Hindawi Publishing Corporation
International Journal of Microwave Science and Technology
Volume 2013, Article ID 950862, 9 pages
http://dx.doi.org/10.1155/2013/950862

Research Article

Permittivity and Backscattering Coefficient of Diesel Oil-Contaminated Soil at C Band (5.3 GHz)

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Received 26 May 2012; Revised 16 October 2012; Accepted 18 December 2012

Academic Editor: Wenlong He

Studying the behavior of soil contaminated by diesel requires the measurement and calculation of electrical parameters such as permittivity and backscattering coefficient. It is also necessary to study the physical parameters such as surface roughness. The intent of this paper is to present a broad and updated overview of the diesel oil contaminated soil, emphasizing permittivity and scattering coefficient that are involved in determining and detecting the rate at which and extent to which hydrocarbons contaminate the soil and environment. The measurement of permittivity and the calculations of backscattering coefficient values were made with different amounts of diesel oil contamination and different incident angles in 5° intervals ranging from 10° to 80° for both horizontal and vertical polarization at C band. The values of scattering coefficient for different look angles (25°, 30°, 35°, 40°, 45°, 50°, and 55°) were calculated and are suitable for comparison with data generated from other remote sensing platforms. Accurate electrical parameter measurements of soil contamination and recognition of their dependence on physical and chemical composition are interesting and can support using microwave remote sensing instruments to observe the earth.

1. Introduction

Improved understanding of spatial variation of soil surface characteristics such as soil contamination, texture, and constituents is critical in remote sensing. Microwave remote sensing data are function not only of the technical parameters of the sensor but also of the geometric forms and electrical properties of the objects on the earth such as permittivity, and backscattering coefficient [1]. The radar backscattering coefficient (σ°) from soil surface depends primarily on the surface roughness and the permittivity of the soil. It also represents the scattering behavior of an object at a given frequency, incident angle, and polarization and it is defined directly in terms of the incident and scattered fields [2].

Microwave techniques can be implemented to determine the extent and the distribution structure of an oil spill on land. Diesel spills in soil cause pollution that can be toxic for biological particles living in the soil [3]. Soil contamination is caused by the presence of man-made chemicals or other alteration in the natural soil environment. The average total worldwide annual release of petroleum (oils) from all known sources to the environment (land and ocean) has been estimated at 1.3 million tons [4]. Land-based sources contamination typically arises from the rupture of underground storage tanks, application of pesticides, percolation of contaminated surface water to subsurface strata, oil and fuel dumping, and leaching of wastes from landfills or direct discharge of industrial wastes to the soil. Pollution of the soil with petroleum and refinery products is one of the factors expressing anthropopression. This type of pollution is a serious problem due to its toxicity, widespread presence, and complex nature. Contamination of soils with crude oil and refinery products is becoming an ever increasing problem.

Petrol stations, garages that service cars and tractors, and seaport are the major locations where soil is polluted by refinery products [5]. Other areas of concern are mining and distribution of petroleum-based products [6–8]. Heavy use of machinery in agriculture leads to high consumption of diesel oil. Negligence while transporting, collecting, or storing refinery products together with unsatisfactory care while the disposing of old or used petroleum products lead to considerable pollution of the natural environment [9]. Spillage of used motor oils such as diesels or jet fuels contaminates our natural environment with hydrocarbons [10]. Soil contamination with diesel and engine oils is becoming a major environmental problem as the usage of petroleum hydrocarbon products increases [11].

The dielectric property of soils which (namely, the permittivity) controls the penetration depth of microwaves has been well established in the literature [12–14]. We define penetration depth as the distance in the medium over which the intensity of propagating radiation decreases (owing to attenuation) by a linear pattern because of the small contrast between the permittivity of dry soil and diesel oil, and, because the amount of diesel oil in the soil is variable, soil contamination by diesel does not largely control the permittivity of the soil and thus penetration depth as well.

