Determination of leachate pollution content in soil using in-situ dielectric measurement

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Abstract

This paper presents the development of an electromagnetic probe to accurately measure the soil electromagnetic properties such as dielectric constant and loss factor in the field. The in-site dielectric probe sensor is designed and methods have been developed to calibrate and validate the accuracy of the sensor in measuring dielectric properties of the material. Clean saturated sandy soil material with porosity 40% was used. The soil samples were contaminated by leachate from municipality solid waste from the landfill site. Five levels of leachate contamination were prepared, ranging from 0% to 10%. Dielectric properties of soil polluted sample were measured using the proposed in-site dielectric sensor. Dielectric properties of contaminated soil were evaluated at a different frequency and leachate content. The result showed that both dielectric constant and loss factor decree with increasing frequency due to the reduction of conductance current at high frequency. Also, the result showed that the dielectric properties of leachate-contaminated soil decrease with increasing leachate content while the loss factor increase with increasing leachate content. Mathematical models were developed to determine the relationship between soil dielectric constant, loss factor and soil leachate pollution content. Copyright © 2019 VBRI Press.

Keywords: Dielectric sensor, soil material, leachate, soil pollution, dielectric properties.

Introduction

Disposal of municipal solid waste MSW is a serious problem in developing countries [**1**]. The cheapest method of MSW throwing away is landfilling [**2**]. Landfill sites are manmade hydrogeological systems; last time the landfill was just a hole in the ground with no control, nowadays sanitary landfill is carefully controlled; in most countries, both the type of material and the operation of the landfill are more cautiously regulated.

Landfill area produces a very high contaminated wastewater known as leachate. The leachate contains very high dissolved and suspended solids, organic and inorganic matters and also heavy metals. Leachate has such characteristic due to the physical, hydrolytic and fermentation process in the landfill. Furthermore, the percolation of liquid through the landfill causes the physical and chemical reactions to occur thus, form leachate that has a complex character.

Hazardous wastes are moreover sent to more protected "permanent" dangerous rubbish dumping sites or are disposed of in little quantities; a procedure is identified as dilution or co-disposal. The method used to dispose of rubbish has also changed; modern landfill mostly has a layer of compacted fine-grained soil (as a material with low permeability), is frequently used in the final cover and bottom lines system in landfills. The fine-grained soil liners are often used in landfills to contain and attenuate the leachate from solid waste materials. Map and monitor the water leaching from the landfill sites is the most concern in the environmental assessment. Groundwater and surface water can penetrate the landfill, and melt or leak movable component from the waste. Therefore, groundwater polluted by landfill leachate became a major environmental problem [**3-5**]. Depending on the type and the level of the chemicals elements of waste, the leachate can be a dangerous material affecting human health [**6-10**].

Several geophysical techniques have been developed which utilizes the difference caused by the contaminants on the soil physical properties [**11, 12**]. Electromagnetic and dielectric methods show high potential for characterization contaminated soil and determination of the level of contaminant. Recently, intensive research conducted to determine soil contamination utilizing dielectric properties of polluted soil [**13-15**]. However, the dielectric behavior of contaminated soil has not yet been fully established.

Several researchers evaluate the dielectric dispersion characteristics of sand contaminated by heavy metal, [**16**] diesel, and petroleum hydrocarbon [**17**]. This paper will investigate the use of dielectric properties of soil material to determine soil leachate contamination. This investigation will use the lab and in-situ dielectric sensor developed for this purpose.

Leachate from industrial and municipal solid waste could contaminate soil material in a sanitary landfill. During raining season the infiltration of water through polluted soil with leachate leads to contaminate groundwater and affect the health of people using groundwater as the main source of drinking water. The acceptable standard method of determination of soil pollution with leachate is taking soil samples and conducted chemical analysis to determine the level and contamination elements in soil. This procedure is costly, time-consuming. In addition, this standard method is limited to sample size and space and could not be used continuously. Therefore, Dielectric method proposed in this study could provide an online monitoring system and could be an early warning system. In addition, this method is unique in saving cost, time and intensive testing [**16-20**].

Dielectric theory

Soil as a dielectric material can be characterized by its complex permittivity. Complex permittivity of soil material is a complex parameter represents the interaction between electromagnetic signal and soil. It also controls the propagation of the signal in the soil. Complex permittivity of soil is composed of real and imaginary parts. The real part results from the polarization of material, while the imaginary part is due to ohmic and polarization losses. The Complex permittivity of soil material can be given by:

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

where, ε* is the complex permittivity. ε' is the real part (dielectric constant) and it represents the amount of energy stored in soil from the applied electric field. ε" is the imaginary part (loss factor) and it represents the energy loss as conductive current. By dividing equation 1 by the permittivity of a vacuum (ε_o), the complex permittivity of soil become unitless representing the dielectric constant and loss factor of soil with respect to air.

