Enabling Responsible Offshore Well Abandonment with Real-Time Methane Monitoring Sensors

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Methane emissions from offshore oil and gas infrastructure represent a pressing challenge in the context of global climate change. Abandoned offshore wells can act as persistent leak points, releasing methane into the surrounding marine environment.[1] Regulatory frameworks worldwide are increasingly emphasizing responsible abandonment practices and post-abandonment surveillance. Continuous monitoring of wells post-abandonment is therefore central to minimizing future liabilities and maintaining alignment with climate and environmental targets.

Current monitoring strategies rely primarily on remote sensing via satellites or on the collection, transport, and analysis of samples in a laboratory.[2] While such approaches provide valuable regional overviews, they remain limited in both spatial resolution and temporal coverage. Critically, these techniques often fail to detect low-intensity, chronic leakage events that may nevertheless contribute significantly to local methane budgets. Thus, the development of robust sensing technologies deployable directly at offshore sites represents a pressing gap in the state-of-the-art.

Advances in materials science have given rise to a special class of adsorbent materials – metal-organic frameworks (MOFs). These crystalline and porous materials with tunable pore design, exceptionally high internal surface areas and adjustable chemical functionalities make them particularly well-suited for selectively entrapping small molecules such as methane from seawater, a challenge where conventional sensing approaches often lack sufficient sensitivity and selectivity.[3]

Selective extraction of methane from water with MOFs needs to be coupled with a sensitive transduction mechanism to obtain a measurable response. Quartz crystal microbalance (QCM), a mass-sensing technology based on shifts in quartz resonance frequency, is a suitable transduction technique that can measure mass changes from methane entrapment in the MOF with nanogram-level sensitivity.[4] We fabricated MOF-QCM sensors and demonstrated the detection of dissolved methane in water at concentrations approaching 100 parts-per-billion, with response times under 60 seconds, making them ideally suited for point-source detection of methane leaks near abandoned wells.[5]

Over the last four years, our research has advanced the MOF-QCM methane sensor from conception to prototype demonstrations, achieving a Technology Readiness Level (TRL) of 6. Stable MOF films were deposited on QCM substrates using scalable techniques, yielding reproducible sensors with a high sensitivity and selectivity for methane. A compact prototype was developed, integrating a flow-cell architecture for continuous injection of water streams to the sensor, all powered by a 5V battery.[5] This prototype can monitor dynamic changes in dissolved methane levels in real time, highlighting both the sensitivity and operational stability of the sensor under conditions relevant to offshore deployments. Figure 1 depicts the essential elements of sensor prototype and development.

Looking forward, the next stage involves tailoring the prototype for offshore use. Potential concepts include integrating the prototype into autonomous underwater vehicles that survey the seafloor near abandoned wells or deploying it directly at vulnerable sites. These sensors would enable operators and regulators to detect, localize, and quantify leaks by providing continuous, real-time dissolved methane data with unprecedented precision. The next phase of the development aimed at improving the technological readiness of the prototype is ongoing at the Technical University of Denmark, funded by the Energy Technology Development and Demonstration Programme.[6]

This work establishes MOF–QCM sensors as a transformative technology for methane monitoring in offshore contexts. By uniting advanced materials with sensitive mass detection, the sensors offer an affordable innovative monitoring solution to an urgent environmental challenge. Additionally, this work serves as a blueprint for developing sensing technologies tailored toward other marine pollutants, by designing MOFs suited for selective extraction of pollutants of interest from water.

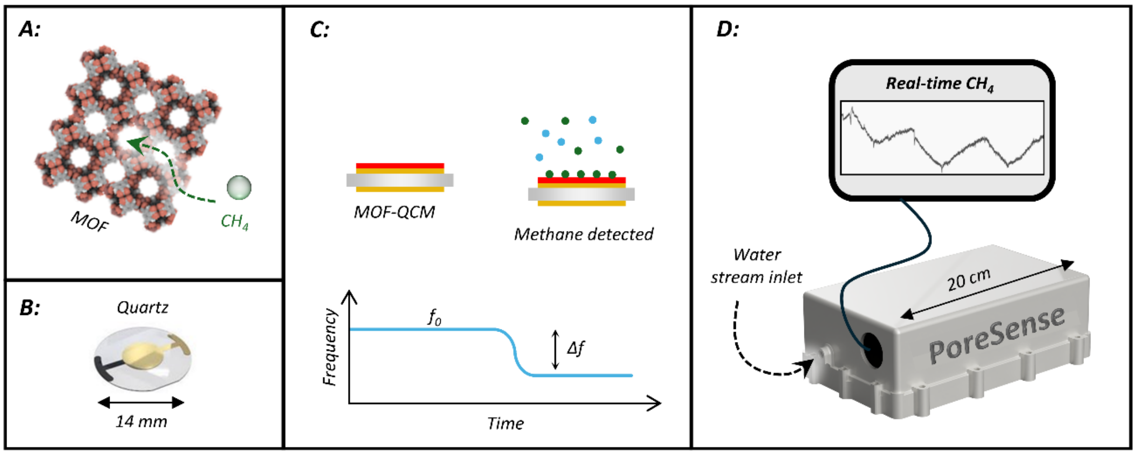

Figure 1: A) *Depiction of a MOF capable of entrapping methane.* ***B)*** *A quartz resonator that enables the QCM technology.* ***C)*** *Frequency shifts in quartz's resonant frequency as the MOF-QCM sensor entraps methane.* ***D)*** *PORESENSE – a TRL 6 prototype that can measure dynamic concentrations of dissolved methane in water.*

References

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