The majority of studies on this subject has been concerned with crude oil contamination in the marine environment which reflects the importance of studying oil contamination on terrestrial ecosystems by using remote sensing techniques. Previously, multispectral satellite imagery was used to map contamination by locating the reflectivity and absorption spectra of diesel-oil contaminated soil and plotting the corresponding spatial distributions [15, 16]. Nonetheless, some attempts at mapping hydrocarbons using Landsat and Daedalus in mid-1990s failed, probably due to the limited spectral resolution of the multispectral sensors [17]. Moreover, the spectral properties of hydrocarbons were identified at the late 1980s [18]. Several studies were conducted during the past few years in the field of petroleum hydrocarbons and reflectance spectroscopy [19–21], that showed the potential of reflectance spectroscopy as a tool for predicting total petroleum hydrocarbons content [17]. In 1990s, the US Department of Energy contracted a private company to investigate the application of reflectance spectroscopy to determine motor oil contamination in sandy loam. A schematic design for a field instrument was suggested, although only one contaminant and one type of soil were tested, using very few samples with a very limited range of contamination [22]. More comprehensive studies were conducted in the last decades, using different types of soil contaminated in the laboratory with several types of hydrocarbons [23, 24]. A recent study by Chakraborty et al. [25] on the prediction accuracy of VNIR-SWIR reflectance spectroscopy of petroleum products contaminated soil and showed fair validation results ($R^2 = 0.64$) [17].

The results of the aforementioned studies also support the use of hyperspectral remote sensing for the direct detection of spills of diesel in different types of soil. Hyperspectral airborne remote sensing was also applied to identifying hydrocarbon contamination. The higher spatial and spectral resolution as well as the very high signal-to-noise ratio of the airborne hyperspectral sensor used (HyMap) [26] yielded successful identification of hydrocarbon- and oil-contaminated soils, but only for high contaminant concentrations [19]. Nevertheless, according to the literature review, there is shallow radius of investigation in the field of microwave remote sensing using different types of sensors (i.e., radars, radiometers, and scatterometers) for detecting and identifying the extent and the amount of diesel contamination in soil.

The present study was undertaken to determine the effect of contamination of soil with diesel oil on the permittivity and scattering coefficient of soil. In this study, laboratory experiments were conducted with the aim of studying the electrical parameters of soil composting with 1% to 22% concentrations of diesel oil (mass percentages) to evaluate the response of the method in monitoring the electrical parameters of the compound. An attempt was made to provide an overview of the microwave remote sensing measurement techniques used to measure the permittivity of diesel-oil contaminated soil using waveguide cell with shift in minima method and to estimate the backscattering coefficient of soil contaminated by diesel in C band (5.3 GHz). The rationale behind this band selection was that the oil spill pollution can be detected using microwave sensors, and one of the useful frequencies is the C band [27]. Many sensors of different satellites such as ERS-1, ERS-2, RADARSAT 1 and 2, and ASCAT operate in the C band. Microwave remote sensing instruments equipped with C band are generally not hindered by atmospheric effects and are capable of "seeing" through clouds. These sensors have the capability of monitoring 24 hours a day, in all weather conditions, at a fairly high spatial resolution (few meters).

The backscattering coefficient is calculated using the measured value of the permittivity for different amounts of diesel contaminations. Using slightly rough surfaces and small perturbation model, the backscattering coefficient was measured for different amounts of diesel contamination and variable angles of incident from 10° to 80°. The database for the scattering coefficient was generated for different angles of incident and for both polarizations. The backscattering coefficients at different incident angles (25°, 30°, 35°, 40°, 45°, 50°, and 55°) were calculated and are useful for comparison with the data of airborne and space borne remote sensing sensors. Therefore, in view of the current and future airborne/spaceborne remote sensing platforms that are being developed to obtain data needed to understand the soil surface characteristics, this study supports the use of low-frequency (C-band), bipolarized, and multiple-angle active microwave observations.

2. Methodology

2.1. Soil Samples, Sample Holder, and Preparation of Soil Samples. The study was conducted in the laboratory. Because of the labor-intensive nature of enumerations and activity measurements, this study was confined to a single fuel (diesel oil), soil type (loamy sand soil), and incubation temperature ($25 \pm 2^{\circ}$C). This type of soil is chosen because it is a desert soil having large percentage of sand. Sandy soil lacks water holding capacity as in the case of Rajasthan, India. Dry soil particles, usually found at the surface in arid regions, might adsorb fuel hydrocarbons to their surfaces, thus being coated or "impregnated" against soil moisture [24]. Laboratory studies were done using soil samples obtained at depths of 0 to 10 cm. To avoid stones and other rough material causing problems during the mixing process, the soils were sieved with a screen shaker and the sample material was placed in an oven. The oven temperature was maintained at 120°C. After drying the soil at 120°C for 10 hours, the soil was cooled in a desiccator and reweighed and the dry weight was calculated. Soil moisture was measured by drying at 120°C to a constant weight. All results throughout the paper were calculated per dry weight. The different percentages of diesel oil were mixed with the soil samples. Different amounts of diesel fuel were introduced into the soil at concentrations of 1% to 22% and the weight percentage of the compound was measured each time. The experiment was done at room temperature ($25 \pm 2^{\circ}$C).