Dielectric sensor

Two dielectric sensors were used in this paper. The first sensor is called a lab dielectric sensor. The second dielectric sensor is developed for in-situ measurement of soil dielectric properties for pollution application. Lab dielectric sensor was used to determine the leachate pollution content in sandy soil material. Lab dielectric sensor is shown in **Fig. 1**. The detail explanation of the sensor was explained in previous work [**17**].

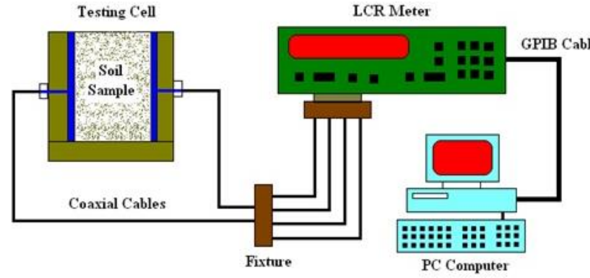

Fig. 1. Schematic diagram of the dielectric measurement system for lab testing.

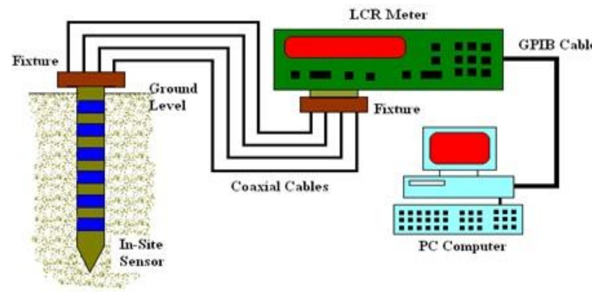

Fig. 2. Schematic diagram of the dielectric measurement system for in-situ testing.

The successful use of lab dielectric sensor for characterization leachate contaminated soil leads to develop a new dielectric sensor which can be used for in-situ testing. The schematic diagram of the in-situ dielectric sensor is given in **Fig. 2**.

Both dielectric sensors used LCR meter as a source of the electromagnetic signal and measure the impedance (Z) of the soil or the admittance of the soil (Y=1/Z). LCR meter connected through coaxial cable and fixture to two electrodes to excite soil in contact with the electrodes by an electromagnetic signal. The measured impedance or admittance of the soil will be used to calculate the dielectric properties of soil [**17**].

(a)

(b)

Fig. 3. Dielectric sensors for soil pollution application, (a) Lab dielectric sensor, (b) In-situ dielectric sensor.

Experimental methods

Leachate samples were collected from Sanitary Landfill. Six main parameters were chosen to determine the characteristic of the raw leachate which is chemical oxygen demand (COD) the micro digestion method is used, biological oxygen demand (BOD the dilution method is used, which is the standard method of the American Public Health Association (APHA) and is approved by the U.S. Environmental Protection Agency (USEPA), suspended solids (SS), dissolved oxygen (DO), Temperature and pH. These parameters were analyzed using DR 2010 HACH spectrophotometer in accordance with the Standard Methods for the Examination of Water and Wastewater. Leachate characteristics are given in **Table 1**.

Table 1. Characterization of landfill leachate.

Leachate Parameter	Value
COD(mg/L)	2433
BOD5(mg/L)	2377
SS (mg/L)	229
DO(mg/L)	1.05
Temperature	34
pH	8.02

Five saturated soil samples were prepared at different leachate percent by volume ranging from 0% to 10% with increment 2.5%. Soil sample properties were determined before contaminated. The soil porosity was 40%. The soil was classified using a unified soil classification system (USCS). According to USCS, the soil was well-graded sand (SW). The soil samples were dried in the oven at 105°C for five hours then saturated with the required tap water and leachate content. Dielectric properties of leachate-contaminated soil were measured using the lab and in-site dielectric sensor at a frequency ranging from 1 kHz to 1 MHz. Phases of soil polluted samples are given in **Table 2**.

Table 2. Phases of soil polluted samples.

Soil sample	Phase percent by volume (%)			
	Soil	Water	Leachate	Air
SL0.0%	0.600	0.400	0.000	0.00
SL2.5%	0.600	0.375	0.025	0.00
SL5.0%	0.600	0.350	0.050	0.00
SL7.5%	0.600	0.325	0.075	0.00
SL10.5%	0.600	0.300	0.100	0.00

Results and discussion

Dielectric constant and loss factor of soil polluted samples versus operating frequency is presented in **Fig. 4**. Both dielectric constant and loss factor of soil contaminated with leachate decrease with increasing frequency. This may attribute to the reduction of current conductance at high frequency.

