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Development of Low Frequency Dielectric Cell for Water Quality Application

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Abstract

Most available methods for determination of water quality in water bodies such as rivers, lakes, and reservoirs are based on the collection of water samples from water bodies and subsequent laboratory analysis. While these methods are standard and could provide accurate measurements and evaluation of water quality, they are costing and time consuming and do not provide the continuous monitoring and assessing of water quality. In this paper, low frequency dielectric cell is developed for determination the water quality. The proposed method was used to measure the dielectric properties of water. The method was calibrated and validated by measuring dielectric properties of standard materials such as Teflon. The measured dielectric properties of water were used to determine several water quality parameters such as salinity, temperature, turbidity. The proposed method has advantages in compare with the available techniques for water quality including simple, low cost, safe, possible to be continuous and online method, and can be used for in-situ as in the lab. Dielectric constant and loss factor of water decrease with increasing frequency. The rise of water temperature caused an increase in loss factor and a decrease in dielectric constant. The dielectric constant increases with increasing water salinity while it decreases with increasing the turbidity of water. Further investigation is needed to determine the effect of other water quality indices on the dielectric properties of water prior to use the proposed system in practical application.

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Keywords: water quality; low frequency; impedance; salinity; dielectric.

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1. Introduction

Most of the water bodies across Saudi Arabia and worldwide have been reported as polluted including ground water, rivers, and shorelines. U.S. Environmental Protection Agency estimated that approximately 40% of US waters do not meet minimum water quality standards [1,2]. In normal conditions, water is the only material exists in all three states of aggregation on our planet. Is also, plays a dominant role in all processes, both industrial and natural. Water also forms the most major constituent of many man made products [3].

Water is classified as polluted if the water does not met a specific standard parameter set for its intended use. Water quality is determined by measuring the physical, chemical, and biological condition of water [4]. Physical water parameter used to determine water quality index including color, taste, odor and suspended solids. Chemical water parameter could be done using chemical analysis of water samples to determine the concentration of elements and compared to a preset value for each element in national and international standards.

Monitoring and assessing the quality of water in streams, reservoirs and lakes are critical for establishing total maximum daily loads to improve water quality. Current techniques for measuring water quality involve on site measurements and/or the collection of water samples for subsequent laboratory analysis. While these technologies provide accurate measurements for a point in time and space, they are expensive, and do not provide either the continuous, spatial or temporal view of water quality needed for monitoring, assessing, or managing water quality[5].

In recent years, many electromagnetic methods have been developed and used because of the low prices of electronic devices and the success of electromagnetic methods in many applications. Examples of these methods, ground penetration radar [6], free space microwave method [7,8], coaxial transmission line method [9], open-ended waveguide [10,11], resonant cavity [12] and parallel plate capacitive or low frequency dielectric cell [13]. Among these methods, the low frequency dielectric cell is intensively used for characterization of materials because of simplicity, suitability for low radio wave frequency, and the convenience of casting or cutting parallel-faced solid material or forming a cell for liquid materials.

Recent years witness an increasing use of electromagnetic parallel plate capacitor in various multi-disciplinary engineering applications such as soil pollution [14], thermal analysis [15], humidity and moisture content [16], cement hydration [17], fiber content in concrete [18] and sitting of composite materials [19]. In spite of that, characterization of material using parallel plate capacitor is based on the measured impedance and the calculated dielectric properties. These measured properties highly depend on the accuracy of removing other unwanted impedances associated with setup of the PPS such as electrode impedance, stray impedance, fringing impedance and air impedance.

In this paper, a parallel plate capacitor called low frequency dielectric cell was designed. A model circuits were developed to remove unwanted impedances from the measured impedance then the dielectric property of water was calculated. The proposed cell was calibrated and validated for accurate measurement of impedance and dielectric properties using the standard material. The cell then used to measure several water quality parameters.

2. Dielectric Theory

The response of materials to alternating electric and magnetic fields is characterized by a complex permittivity (ε^*) and a complex permeability (μ^*). Because water is nonmagnetic material this will limit the discussion to complex permittivity. It is natural to separate its real and imaginary parts, which is done by Equation 1.

$$\varepsilon^* = \varepsilon' - j\varepsilon'' \tag{1}$$

Where, ε' is the real part of the permittivity called dielectric constant, which is related to the stored energy within the medium and ε'' is the imaginary part of the permittivity called dielectric loss factor, which is related to the dissipation (or loss) of energy within the medium.

Impedance (Z) is the basic electromagnetic parameter used to characterize electronic circuits and materials. The mathematical definition of impedance for alternative current (AC) is defined by Ohms Law.