The specific properties of the soil samples were the moisture content in percent, $W = 4.4$, and the specific gravity of soil grains, $G_S = 2.6$. The sample was a loamy-sand soil with an average texture of 83.30% fine sand, 3.40% coarse sand, 3.33% silt, and 9.85% clay with a wilting coefficient of 0.06. The density of diesel is about 780 to 1074 kg m^{-3} with a specific gravity of 94 to 129 kg m^{-3} at 25°C. Once you mixed the diesel with soil, the diesel occupies the pores by replacing air. Also when pores are filled, a thin layer is formed on the surface and it does not settle below the soil and a sort of contaminated soil with diesel will be created, where the molecules of diesel get bound on soil particles and some molecules of diesel remains free and so there is both bound diesel and free diesel. In this case, only the free diesel affects the dielectric constant of the mixture of diesel and soil. Because of free and bound molecules of diesel the final dielectric constant will be lower than the lowest because this combined results will be always less than the lowest.

2.2. Permittivity. The permittivity is one of the most important parameters for studying the behavior of materials in microwave remote sensing. The fundamental electrical properties through which the interactions between the electromagnetic wave and the material are described mathematically

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

where the real part, ($\varepsilon^{'}$), or the strong factor, characterizes the ability of a material to store the electric-field energy. The imaginary part, ($\varepsilon^{''}$), the dielectric loss factor, reflects the ability of a material to dissipate electric energy in the form of heat.

There are several methods for measuring permittivity. Permittivity is one of the most important factors for evaluating the physical and chemical properties of the materials. Measurement of permittivity can be done in the laboratory as well as in the field using four methods, namely, the following:

(1) transmission line method, (2) resonant cavity method, (3) free space method, and (4) waveguide cell method. The measurement techniques appropriate for any particular application depend upon the dielectric properties of the materials to be measured, the physical state of the materials (solid, semisolid, or liquid), the frequency range, and the degree of accuracy required [24].

In this paper, waveguide cell device is used to measure the permittivity of diesel oil using shift in minima method. Narrowband waveguide cells require careful sample preparation but they provide accurate permittivity measurements for solids, particulates, and liquids. The formula used for calculation of permittivity can be described as follows.

The characteristic impedance Z_0 of a transmission system may be defined as an impedance to have the same value at the other extremity. In free air and for a uniform plane wave this characteristic impedance is

$$Z_{0a} = \sqrt{\frac{\mu_0}{\varepsilon_0}}, \qquad \lambda_a f = c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}, \tag{2}$$

where λ_a is the wavelength in free air. In free space filled with a dielectric material with dielectric constant ε_r

$$Z_{0\varepsilon} = \sqrt{\frac{\mu_0}{\varepsilon_{0\varepsilon_r}}} = \frac{Z_{0a}}{\sqrt{\varepsilon_r}}, \qquad \lambda_\varepsilon f = \frac{c}{\sqrt{\varepsilon_r}}, \qquad \frac{\lambda_a}{\lambda_\varepsilon} = \sqrt{\varepsilon_r}, \tag{3}$$

where λ_ε is the wavelength in the dielectric material. From the above equations

$$\frac{Z_{0ga}}{Z_{0g\varepsilon}} = \frac{\lambda_{ga}}{\lambda_{g\varepsilon}}. \tag{4}$$

Z_{0ga} and $Z_{0g\varepsilon}$ are the characteristic impedances of the wave guide filled with air and the dielectric material, respectively. λ_{ga} And $\lambda_{g\varepsilon}$ are the wavelengths in the waveguide filled with air and the lossless dielectric material, respectively. Considering a short circuited waveguide which contains a square cut sample of dielectric material with a physical length L that touches the short circuit plane, one can derive the impedance Z for the region of the dielectric nearest to the generator:

$$Z = Z_{0g\varepsilon} \tan \frac{2\pi l}{\lambda_{g\varepsilon}}. \tag{5}$$

When the piece of dielectric material is removed, the same impedance Z is measured at a position $d + L$, where d is the displacement of the minimum of the standing wave pattern which is caused by the change in the wavelength. Thereby one may write

$$\frac{\tan\left(2\pi\left(d+L\right)/\lambda_{ga}\right)}{2\pi L/\lambda_{ga}}=\frac{\tan\left(2\pi L/\lambda_{g\varepsilon}\right)}{2\pi L/\lambda_{g\varepsilon}}, \quad (6)$$

where L is thickness of the sample; d is shift in minima; λ_{ga} is guide wavelength in the air-filled wave guide; $\lambda_{g\varepsilon}$ is guide wavelength in dielectric-filled wave guide. In a rectangular waveguide system, the propagation constant is given by

