Distributed Sensor Networks for Monitoring Methane Leaks near Abandoned Wells

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Methane emissions from offshore oil and gas operations have emerged as a critical concern in addressing climate change. Once abandoned, offshore wells can remain as long-term leak points, releasing methane directly into surrounding waters and the atmosphere.[1] Regulators worldwide are placing increasing emphasis on responsible well abandonment and long-term monitoring strategies. Achieving this requires safely sealing and continuously monitoring wells for methane leaks over extended timescales.

Conventional monitoring methods such as satellite-based remote sensing or laboratory analysis of water samples provide valuable regional assessments but lack the spatial resolution and continuity needed to detect small, chronic emissions.[2] Localized leaks often go unnoticed when sampling is intermittent or averaged across wide areas. The key challenge is to develop sensor systems capable of covering large spatial regions around well sites and deliver continuous, geolocated data for rapid operator and regulator response.

Optical fibers provide a promising route toward such distributed systems. Widely used in telecommunications due to their ability to transmit light with minimal loss (~0.2 dB/km),[3] they already span over 1.5 million kilometres of seafloor.[4] Their low attenuation arises from total internal reflection, where light traveling in the fiber core is reflected at the boundary with the lower-index cladding. Certain optical fibers, such as fiber Bragg gratings (FBGs) can also serve as sensors. An FBG consists of a periodic modulation of refractive index in the fiber core, which reflects a narrow wavelength band of light, based on the spacing of the grating and shifts when the fiber is strained. Using this principle, FBGs have been demonstrated as chemical and biochemical sensors.[5], [6]

The sensitivity and selectivity of FBG-based sensors can be significantly enhanced by coating them with special adsorbent materials that can capture methane from water. Recently, porous materials such as metal–organic frameworks (MOFs) have demonstrated sensing capability for dissolved methane in water sources upon incorporation into a quartz crystal microbalance reaching a detection limit near 100 parts-per-billion.[7] While highly effective at their deployment site (as a point source sensor), they lack the ability to cover the large spatial regions essential for comprehensive offshore monitoring near abandoned wells.

An FBG functionalized with a methane-selective MOF would, in principle, undergo a detectable strain upon capturing methane. A key advantage with a fiber-based sensing platforms is that multiple FBGs can be inscribed along a single optical fiber, each providing distinguishable geo-specified strain signals through multiplexing.[8] This approach leverages the selectivity of MOFs with the sensitivity and precise geolocation of optical signals on a fiber with multiple FBGs, thus creating a distributed sensing platform capable of monitoring large areas with a single optical fiber.

We are currently developing MOF-coated fiber-based sensors that can detect methane across multiple spatial locations along a single fiber. Such a system would deliver both sensitivity and spatial coverage, enabling detection and localization of methane leaks near abandoned wells (Figure 1). Deploying arrays of these fibers around vulnerable sites could give offshore operators and regulators a powerful tool for early detection, precise localization, and effective mitigation of methane emissions.

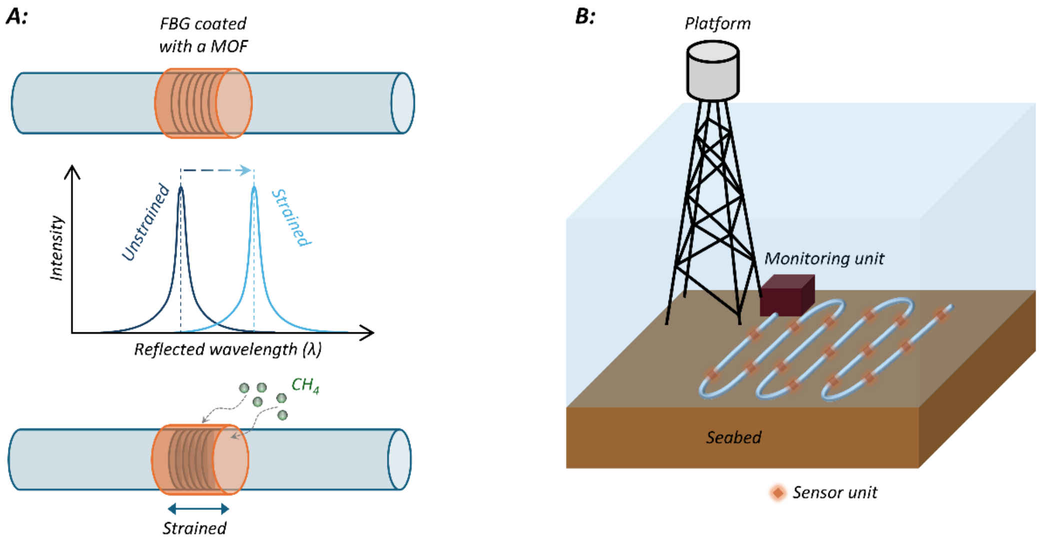

Figure 1: A) *MOF-coated unstrained fiber undergoes a shift in reflected wavelength as the capture of methane molecules in the MOF puts a strain on the FBG.* ***B)*** *Depiction of a fiber-based distributed sensor network for monitoring methane leaks at the seabed near an abandoned well with multiple sensing units along the fiber.*

References

[1] Y. Mahmutoglu and K. Turk, ‘A passive acoustic based system to locate leak hole in underwater natural gas pipelines’, *Digit. Signal Process.*, vol. 76, pp. 59–65, May 2018, doi: 10.1016/j.dsp.2018.02.007.

[2] B. J. Schuit *et al.*, ‘Automated detection and monitoring of methane super-emitters using satellite data’, *Atmospheric Chem. Phys.*, vol. 23, no. 16, pp. 9071–9098, Sept. 2023, doi: 10.5194/acp-23-9071-2023.

[3] G.-D. Peng, Ed., *Handbook of Optical Fibers*. Singapore: Springer Singapore, 2019. doi: 10.1007/978-981-10-7087-7.

[4] ‘In at the deep end: how subsea fibre optic cables keep the world connected’, www.europe.fujikura.com. Accessed: Sept. 12, 2025. [Online]. Available: https://www.europe.fujikura.com/insights/in-at-the-deep-end-how-subsea-fibre-optic-cables-keep-the-world-connected/

[5] M. A. Riza, Y. I. Go, S. W. Harun, and R. R. J. Maier, ‘FBG Sensors for Environmental and Biochemical Applications—A Review’, *IEEE Sens. J.*, vol. 20, no. 14, pp. 7614–7627, July 2020, doi: 10.1109/JSEN.2020.2982446.

[6] D. H.-C. Wang, S. S. H. Hwang, S. A. Maunder, N. G. Blenman, and J. W. Arkwright, ‘Optical fiber Bragg grating based chemical sensor’, in *2012 IEEE Sensors*, Taipei, Taiwan: IEEE, Oct. 2012, pp. 1–3. doi: 10.1109/ICSENS.2012.6411198.

[7] J. S. Malhotra, C. DávilaDuarte, P. Reichert, D. Krishnan, and J. Sundberg, ‘Quantification of Methane in Water at Parts Per Billion Sensitivity Using a Metal–Organic Framework-Functionalized Quartz Crystal Resonator’, *ACS Appl. Nano Mater.*, vol. 8, no. 9, pp. 4542–4552, Mar. 2025, doi: 10.1021/acsanm.4c06883.

[8] J. D. C. Jones and R. McBride, ‘Multiplexing optical fiber sensors’, in *Optical Fiber Sensor Technology*, K. T. V. Grattan and B. T. Meggitt, Eds, Boston, MA: Springer US, 1998, pp. 117–166. doi: 10.1007/978-1-4615-5787-6_4.

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