JOEMS

Journal of Opto-Electro-Medic Science

Vol. 1, No. 1, February 2025, pp. 9-14, DOI: 10.59190/joems.v1i1.298

PUBLISHED BY

LSPRAR

Analysis of fiber optic evanescent wave sensor for the rapid detection of organic pollutants in drinking water sources: A review

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ABSTRACT

Fiber optic evanescent wave (FOEW) sensor is an optical-based technology used to detect organic pollutants in drinking water sources quickly and efficiently. It utilizes the interaction of evanescent waves with a sensitive coating to identify optical changes that indicate the presence of organic contaminants. This research examines the working principle of the FOEW sensor, including the ability to detect volatile organic compounds in water at low concentrations of up to 10 ppb within five minutes. FOEW technology offers various advantages, such as corrosion resistance, fast response, low cost, and ease of real-time online measurement. Results show that FOEW sensors have high sensitivity for detecting organic contaminants and provide accurate data for water quality monitoring. These findings demonstrate the great potential of FOEW sensors as a reliable environmental monitoring tool, particularly in detecting water pollution due to human activities.

ARTICLE INFO

Article history:

Received Dec 5, 2024
Revised Jan 8, 2025
Accepted Feb 11, 2025

Keywords:

Environmental
Evanescent Wave Sensor
Organic Pollutants
Water Pollution
Water Quality

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1. INTRODUCTION

Water is a crucial natural resource within any economic framework. It serves as nourishment and a source of growth for all living organisms. Life on the surface of the Earth would be unattainable without water. The term "water" is synonymous with "life." All organisms, particularly humans, rely on water for sustenance and development. Water signifies agriculture, sustenance, hydration, and energy. Water constitutes around 75% of human body content and approximately 90% of plant makeup [1].

Groundwater constitutes a highly appealing and accessible source of potable water in numerous countries. This has led to the extensive utilisation of groundwater, especially boreholes, as the primary supply of drinking water over the previous four decades. Boreholes have markedly lowered death rates associated with diarrhoeal illnesses. Water contamination has become a significant global issue, particularly concerning groundwater, which serves as a primary source of potable water. Organic pollutants in groundwater primarily originate from diverse human activities, including the leakage of underground storage tanks, application of sewage sludge, unlawful and improper chemical disposal, utilisation of various pesticides and fertilisers, pharmaceuticals, insecticides, animal husbandry, industrial effluents, and personal care products [2].

Sophisticated monitoring techniques are essential for detecting pollutants in groundwater. Fiber optic evanescent wave (FOEW) sensors are advantageous for pollution detection and water quality assessment owing to their exceptional corrosion resistance, intelligent design, electromagnetic interference immunity, and cost-effectiveness. The FOEW sensor can thereafter serve as an efficient tool for monitoring water quality and addressing groundwater contamination from organic contaminants, which directly affects human health [3].

2. THEORITICAL REVIEW

2.1. Optical Principles of Fiber Evanescent Wave Sensors

Evanescent or field waves are solutions to the wave equation that do not propagate from the source or surface; instead, their amplitude diminishes exponentially with increasing distance from the surface. Fiber optic sensors that function based on evanescent wave sensors are referred to as FOEW sensors. Numerous varieties of FOEW sensors have been created to date. FOEW sensors can be categorised into two types based on the condition of the optical fiber core: FOEW sensors utilising structured optical fibers (SOFs) and FOEW sensors employing fine guidance sensors (FGs). FOEW sensors utilising SOFs for water quality detection can be classified into uncoated/thinned, D-shaped, U-shaped, and tapered sensors. FOEW sensors utilising FGs represent a category of fiber devices characterised by periodic alterations in the fiber core, offering advantages like as compactness, resistance to electromagnetic interference, corrosion resistance, and the capability for dispersed measurement. Based on the grating period, FGs can be categorised into short-period FGs with a grating period of less than 1 micrometre and those with grating periods ranging from tens to hundreds of micrometres.