$$\gamma^2=\left(\frac{m\pi}{b}\right)^2+\left(\frac{n\pi}{a}\right)^2-\omega^2\varepsilon\mu, \quad (7)$$

where $\gamma = \alpha + j\beta$ in which α is the attenuation constant assuming a lossless material ($\alpha = 0$) and with $m = 0$, $\mu = \mu_0$ and $n = 1$ formula (7) will transform into:

$$\varepsilon_r=\left(\frac{\lambda_a}{2a}\right)^2+\left(\frac{\lambda_a}{\lambda_{g\varepsilon}}\right)^2, \quad (8)$$

where a is width of the waveguide; λ_a is wavelength in free space. From (6) the value of $\lambda_{g\varepsilon}$ can be extracted; substituting in formula (8), the permittivity can be calculated.

Excessive work was done to measure the dielectric permittivity of soil contamination by diesel. Dielectric permittivity can change with frequency, temperature, orientation, mixture, pressure, and molecular structure of the material. The electrical parameters such as scattering coefficient depend upon the permittivity of the material. At radio frequencies the value of the permittivity of a natural material is related to its physical parameter.

The source of errors in the waveguide with shift in minima method can be defined as follows. (1) A number of minima positions are sometimes obtained and then it is a matter of choice to select the correct minima. (2) Error is also introduced in the slotted line section due to backlash error and improper insertion of the probe, which can be reduced by careful handling. (3) Error is introduced if there is nonconsistency in the dimensions of the waveguide used in the test bench setup and the waveguide cell carrying the sample. (4) The weight of the dielectric sample is a very important parameter and inaccuracy in its measurement may lead to considerable errors. So the waveguide with shift in minima method errors is approximately ±4% as investigated in [2].

2.3. Experimental Setup. In the waveguide method, the permittivity is measured by calculating the shift in minima of the standing wave pattern inside a rectangular waveguide. This shift occurs due to the change in the guide wavelength when a dielectric material is introduced into the waveguide. Figure 1 depicts a block diagram of the experimental setup. In this setup, Gunn power supply comprises of an electronically regulated power supply and a square wave generator designed to operate the Gunn Oscillator and Pin Modulator. An isolator is a two-port device that transmits microwave or radio frequency power in one direction only. It is used to shield equipment on its input side, from the effects of conditions on its output side; for example, to prevent a microwave source being detuned by a mismatched load. The oscillator uses a cavity; the size of this cavity determines the time/phase delay which sets the resonant frequency. In this case, each diode induced fluctuation travels up the cavity and reflected from the far end, returning to the diode after a time. The power of the microwave signal generated by the Gunn Oscillator can be varied by varying the voltage applied to this oscillator by the Gunn Power Supply. In the microwave terminology, any dissipative element inserted in energy field is called an attenuator. It consists of a resistive or "lossy" surface, sometimes referred to as a "card" placed in the center of a waveguide through a slot. On increasing the penetration of the card, it absorbs more energy and the attenuation, therefore, increases. As the card is moved upwards the attenuation decreases toward the minimum. The adjustment is done with a micrometer whose position is related to the attenuation. The entire assembly is called a calibrated variable attenuator. The microwave frequency meter is used for measuring frequency without resorting to the slotted line quickly and easily. Directional couplers are used for sampling a part of microwave energy for monitoring purposes. A microwave power meter is an instrument which measures the electrical power at microwave frequencies. Usually a microwave power meter will consist of a measuring head which contains the actual power sensing element, connected via a cable to the meter properly, which displays the power reading. The head may be referred to as a power sensor or mount. Different mounts can be used for different frequencies or power levels. The slotted section is primarily a section of waveguide having dimensions suitable for the frequency range in use. "VSWR" stands for "voltage standing wave ratio". It is an RF (radio frequency) signal source. VSWR meter is used for measuring voltage standing wave ratio, attenuation, and total mismatch on the line.

A brief description of the procedure can be explained as follows. Build up the measuring setup shown in Figure 1. Turn on the gun power supply. Adjust the gun power supply in order to get maximum output power. To do this set the probe of the voltage standing wave meter in a maximum position. Find at least three successive minima x_a, x_a', x_a'', by using the calibrated attenuator at minimum attenuation. Introduce the dielectric sample and determine again, at least three successive minima x_ε, x_ε', x_ε''. For calculating the displacement, either the average of the shifts or the shift value which occur maximum number of times can be taken. Calculate the first term of (6); when (d) is positive the minima is shifted towards the load, so (d) determines the sign for tan x/x. Look up in the tan x/x table and the various values which $2\pi(d + l)/\lambda_{g\varepsilon}$ can have and thus find values of $\lambda_{g\varepsilon}$ and ε_r in accordance with (8). To find the correct value of ε_r the measurement should be repeated with a sample of a different length and the common value of the two series should be taken. When the order of magnitude of the dielectric permittivity is known, the measurement with a different length is not necessary.

