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Research paper

Determination of Water Quality Parameters Using Microwave Nondestructive Method

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Abstract

This paper presents an investigation of microwave reflection and dielectric properties measured by the open-ended rectangular waveguide in the frequency range of 8-12 GHz to determine water quality parameters. Microwave method shows a potential to determine the salinity and some water quality index. The complex permittivity called dielectric properties in the microwave frequency were calculated from the microwave reflection. Several water quality parameters such as salinity, turbidity and temperature were related to the measured microwave properties of water using mathematical regression models. The results indicate that the reflection and dielectric properties of water decrease with increasing the temperature of water samples. The salinity of water sample increase the loss factor and decrease the dielectric constant of the water sample. Also, the reflection of the microwave signal and dielectric properties decrease with increasing microwave frequency and turbidity of the water. The microwave system which used microwave reflection and dielectric properties of water bodies could make the determination of water quality parameters and water indexes more simple, fast, relatively low cost compared with the current used method. Microwave method for water quality may also save a good amount of time and money compared to existing standard methods. Further investigation is needed to determine the possibility of using microwave method for predicting other water quality factors.

Keywords: *Dielectric Properties; Microwave; Salinity; Turbidity; Water Quality.*

1. Introduction

Water bodies cover more than 75 percent of the earth surface. The water in oceans forms about 1.3 billion km3 while the amount of fresh water in all sources is 36 million km3. The availability of fresh water for human use is about 4.6 million km3 which equal 12% of total freshwater [1]. Pollution and contamination of fresh water increased significantly in recent years due to an increase in human activities. Management of water quality and monitoring of water quality parameters become a crucial issue worldwide [2].

Water resources and water reservoirs are polluted and contaminated in many part in the world including Saudi Arabia. These polluted and contaminated resources including all water sources such as groundwater reservoirs, rivers, and lakes. United State Environmental Protection Agency stated that about 40% of water in the United States are polluted and it does not meet the standard level of water quality parameters [3,4]. Naturally and under normal conditions, water could be in all possible states (solid, liquid and vapor). Water could also carry a critical and dominant role in several and major covering the made-up and natural one. Water also form a vital and most significant part of most human-made activity and product [5]. Water quality could be estimated by determining and evaluating the physical, chemical and biological condition of the water. Physical water quality index determined using measured physical parameters such as temperature, color, taste odor and turbidity. Chemical water quality estimated using chemical parameters such as pH, total dissolved solids, salinity, hardness, and COD. These water quality parameters could be determined by taking water samples and send it to the chemical laboratory. Chemical analysis of water sample will be conducted to determine the concentration polluted element in water samples. These concentration of contaminated elements will be compared to the acceptable concentration level stated for each element in the international standard in general and national standard in particular. It is clear that these chemical analysis of water samples consumed a significant amount of time and cost. In addition, this way of testing water quality limited to space because of limited number of samples and representing the quality of water at time of sampling only and could not be online monitoring system. Online and in-situ monitoring of water quality will be of great interest. Microwave system could provide such option to determine water quality continuously and cover a large area (spatial) [6,7].

Several microwave method was used to measure a reflection of the microwave signal and dielectric properties of several materials including liquid, solid and particulate material. These microwave methods include techniques such as microwave non-contact method called free space [8], transmission line method using waveguide or coaxial cable [9], microwave resonant cavity method [10], microwave ground penetration radar method [11] and microwave terminated open-ended waveguide or coaxial cable [12]. Among these methods, terminated open-ended waveguide method seems promising method for field testing and online application. Also, waveguide method witnesses a success in the characterization of several materials such as determination of concrete moisture content [13], detection of chloride in concrete [14]. Several investigations were conducted to measure microwave dielectric properties of water. Limited research is available for water quality application. Review of dielectric properties of water over wide frequency range is available in reference [15]. In previous research, the author investigates the use of microwave method and develop a reflection meter for measurement of dielectric properties of water [16,17].

In this research, microwave method using an open-ended rectangular waveguide to measure the reflection of the microwave signal and dielectric properties of water at different temperatures and salinity of the water. The results indicate that the proposed method is a promising tool for determination of some water quality parameters such as water salinity, the temperature of water, and water turbidity. All test results were evaluated in the X-band microwave frequency range from 8 GHz to 12 GHz. Further investigation is under consideration to determine the effects of other water quality parameters such as COD, BOD, pH and total suspended solids.