2.2. Soil Water Pollution

Groundwater serves as the principal water supply in numerous regions globally. The escalating vulnerability of this valuable resource has rendered it unsuitable for agricultural and residential purposes. Numerous human activities, together with prevailing hydrogeologic conditions, frequently jeopardise groundwater resources. Alongside established contamination causes, other variables such as population growth, climate change, extensive pesticide usage, land application of biosolids, unregulated waste management, and escalating industrialisation additionally jeopardise groundwater resources [5].

2.3. Compound Organic

Human-derived organic compounds, including insecticides, medicines, surfactants, personal care items, food, and industrial additives, are utilised daily across multiple sectors worldwide. Compounds present in the environment at unwanted or harmful amounts are classified as emerging organic contaminants (EOCs).

3. RESEARCH METHODS

3.1. Optical Principles of Fiber Evanescent Wave Sensors

The subsequent elucidation pertains to the operational principle of a fiber optic evanescent wave sensor: The laser source transmits light through an underground optical fiber. A minor fraction of this light propagates outward from the optical fiber as evanescent waves, interacting with the surrounding environment, including atmospheric air. The intensity and phase of these evanescent waves are altered upon interaction with different media, including groundwater. The detector will record the alterations in the evanescent waves reflected back to the optical fiber. The alterations are subsequently elucidated to ascertain the presence of groundwater and its characteristics, including salinity and temperature [4].

3.2. Identification of Organic Contaminants in Aquatic Soil

The identification of organic compounds in water with FOEW sensors use the notion of interaction between evanescent waves and a modified sensitive layer. Interaction of organic substances with the sensitive layer induces a detectable alteration in optical characteristics by the sensor. These alterations are subsequently transformed into electrical signals that may be quantitatively assessed to ascertain the quantity of organic chemicals in the sample.

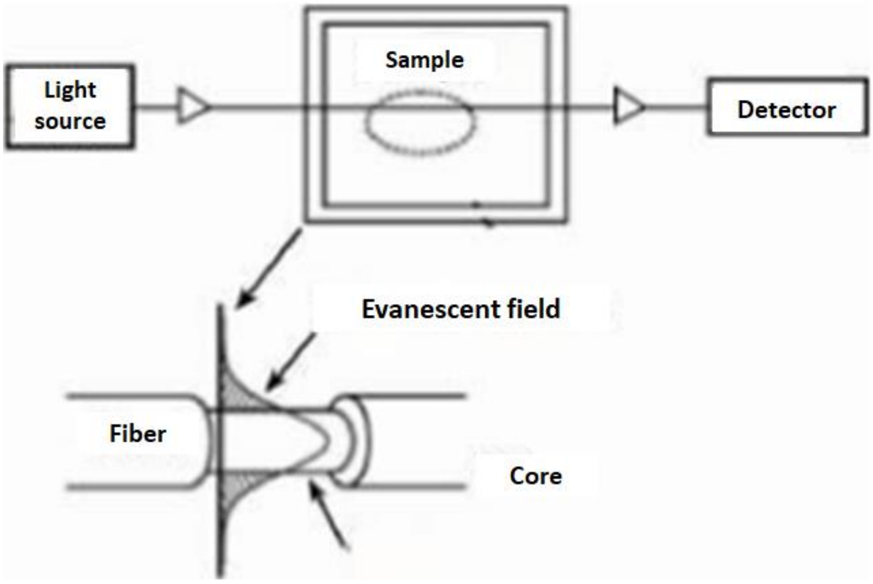

Figure 1. Optical fibre evanescent wave sensor.

3.3. Volatile Organic Compounds (VOCs)

The quantity of organic contaminants in water is typically minimal, complicating measurement and analysis relative to conventional pollutant detection techniques like gas chromatography and liquid chromatography. Fourier transform infrared spectroscopy utilising FOEW sensors presents significant advantages. For instance, FOEW sensors can reduce measurement time and significantly enhance the effectiveness of emergency monitoring, in addition to their compact size, rapid response, low detection cost, and simplicity for swift online measurement.