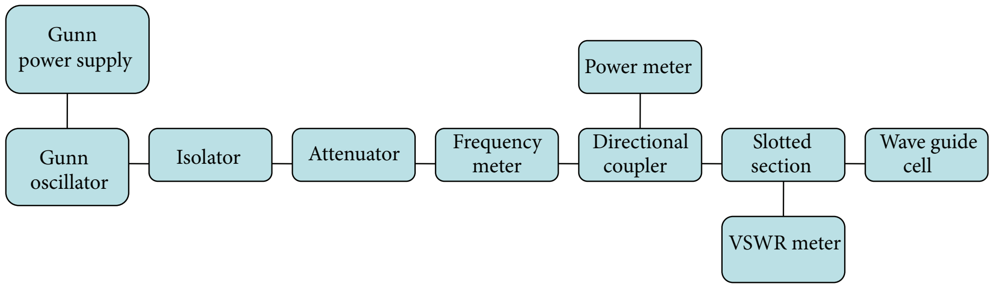

Figure 1: Block diagram of experimental setup.

3. Scattering Coefficient

When an electromagnetic wave is incident on the boundary surface between two semifinite media, a portion of the incident energy is scattered backwards, with the remainder transmitted into the second medium. In special cases where the lower medium is homogenous, the phenomenon of scattering is called surface scattering. If the lower medium is inhomogeneous, scattering takes place from within the volume of the lower medium, which is called volume scattering. The surface pattern plays an important role in estimating the scattering coefficient. A surface may appear very rough for an optical wave, but the same surface may appear very smooth to a microwave signal. The two important parameters used to characterize surface roughness are the standard deviation of the surface height variation (σ, r.m.s. height) and the surface correlation length (l) in terms of wavelength. As the surface correlation length increases, the surface becomes smoother and the radiation pattern becomes more directional.

Ulaby et al. [28] suggested that depending on the surface pattern, three different models are used to estimate the scattering coefficient: the perturbation model, the physical optics model, and the geometric optics model. Using a model to estimate the scattering coefficient depends on surface roughness. The scattering coefficient of the materials can be obtained in two ways: directly, by measuring the scattering coefficient of the material using a scatterometer or radar or by measuring the dielectric permittivity and using available models. The perturbation, physical optics, and geometric optics models are used for slightly rough, medium rough, and undulating surfaces, respectively. It is also necessary to note that, on a homogeneous soil with perfectly smooth surface, scattering of electromagnetic waves is totally forward and depends on permittivity of the medium. Selecting a computation model for a particular surface will depend on the validity of that model for the surface under investigation.

The perturbation model is appropriate for slightly rough surfaces where both the surface standard deviation and correlation length are smaller than the wavelength. The standard deviation should be at least 5% less than that of the electromagnetic wavelength, and the slope of the surface should be of the same order of magnitude as the wave number times the surface standard deviation. This relationship is represented mathematically as follows:

$$K\sigma < 0.3, \qquad M < 0.3, \tag{9}$$

where $K = 2\pi/\lambda$, $M = (2)^{1/2}\sigma/l$ is surface slop (r.m.s), σ = r.m.s. surface height, and l is correlation length. Thereby for estimation of backscattering coefficient the validation condition can be considered:

$$K\sigma = 0.25, \qquad M = 0.25. \tag{10}$$

The backscattering coefficient is given by

$$\sigma^0_{ppn}(\theta) = 8k^4\sigma^2\cos^4\theta\left|\alpha_{pp}\theta\right|^2 W(2k\sin\theta), \tag{11}$$

where p is polarization, v is vertical polarization, h is horizontal polarization, and $|\alpha_{nn}(\theta)|^2 = \Gamma_n(\theta)$ is the Fresnel reflection coefficient. The value for the Fresnel reflection coefficient under horizontal polarization is obtained by

$$\alpha_{hh}(\theta) = \frac{\cos\theta - \left(\varepsilon_s - \sin^2\theta\right)^{1/2}}{\cos\theta + \left(\varepsilon_s - \sin^2\theta\right)^{1/2}}. \tag{12}$$

