Real-time monitoring of accidental oil pollution in ground waters using an innovative transducer

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***Abstract* — The oil pollution of the environment is unfortunately very often reported not only by the Environmental Protections Agency, but also by tourists and environmental NGO. This is a serious problem for the nowadays society, due to their harmful effects even at low concentrations toward the public health. The main sources for oil pollution of ground and surface waters are: oil extraction, transportation and accidental spills in water. The main objective of this study is the development of an inexpensive transducer for the detection of petroleum products, allowing the monitoring of the above mentioned compounds from the ground waters. The working principle of this transducer is based on the modification of the electric permittivity of sorbent media (dielectric) as a result of capillary ascension of petroleum products into the sorbent matrix.**

***Index Terms* — cylindrical capacitor, capillary ascension, electric permittivity, sorbent, detection of petroleum products**

I. INTRODUCTION

Oil is the most important energy resource in the world economy, involving a lot of activities with a negative impact toward the environment: research, exploration and exploitation in different parts of the world. The main oil pollution sources of water resources are: extraction, transport and accidental spills of oil in the water. Nowadays, the development of simple, rapid, cheap and efficient methods for oil pollution prevention of the environment is a first degree priority and a technological challenge. In order to reach this target, the adsorbent materials, especially the natural cheap ones, become a first option in the choice of the pollutants removal processes. Based on the adsorptive properties of the natural materials (high hydrophobic character) toward various petroleum fractions, a methodology for the detection and measurement of oil content in water has been developed. In an opposite manner this idea can be used so as some low cost sorbents with a high affinity to water (high hydrophilic character), can be used in the development of sensors for the detection of low water content in oil.

The advantages to use natural sorbents are: their biodegradability, renewability, low cost, low environmental impact, and simplicity in manipulation. After the use of natural sorbents for the petroleum products spill, the generated waste can be treated using the bulk biodegradation (composting); thus, both sorbent and oil product are decomposed in simple products [1-9].

The main objective of this study is the development of an inexpensive transducer for the detection of petroleum products, allowing the monitoring of the above mentioned compounds from the ground waters.

II. EXPERIMENTAL

Different petroleum products were investigated, in order to simulate the water pollution by petroleum products: Gasoline, Diesel oil, Light oil available in the PETROM gas stations. Their main properties (density, total content of sulfur, total content of water, total content of aromatic hydrocarbons) are presented in TABLE I.

The transducer comprises a tubular chamber where the sorbent material is introduced. The bottom surface of the tubular chamber is perforated and covered with permeable hydrophobic material, in order to allow passing of the oil and to avoid the water penetration.

As a result of oil capillarity of the sorbent pack, the electric permittivity of the sorption medium, (the cylindrical capacitor) is changed in comparison with the initial one. This signal is amplified and recorded, being in line with the intensity of pollution with petroleum.

In order to develop the transducer designed for the in-situ determination of petroleum products from water, some studies on the capillarity and sorption capacity of various materials placed in tubes with different geometric dimensions were previously carried out.

The use of the sorption process for the petroleum products requires understanding the phenomenon of capillary rise. When a liquid is placed in contact with a dry porous medium, i.e., a sorbent, the liquid is "channeled" through the porous medium [10].

The fluid absorption/adsorption and retention mechanisms depends on the shape and size of pores, the specific surface of the solid, the surface tension of the oil product and the angle of contact [11]. By using several capillary columns, with different diameters, filled with sorbent material and immersed in several liquids (different type of petroleum products), it is possible to simulate the liquid penetration into the dielectric material of the cylindrical capacitor introduced between the electrodes of the proposed system for detection and measurement.

The constructive diagram of the transducer, based on the detection principle above mentioned [12], is presented in (Fig.1)

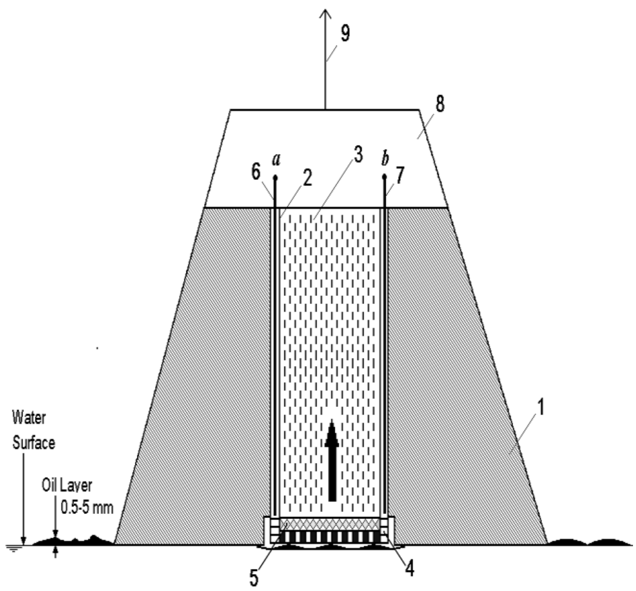


Fig.1 The transducer (constructive diagram) for in-situ determination of oil in contaminated water