2. Microwave Theory

Microwave signal is an electromagnetic wave signals travel in the frequency spectrum from 300 MHz to 300 GHz and the corresponding wavelength will range from 1 meter to 1 millimeter [18]. The most important properties of material control the propagation of microwave signal in material is called complex permittivity (ε^*). Complex permittivity consist of two distinguished parts. The real part of complex permittivity called dielectric constant (ε') and it represented the amount of energy the material absorbed from microwave energy resulted from polarization phenomena. The imaginary part of complex permittivity is called loss factor (ε'') and represented the microwave energy lost as current conductance. When exciting the material such as water by microwave signal, the microwave signal partial transmittance and partial reflectance when the microwave signal travel from one medium into another one (like travel from air to water). The reflection coefficient (S_{11}) determines the ratio of the reflected wave to the incident wave. complex permittivity of water deduced from the measured microwave reflection. Complex permittivity and its two major parts are given in equation 1.

$$\varepsilon^* = \varepsilon' - j\varepsilon'' \quad (1)$$

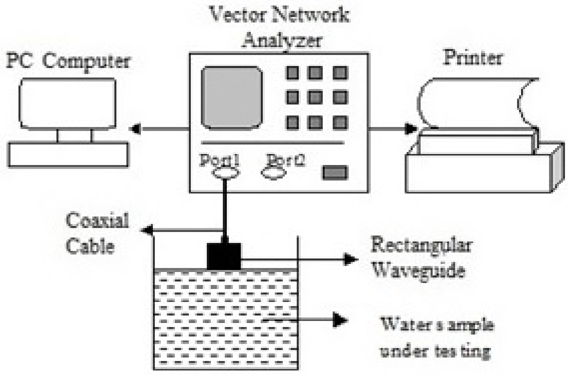
3. Microwave Reflection Method

Setup of the microwave reflection method is shown in Fig. 1. The microwave measurement system was design and setup using Wiltron 37269A Vector Network Analyzer (VNA). VNA was connecting via coaxial cable to an open-ended waveguide. The open-ended waveguide terminated by Teflon impedance transformer. The Teflon transformer exposed to water sample and excite the water with microwave signal. The VNA measured the reflection of microwave signal and the water dielectric properties calculated from the microwave reflection. The microwave system was validated and calibrated using LRL (line, reflect line) calibration standard method. The waveguide used was WR-90 cover the X-band microwave frequency range of 8 to 12 GHz. The waveguide form the water quality pollution sensor. The rectangular waveguide sensor exposed to the water body and water samples to measure microwave reflection from water as shown in Fig. 1. Dielectric properties of water samples calculated from the measured microwave using iterative techniques explained previous work, and it could be found in references [13] and [14].

4. Water Samples

Several water samples were prepared. The microwave reflection and dielectric properties of all water samples were measured in the frequency range 8-12 GHz. Two water samples were prepared. The first sample deionized water (0% salinity) and the second sample were prepared with 1% salinity. Microwave reflection and dielectric properties of these two samples were evaluated at frequency 8-12 GHz. Water pollution is mostly associated with temperature especially industrial pollution in rivers and shorelines. To evaluate the effect of the temperature of water sample on its microwave properties, dielectric properties of water samples were evaluated at water temperature in the range of 25 to 75°C. Finally; microwave dielectric properties of water sample were measured at different water salinity ranging from 0% to 1%.

To determine the potential use of microwave method to evaluate and measure the turbidity of water, water sample were prepared at five level of turbidity. Five samples of distilled water was used. Each sample equal to 500 mL of water. Very fine Clay soil was used to introduce turbidity to distilled water samples. Different amount of clay were added to form five samples with different turbidity level. The first distilled water sample was kept free of clay. The amount of clay powder was increased for other four water samples. Turbidity of all five water sample were determined using standard turbidity method.



(a) Schematic diagram of microwave system

(b) water samples under testing

Fig. 1: Schematic diagram of a microwave system and water under testing.

5. Result and Discussion

The magnitude of microwave reflection and phase shift of 0% salinity (deionized water) and 1% salinity at different frequencies are shown in Figure 2. The results show that both the magnitude and phase shift of water samples decreases with increasing frequency. This trends may attribute to the reduction of the current conductance of water at high frequency. The results also indicate that saline water has lower reflection properties than the deionized water because anion and cation charge of salt increase the absorption of the microwave signal and decrease the reflection of the wave due to the high conductivity of saline water. Dielectric constant and loss factor of water over frequency in the range 8-12GHz are shown in Figure 3. The results show that dielectric constant decrease with increasing frequency and the loss factor increase with increasing frequency. The rate of change in both dielectric constant and loss factor of saline water is higher than the rate for deionized water.