For vertical polarization, the Fresnel coefficient σ_{vv} is obtained by

$$\alpha_{vv}(\theta) = \left(\varepsilon_s - 1\right)\frac{\sin^2\theta - \varepsilon_s\left(1 + 2\sin^2\theta\right)}{\left[\varepsilon_s\cos\theta + \left(\varepsilon_s - \sin^2\theta\right)^{1/2}\right]^2}, \tag{13}$$

where ε_s is the dielectric permittivity of the emitter and θ is the angle of incidence. $W(2k\sin\theta)$ is the normalized roughness spectrum which is the Bessel transform of the correlation function $\rho(\xi)$, evaluated at the surface wave number of $2K\sin\theta$. For the Gaussian correlation function $\rho(\xi) = \operatorname{expo}(-\xi^2/l^2)$, the normalized roughness is given by

$$W(2k\sin\theta) = \frac{1}{2}l^2\operatorname{expo}\left[-(kl\sin\theta)^2\right]. \tag{14}$$

Estimation of the scattering coefficient of diesel oil-contaminated soil for a slightly rough surface was done in the C band (5.3 GHz) for different look angles in 5-degree intervals ranging from 10 to 80 degrees and for two polarizations. This model is used for the research because in natural conditions the soil surface roughness normally observed fits into the small perturbation model that has been chosen for this paper. Moreover, since this study is relevant to the back scatter σ° and σ° depends upon ε' not ε''. The ε'' which is loss factor has no significance.

4. Results and Discussion

Measurements of diesel oil-contaminated soil were performed on different dried soil samples. We will present some results obtained using the created application. The dielectric permittivity and scattering coefficient of the compound were calculated. The measurements were made in C band (5.3 GHz) for different amounts of diesel oil contamination at different incident angles for the both horizontal and vertical polarizations. The saturation point was observed after the introduction of 22% of diesel oil to soil. At this weight percentage of diesel, the dielectric constant of the compound is close to the dielectric constant of diesel. After this specific percentage of diesel in soil, the amount of change in the dielectric constant of compound is negligible. This may be due to the fact that as diesel oil and other refinery products that penetrate deep into soil, block air spaces that allow air and water to enter soil layers. As a result, the soil becomes more compact, its physical, chemical, and biological properties alter; finally its characteristics become more similar to characteristics of diesel oil and consequently cause the changes in the its dielectric permittivity and backscattering coefficient. Finally based on the physicochemical properties of soils and diesel, the spectral response of soils and diesel as single components, and the distribution pattern and environmental behavior of fuel hydrocarbons (e.g., diesel) as contaminants in soils, it is anticipated that both uncontaminated soil and soil contaminated with diesel that are exposed at the surface are relatively homogeneous media over larger areas.

Figure 2 represents the dielectric permittivity of soil, diesel, and diesel-oil contaminated soil for different weight percentages from 1% to 22%. The errors explained in measurement method (±4%) are introduced in the graph (error bars). The amount of change in dielectric constant for the diesel-oil contaminated soil is around 7.3% for a 1% change in the weight of diesel in soil.

The scattering coefficient was estimated for different look angles varying by 5-degree intervals from 10 to 80 degrees and for both vertical and horizontal polarization. Figure 3 shows the variation of the scattering coefficient of soil with different weight percentages of diesel with respect to look angles ranging from 10 to 80 degrees for a slightly rough surface and for both horizontal and vertical polarization at a fixed frequency 5.3 GHz. From the figure it is observed that the scattering coefficient for slightly rough surface decreases as the look angle increases for horizontal polarization. The difference in scattering coefficient between HH and VV polarization increases as the look angle increases for each of the weight percentages of diesel-oil contaminated soil. The values of the scattering coefficient for VV polarization are higher than the values for HH polarization. The scattering coefficient for vertical polarization is higher than for horizontal polarization. Vertical polarization for both transmission and reception (VV) yields better results for the scattering coefficient than the HH configuration. Moreover, the real part of the dielectric permittivity ranges from 3.88 for dry soil to about 2.35 for diesel oil-contaminated soil. This variation can result in a change on the order of 3.8 dB in the magnitude of the backscattering coefficient for both HH and VV polarization at 10-degree incidence angle, and 0.8/4.3 dB in the magnitude of the backscattering coefficient for HH and VV polarization, respectively, at 80-degree incidence angle.