1-the floating part; 2- tubular chamber; 3-sorbent pack; 4-perforated plate; 5-hydrophobic material; 6-electrode; 7-electrode; 8-box containing the electronic circuits for capacitance measurement and wireless data transmission; 9-*radio transmission antenna*

If an oil thin film is present on the surface of contaminated water, it will pass through the hydrophobic material of the membrane 5, due to the capillary rising, and impregnates the granular porous dielectric material. Since the dielectric is located between two insulated electrodes 6 and 7, arranged vertically and parallel with the tube 2, its electric permittivity changes. The contacts ***a*** and ***b*** are the connection points of the condenser transducer in the measuring circuit. The change of the electric permittivity values leads to variations in the capacitance which was measured with a specialized integrated circuit of AD7747 type.

The sensor selectivity is achieved by using a hydrophobic material which prevents the penetration of water in the structure of the dielectric material. Thus, in the absence of the thin layer of oil, the sensor generates no signal in correlation with the change in electrical permittivity of the sorptive medium, corresponding to the pollution-free groundwater with respect of petroleum products in layered state.

After the occurrence and identification of an accidental pollution with petroleum products and after the depollution, the sensor sorbent cartridge is replaced, but its electronic circuits and antenna are reused, thus the cost of such a monitoring system is low and quickly amortized.

Figure 2 presents the schematic functionality diagram of the sensor for the monitoring of groundwater susceptible of pollution by layered oil products.

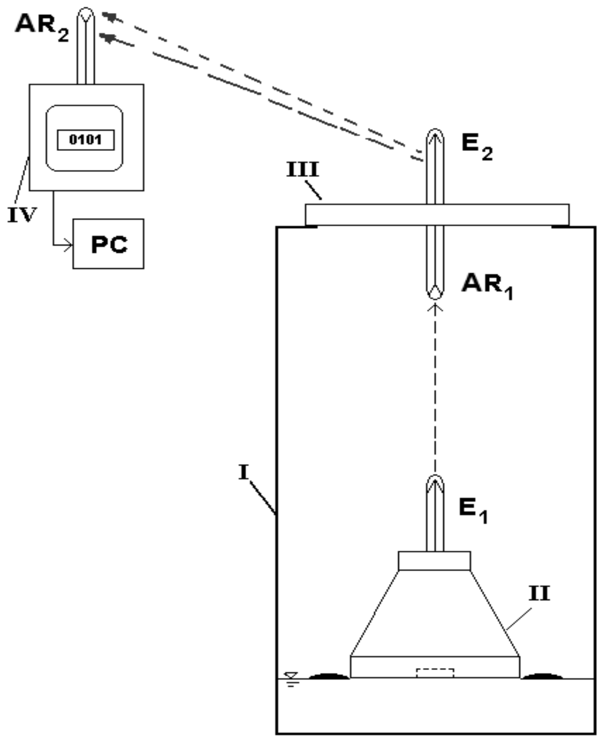


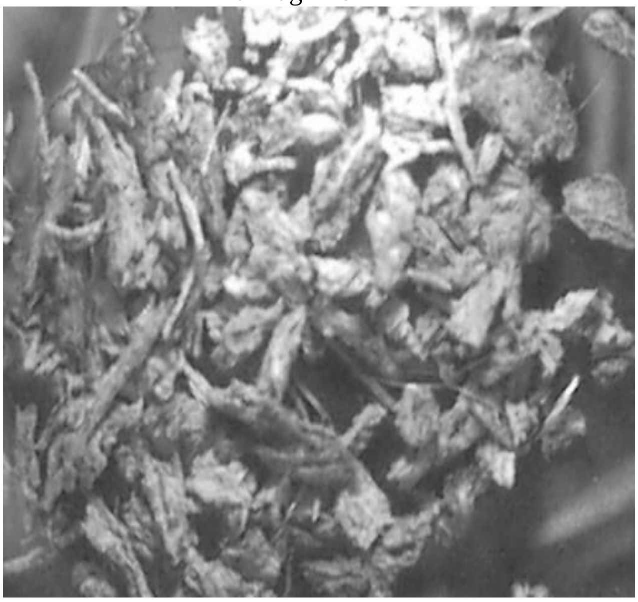
Fig.2. The schematic diagram of the real time monitoring system of oil pollution in ground waters using the developed oil transducer

I-groundwater monitoring well; II-oil transducer with radio transmission system; III-protective casing including a radio retransmission system; IV-receiving station