Contaminated water bodies by industrial wastes mostly associated with temperature rising of water. This were observed in rivers, lakes, and streams world wide. Continuous measurement of water temperatures could be a very useful indicator and early warning system for water pollution. Therefore, In this study, the relationship between the temperature of water and its microwave reflection coefficients such as magnitude and phase shift were investigated. The results of the magnitude of microwave signals reflected from water body at different temperatures are presented in Fig. 4a while the results phase shift are presented in Fig. 4b. From these results, it is clear that both magnitude and phase shift of reflection coefficients of microwave signal decrease with increasing water temperature. Therefore the microwave system can be used to determine the variation of the temperature of water continuously.

Dielectric properties of water at different salinity and water turbidity are shown in Figure 5. The results show that dielectric constant decrease with increasing water salinity while the loss factor increase with increasing water salinity. The salinity of water increases the conductivity of water and leads to an increase in the loss factor of water with the increasing salt content. This trend may attribute to the increase in water conductivity of saline water as a result of increasing anion and cation charge of the salt compound in water. When the water contaminated with very fine particles, these particles will suspended in the water and increase the turbidity of water. The increasing turbidity of water results in an increase of both microwave dielectric constant and loss factor decrease of water. The relationship between microwave properties of water and water turbidity were established.

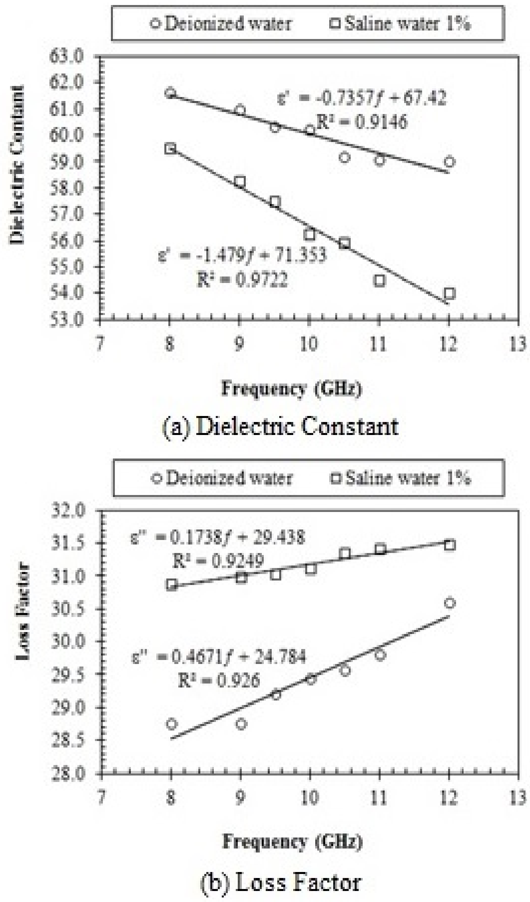


Fig. 3: Dielectric properties of water samples versus frequency.

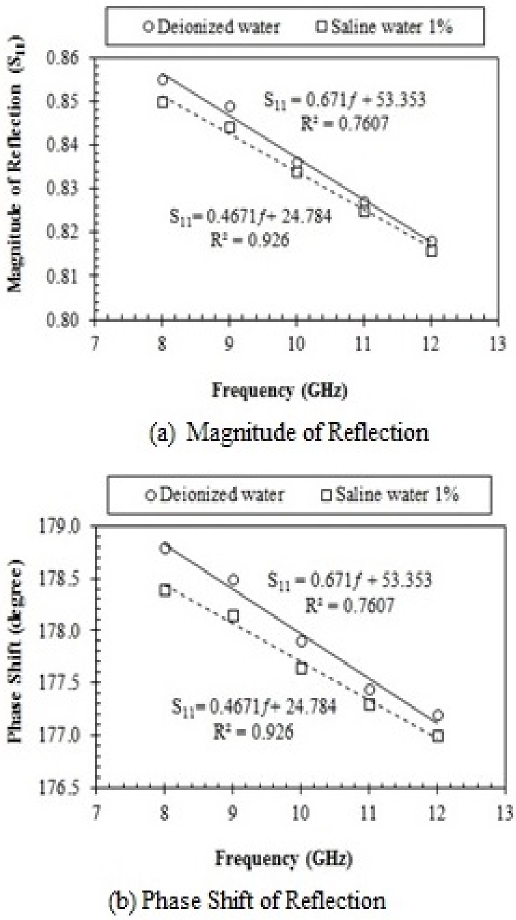


Fig. 2: Microwave reflection properties versus operating frequency.