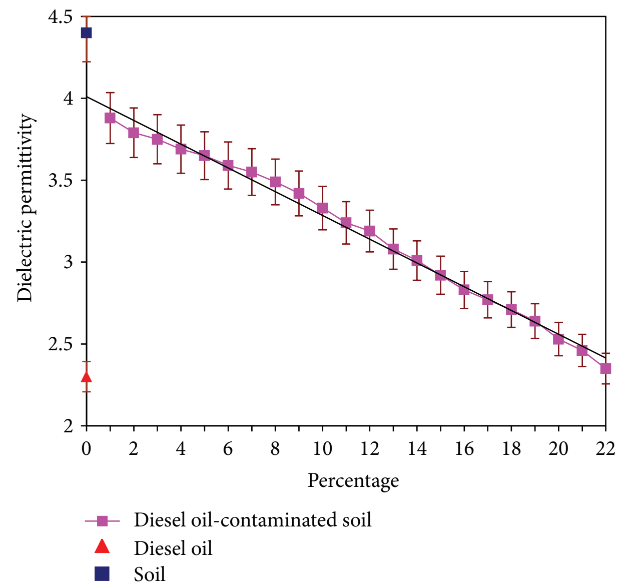

Figure 2: Dielectric constant of diesel oil, soil, and diesel oil-contaminated soil.

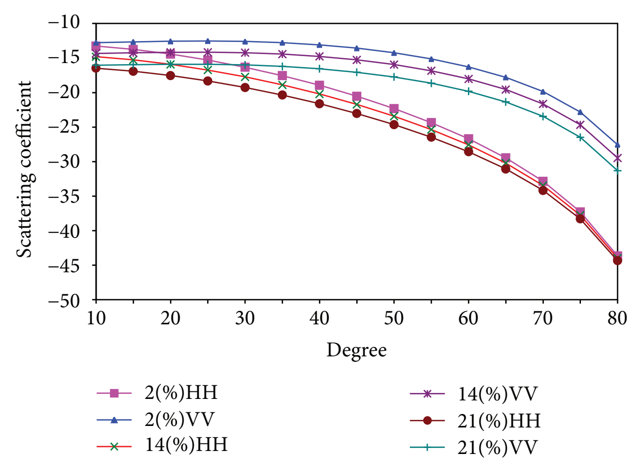

Figure 3: Variation of scattering coefficient with respect to the different look angles for 2%, 14%, and 21% diesel in soil.

Figure 4 represents the scattering coefficient at different special angles that are desirable for remote sensing sensors. The results of the experiment for scattering showed that there is a slight decline in the scattering coefficient as the weight percentage of diesel increases during the process. Figure 4 demonstrates that the scattering coefficient decreases as the combination of soil and diesel increases in both horizontal and vertical polarization. The scattering coefficient values for vertical polarization are more than those for horizontal polarization. The scattering coefficient pattern for these three specific angles followed a typical linear equation.

Table 1: Equations and correlation coefficient of variation of scattering coefficient for different look angles and dielectric constant of diesel oil-contaminated soil from 1% to 22%.

	Equation	Correlation coefficient (R^2)
25 (HH)	$y = -0.1615x - 14.661$	0.9592
25 (VV)	$y = -0.1804x - 11.832$	0.9607
30 (HH)	$y = -0.1563x - 15.72$	0.9588
30 (VV)	$y = -0.1823x - 11.882$	0.961
35 (HH)	$y = -0.15x - 16.961$	0.9584
35 (VV)	$y = -0.184x - 12.055$	0.9615
40 (HH)	$y = -0.1425x - 18.386$	0.958
40 (VV)	$y = -0.1853x - 12.372$	0.962
45 (HH)	$y = -0.1338x - 20.003$	0.9574
45 (VV)	$y = -0.1864x - 12.854$	0.9627
50 (HH)	$y = -0.1238x - 21.831$	0.9569
50 (VV)	$y = -0.1873x - 13.523$	0.9636
55 (HH)	$y = -0.1124x - 23.909$	0.9563
55 (VV)	$y = -0.1882x - 14.409$	0.9646
Dielectric permittivity t of diesel oil contaminated soil	$y = -0.0725x + 4.0825$	0.9928

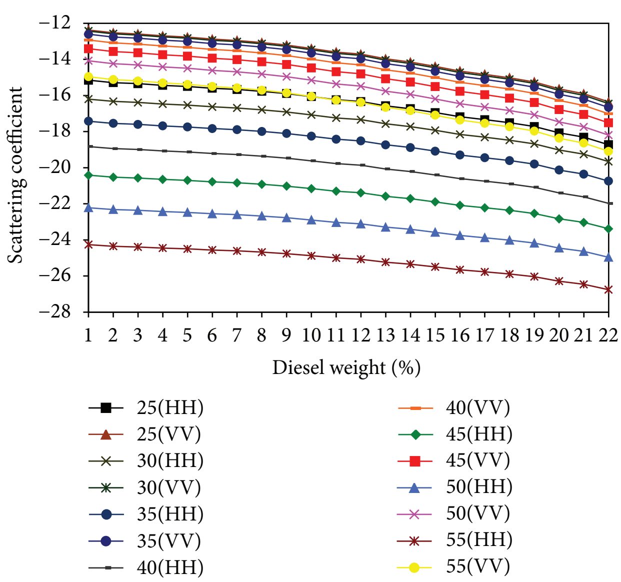

Figure 4: Variation of scattering coefficient in respect to different weight percentages of diesel in soil for different look angles.