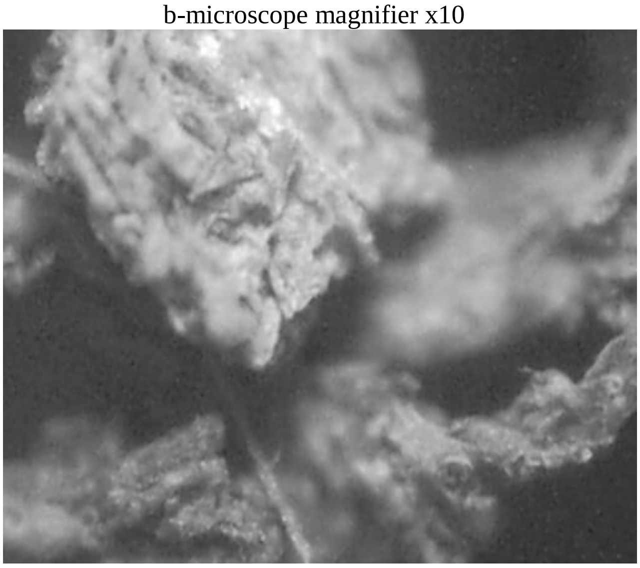
According to Fig.2, the ***oil transducer II*** is inserted in the monitoring well, floating on the groundwater surface by the means of a floater. When an oil product layer appears on the water surface, the signal measured by the sensor is sent to the emitting ***antenna*** E_1 towards ***the signal relay system III*** (retransmission relay) provided with a ***receiver antenna*** AR_1 and a ***retransmission antenna*** E_2. The signal intercepted by the ***retransmission system III*** is amplified and ***retransmitted to the receiving system IV*** equipped with a ***receiver antenna*** AR_2 and a digital display monitor, and finally the information is sent to a computer for data storage [13].

The low cost sorbent material (based on Romanian peat bog) [14-17] for construction of oil detection transducer is presented in Fig.3

a-magnifier x1



b-microscope magnifier x10



c- microscope magnifier x100

Fig.3. The low cost sorbent material (based on Romanian peat bog) for construction of oil detection transducer

III. RESULTS AFTER EXPERMENTAL TESTS

Based on the above general considerations and on the effective constructive elements (sorbent, hydrophobic membrane, metallic electrodes, capillary) an oil transducer was developed to detect oil spills on groundwater, pointing out the pollution state, using the principle of the capillary rise. The sensor presents a simple construction and represents an inexpensive solution for oil spills monitoring in groundwater. After the development of the transducer as a functional prototype, it was tested to study all the selected petroleum products, leading to the generating of a capacitive signal of pF magnitude, when the sensor was plunged for 30 minutes in water with oil layer of 0.5 mm thickness.

The capillary ascension and the change of the capacitance values as a result of the dielectric modifications of the cylindrical capacitor of the transducer under the tests with the petroleum products are displayed in TABLE I.

TABLE I. EXPERIMENTAL TESTS OF TRANSUCER FOR OIL DETECTION

No	Product name	Density (g/L)	Total sulfur (%, w/w)	Water content (ppm)	Aromatic hydro-carbons (%, w/w)	Capilar ascen-sion (mm)	Change of Capacity (%)
1	Gasoline	753	0.5	5	0.5	13.2	36.1
2	Diesel oil	845	9	200	8	9.3	28.3
3	Light oil	930	1.4	1	-	8.7	24.5

After a while, the water reaches saturation by the capillary rise in the pores and the hydrophobic polymer layer minimizes its entry in the column, acting as a selective membrane.

The hydrophobic selective membrane was prepared according to the methodology developed at "Petru Poni" Institute of Macromolecular Research of Iasi, branch of the Romanian Academy of Sciences.

The waterproofing textile material, used as a semi permeable membrane for the passage of oil products was achieved by depositing a polyethylene film on hemp yarn dry or wet (using water treatment for 4 hours, at t = 70...95 °C).

The polyethylene deposits, with a thicknesses ranging from 0.1 to 0.2 mm, were performed by passing the yarn with a speed of 0.30 - 0.5 m/s, through a melted polyethylene thermostat bath at 160 - 170 °C, (having low density and flow index of 20-25 g/10 min), followed by natural cooling of the deposited layer.

The capillary column is clogged with such a yarn, resulting a "plug" with 0.5-1 cm length, which is actually the waterproof membrane. The membrane perm-selectivity toward all the studied petroleum products was tested, obtaining similar results for each of them.

IV. CONCLUSION

A tube provided at the bottom with waterproofing system was used to develop a sensor for oil products. A series of tests on capillary sorption capacity of peat placed in tubes with optimal size were performed for several commercial oil products.

A cylindrical capacitor was developed by depositing metal layers as electrodes on the walls of a capillary tube, working as a system of quantitative analysis, based on the electrical permittivity of the dielectric material, which is modified by the oil front ascension from the water.

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