3.4. Volatile Organic Compounds in Multiparametric Assessments

The attenuated total reflectance-infrared (IR-ATR) sensor concurrently identifies several VOCs in water at a concentration of approximately 10 ppb within 5 minutes. IR-ATR technology has been employed to quantify crude oil in groundwater.

3.5. Selective Measurement of VOCs

Discriminative assessment Advanced selective coating materials have been developed and integrated onto FOEW sensors based on SOFs to boost the selectivity for target molecules and improve the sensitivity in detecting VOCs in water.

4. RESULTS AND DISCUSSIONS

4.1. Identification of Organic Contaminants in Aquatic Soil

Groundwater serves as a crucial supply of potable water for millions globally, nonetheless, it presents the most significant hazard and detrimental effect on human health when contaminated by organic contaminants. FOEW sensors have demonstrated significant utility for the real-time detection and monitoring of several parameters in water. Nonetheless, these sensors encounter numerous problems, including inadequate sensitivity and selectivity, as well as elevated detection limits.

4.2. Examination of VOCs

The Fourier transform infrared spectroscopy utilised in the FOEW sensor exhibits significant advantages. For instance, FOEW sensors can reduce measurement duration and significantly enhance the effectiveness of emergency monitoring, in addition to their compact size, rapid response, low detection cost, and simplicity for swift online measurement.

4.3. Examination of VOCs in Multiparameter

Quantifications the IR spectra of the FOEW sensor offer qualitative insights into the chemical composition of oil and treated groundwater from crude oil. The primary distinction between the two is the elevated water content in the oil-water mixture, as evidenced by the more pronounced O-H stretching peak illustrated in Figure 2. This is elucidated by the X-axis, which represents the wave number (in cm-1), serving as a measure of infrared energy. Increased wave number correlates with elevated energy levels. The Y-axis indicates the absorption, reflecting the extent to which the sample absorbs infrared radiation at a specific wavenumber. Increased absorption correlates with greater radiation absorption by the chemical link. The wave number in the O-H region is approximately 3500 cm-1, signifying the presence of hydroxyl groups (-OH) in the sample, commonly seen in compounds like alcohol and water.

The oil-water spectrum at this peak is more pronounced and strong than that of crude oil, signifying a higher water content in the oil-water mixture. The C-H stretching peaks occur at approximately 3000 cm^{-1}, signifying the existence of C-H bonds in organic compounds. Both spectra exhibit pronounced peaks in this region, signifying the presence of numerous C-H bonds in both oil-water and crude oil. The H-O-H and C-H bending points occur at wave numbers of 1600 – 1500 cm^{-1}, signifying the bending of H-O-H bonds in water and C-H bonds in organic compounds. Librations are oscillations of intricate molecules that often manifest at lower wavenumbers. In these spectra, librations may signify intermolecular interactions or the existence of distinct molecular conformations. The distinction between oil water and crude oil lies in the larger water content and more pronounced O-H stretch peak of oil water, signifying substantial water present. Conversely, molecular complexity indicates that crude oil possesses a more intricate molecule structure with various types of CH bonds, resulting in larger spectra with a greater number of peaks compared to oil water.