Table 1 shows the equations and correlation coefficient of variation of scattering coefficient for different look angles from and the dielectric permittivity of diesel-oil contaminated soil from 1% to 22%. Weight percentage of diesel in soil can be used to measure the dielectric permittivity of diesel-oil contaminated soil in the laboratory or in the field, and vice versa if the dielectric permittivity of diesel-oil contaminated soil is known then it is possible to estimate the weight percentage of diesel in soil. As it is observed from Table 1, for estimating the values of scattering coefficient of diesel-oil contaminated soil, there is no need for calculating the dielectric permittivity and with substituting the weight percentage value of diesel in soil by x in the corresponding equation the values of scattering coefficient are obtainable. On the other hand for known values of scattering coefficient which are derived from the satellite data, the weight percentage of diesel in soil can be calculated easily from the equations. Also it is possible to find the dielectric permittivity, and scattering coefficient values for all the weight percentages which are not mentioned here.

Terrestrial oil spills are characterized primarily by vertical movement of the oil into the soil, rather than by the horizontal spreading associated with slick formation [9]. Further studies are required to elucidate diesel oil-contaminated soil conditions in different microwave bands such as X, S, and L band to illuminate the penetration capabilities of the wave in cases of soil pollution. On the other hand further research is necessary to study the passive microwave remote sensing of diesel oil-contaminated soil in different microwave bands. Due to the health and environmental risks associated with the loss of volatile compounds, composting of hydrocarbons especially gasoline-contaminated soil in vast field experiments is not recommended. Moreover further investigation is necessary to study the effect of refinery products, for example, diesel oil, on different types of soil by remote sensing techniques. Furthermore, additional studies are necessary to identify the functions of the imagery part of the dielectric permittivity and its effects on emission and scattering of the compound. At the end, it is worth noting that for any microwave imaging and nonimaging applications aimed at the detection of fuel hydrocarbon contaminated soil, it should be taken into account that areas of contaminated soil have been covered with uncontaminated material due to natural erosion and deposition processes. Due to this fact, microwave remote sensing sensors are highly applicable because of their penetration capability. Moreover, recommendations for required resolutions (spatial, temporal, etc.) for the application of microwave imaging for detection and investigation of contamination of soil with fuel hydrocarbon need to be derived based on scattering properties and spatial distribution of the target being observed. Furthermore, in case of diesel or similar fuel(s), dark coloring indicates heavy diesel fuel contamination on the soil (e.g., in surrounding of the petrol pump or refineries on an area of approximately ten(s) of meters). So synergy of microwave remote sensing with imaging spectrometry or any other remote sensing techniques might be used to locate the contaminated site(s) and the extent of it very accurately. At the end, it is worth mentioning that a comprehensive study including several types of soil with several types of petroleum hydrocarbons at a large variety of contamination levels has not yet been published. Most of the studies were performed with laboratory-prepared samples and almost none collected in the field. Furthermore, no generic models were developed, and no quantitative models were tested, although this was mentioned as an avenue of further study [24], especially combining laboratory and field samples, and no real quantitative operation model was presented for real-life applications.

5. Summary and Conclusions

The dielectric permittivity of oil has a direct effect on scatterometer, and radar sensors mounted on ground based, airborne and spaceborne platforms. A good understanding of the electrical properties of oil is vital to extract usefull information from the remotely sensed data for earth resources monitoring and management. Prompted by the need to measure the microwave dielectric permittivity of oil, a practical technique suitable for measuring the dielectric constant is sought.

In this paper, the dielectric constant is measured using waveguide with shift in minima method, the scattering coefficient of soil contaminated by diesel was measured at 5.3 GHz in the C band using perturbation.

From the results presented in this paper it is possible to determine the values scattering coefficient for known weight percentage of diesel in soil directly without measuring the dielectric permittivity and, on the other hand for known value of scattering coefficient, we can estimate the value of weight percentage of diesel in soil.

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