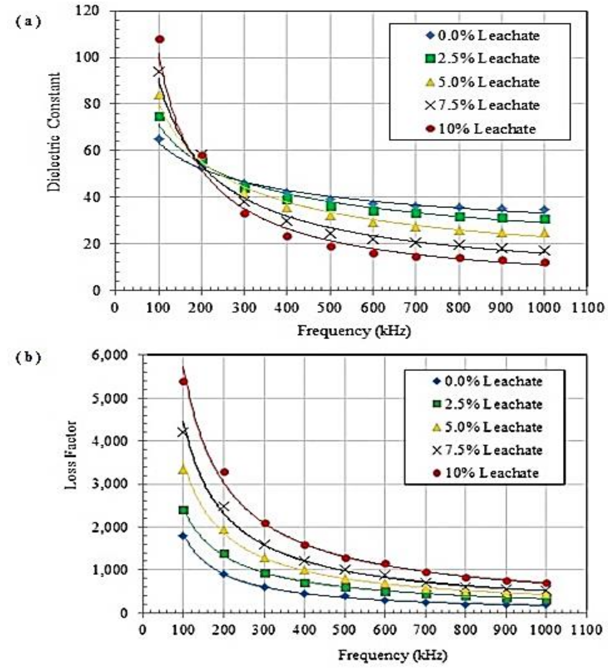

Fig. 4. Dielectric properties of leachate-contaminated soil versus frequency, (a) Dielectric constant, (b) Loss factor.

The results indicate that the dielectric constant at a frequency less than 200 kHz is increased with leachate content and the opposite trend occurred over 200 kHz, while the loss factor is increased with increasing leachate content overall frequency. This may attribute to the electrode polarization at low frequency which reduces the polarization of soil material due. These phenomena will end at a frequency more than 200 kHz.

Dielectric constant and loss factor of soil polluted samples versus leachate content at frequency 500 kHz and 700 kHz is presented in **Fig. 5**. Dielectric constant

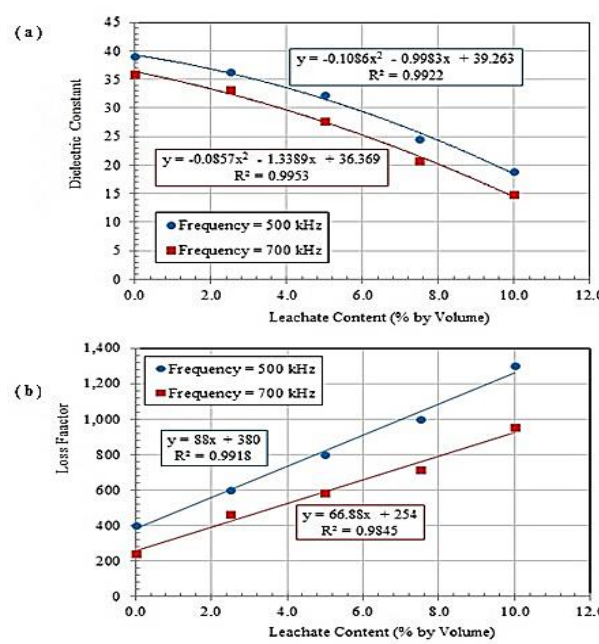

Fig. 5. Dielectric properties of leachate-contaminated soil versus leachate content at 500 and 700 kHz, (a) Dielectric constant, (b) Loss factor.

decrease with leachate content in soil while loss factor increases with increasing leachate level. This increasing can interpret because of the increasing the ion polarization which comes from leachate composition where it contains various ionic suspended solids which have high conductivity. The results indicate that the relationship between the dielectric constant of saturated sandy soil and the leachate content can be presented by the quadratic equation while the loss factor can be presented by a linear equation as shown in **Fig. 5**. The good fit regression model was indicated by the high square correlation coefficient greater than 98%. These model could be used to estimate leachate content in the soil.

Conclusion

Two dielectric sensors have been developed for soil pollution application. One sensor for lab testing and another design for in-situ testing. Both sensors were calibrated using open/short calibration standard and known material. Validation of the sensors was conducted by measuring material with known dielectric properties. The error of the sensors in measuring dielectric properties of the material such as soil was less than 1%. The result of dielectric properties of leachate-contaminated soil shows that both the dielectric constant and loss factor of contaminated soil decrease with increasing frequency this is due to the reduction of current conductance of material at high frequency. The dielectric constant decrease with leachate content while the loss factor increase with increasing leachate content in the soil. These results indicate that dielectric properties of soil could be used to quantify leachate level in the soil. Regression models were developed to relate soil leachate content to soil dielectric contamination. The proposed method could save time and cost. In addition, this method could be used as an early warning system for soil pollution.

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Author's contributions

All authors contribute in all work to produce this paper including, conceived the plan, performed the experiments, data analysis, and wrote the paper. Authors have no competing financial interests.

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