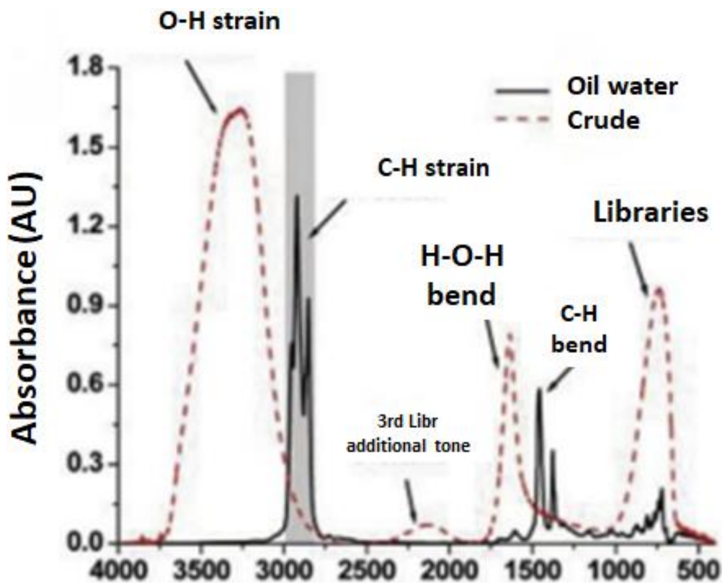

Figure 2. Coating IR-ATR spectra of oil, water, and crude oil.

4.4. Examination of VOCs by Selective Measurement

The wavelength shift (nm) in relation to response time (s) at different concentrations of a chemical (measured in microgrammes per litre, µg/L) is illustrated in Figure 3. Modified AgX The EPB denotes that the experiment was performed on a substance known as AgX, treated with EPB. AgX may refer to a specific product or material, while EPB is an additive utilised to modify the properties of AgX. The X-axis denotes the concentration (ppm), reflecting the variation in the crude oil concentration utilised in the experiment. The greater the distance to the right, the elevated the concentration of crude oil. The Y-axis peak area (AU) represents the amplitude of the measured signal. A larger peak size correlates with a more robust detected signal. In this context, the peak area can be associated with the quantity of crude oil present. Data points signify measurement outcomes at varying crude oil concentrations. Each point denotes a pair of values related to the concentration and the associated peak area. The greater the concentration of crude oil, the larger the measured peak area. This indicates that the signal produced by crude oil intensifies with an increase in the quantity of crude oil.

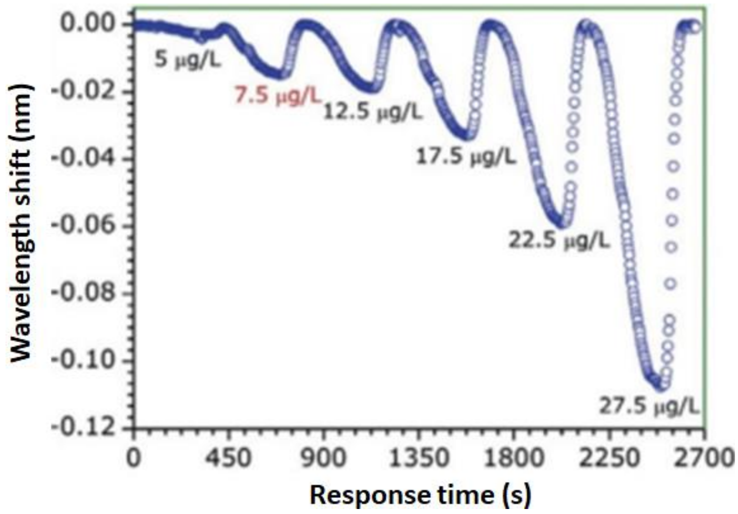

Figure 3. Sensitivity of the sensor.

5. CONCLUSION

In summary, FOEW sensors have demonstrated efficacy in detecting many water quality indicators associated with organic chemicals, owing to their superior corrosion resistance, intelligent design, resistance to electromagnetic interference, and cost efficiency. Organic contaminants in groundwater, predominantly derived from anthropogenic activities including the application of pesticides, medications, and personal care items, substantially contribute to water contamination. Furthermore, oil-water mixes demonstrate increased water content and a more pronounced O-H strain peak, indicating substantial water present relative to crude oil. As the concentration of crude oil rises, the recorded peak area expands, signifying a more robust signal produced by the crude oil, hence improving detection sensitivity. These findings underscore the efficacy of FOEW sensors in environmental monitoring and pollution detection.

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