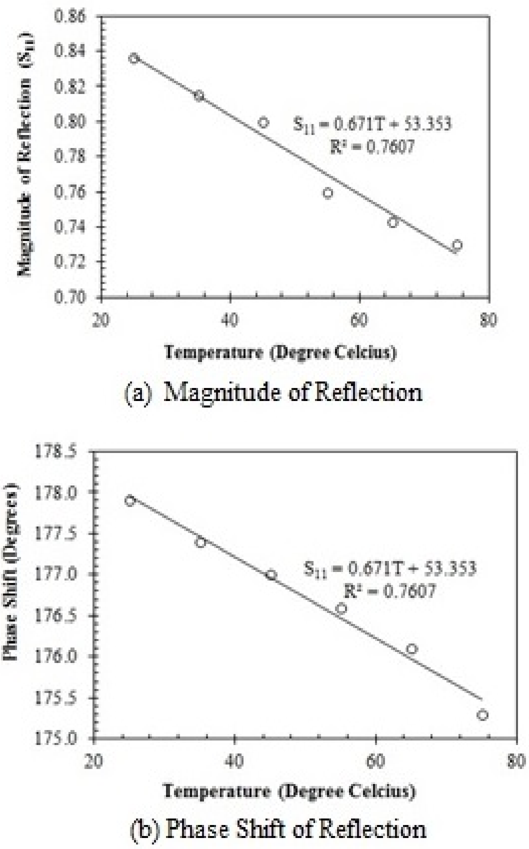


Fig. 4: Water temperature versus microwave reflection properties.

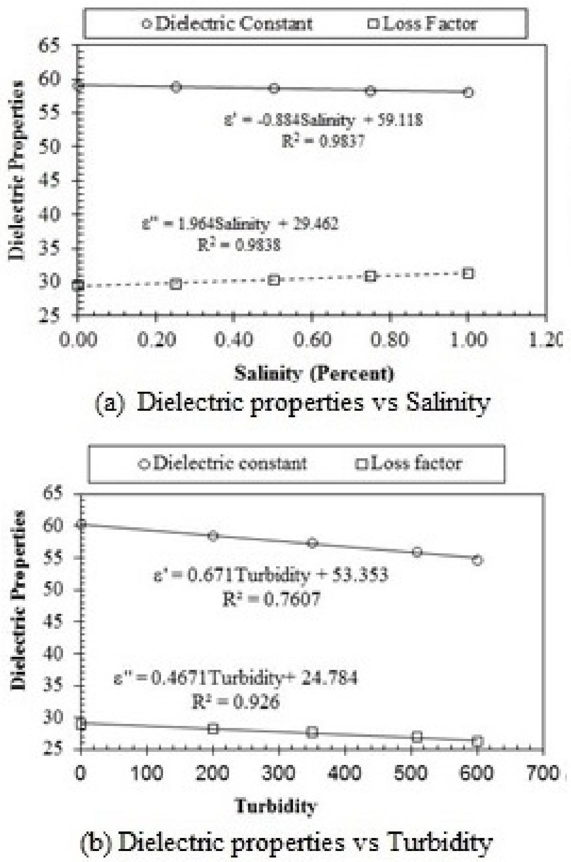


Fig. 5: Dielectric properties of water versus salinity and turbidity of water samples.

6. Conclusion

A prototype instrument of microwave reflection probe is being developed to measure the electromagnetic properties of water for quality control application. Microwave reflection coefficients such as magnitude and phase shift decrease with increasing frequency this may attribute to the reduction of current conductivity at high frequency. Dielectric constants of water decrease with increasing salt content (salinity) while loss factors of water increase with increasing salinity. Microwave reflection properties of water decrease with increasing the temperature of water. Microwave system can be used to determine the turbidity of the water. Further investigations to include other water quality parameters such as pH, BOD, and COD is needed before putting this microwave method to practical use.

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