho Technology Ltd.Co, Beijing, China
Jilin University, Changchun, China

Groundwater is a vital resource for human survival, stored in porous sandy soils at varying depths underground. However, the petroleum hydrocarbon contaminants pose a serious threat to groundwater quality when they infiltrate soil pores, causing persistent pollution. Such contamination disrupts the biological, chemical, and physical properties of soil and endangers organisms in affected ecosystems. Effective remediation is therefore imperative, requiring precise detection and quantification of petroleum hydrocarbons in sandy soils. Accurate identification of contaminant types and concentrations is critical for optimizing remediation strategies.

Nuclear magnetic resonance (NMR) is a promising technique for monitoring soil contaminants and mitigating groundwater pollution. It characterizes fluid dynamics in porous media and provides key hydrological parameters, including total porosity, fluid saturation, and soil properties. Conventional NMR logging tools, however, are often impractical for groundwater and soil moisture measurements due to their bulky size and high cost. To overcome these limitations, compact NMR logging tools with smaller diameters have been developed. Despite progress, most commercial small-diameter NMR tools lack advanced two-dimensional NMR capabilities (e.g., D-T_2 correlation map) because of their low-gradient static magnetic fields—a critical shortcoming for distinguishing complex fluid compositions such as water, oil, and hydrocarbons.

To address these challenges, we developed a compact NMR logging tool (60 mm diameter) based on the NUMAR design for soil contaminant detection. The tool is compatible with PVC or fiberglass-cased boreholes (70 mm diameter) and features a hybrid magnet structure comprising a ferrite main magnet and a samarium-cobalt polarization magnet. The coil structure is optimized using an inverse design method, enhancing circumferential excitation uniformity and ensuring the signal-to-noise ratios. The tool could achieve the performance under operation frequency about 650 kHz and field gradient of about 50 Gs/cm, and also with a depth of investigation of 120 mm (from borehole axis), and a vertical resolution of 300 mm. Laboratory experiments confirm the tool's feasibility for both 1D and 2D NMR measurements, enabling reliable identification of water and hydrocarbon contaminants. Field tests will be conducted in the future work.

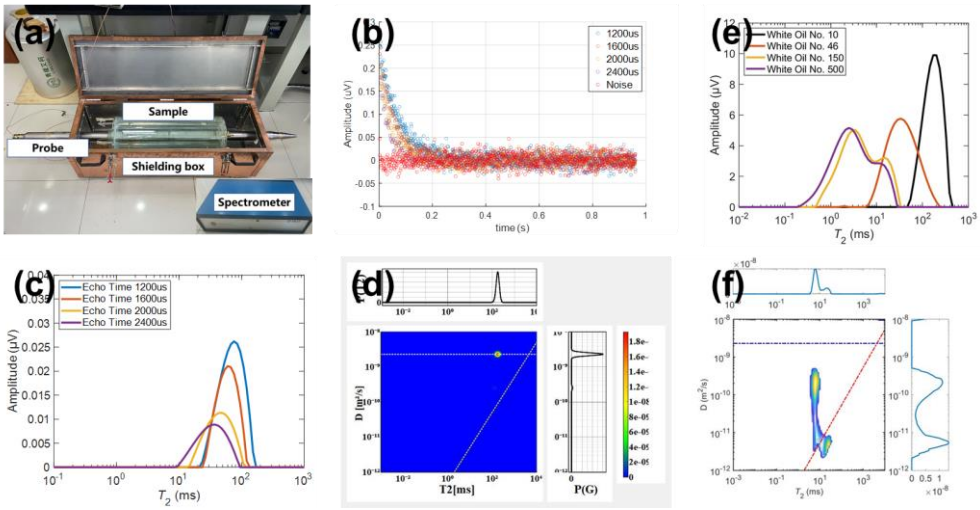

Fig. 1: (a) Compact NMR tool and laboratory experimental condition; (b) Acquired echo train with different echo spacing; (c) T_2 distributions of copper-sulfate solution with different echo spacing; (d) D–T_2 correlation maps of copper-sulfate solution; (e) T_2 distributions of white oil with different viscosities; (f) D–T_2 correlation maps of no. 500 white-oil samples.

References:

[1] Lizhi Xiao. Practical NMR for Oil and Gas Exploration. Royal Society of Chemistry, (2023).
[2] Zhihao Long, Lizhi Xiao, Sihui Luo, Huabing Liu, Xiaoguang Zhao. Inverse design of RF coil for slim nuclear magnetic resonance tool. IEEE Transactions on Instrumentation and measurement, (2024).
[3] Tingting Lin, Yida Wang, Jinshuo Cheng, Yujing Yang. Detecting and quantifying diesel and gasoline contaminants in sandy soil by multivariate analysis based on nuclear magnetic resonance T2 spectrum. IEEE Transactions on Instrumentation and measurement, (2024).