Estimation of emissivity and scattering coefficient of low saline water contaminated by diesel in Cj band (5.3 GHz) and Ku band (13.4 GHz)

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In case of low salinity or variable salinity, there is a very shallow radius of investigation. The dielectric constant of low saline water can be significantly modified by the presence of diesel. Techniques based on the propagation of electromagnetic waves may be used to detect contaminant and evaluate decontamination processes. Microwave remote sensing of diesel oil contaminated low saline water requires the study of electrical parameters of low saline water as well as diesel such as dielectric constant, emissivity and scattering coefficient along with their physical parameters like surface roughness, etc. The measurement of dielectric constant is very essential for estimating the emissivity and scattering coefficient. The measurement of dielectric constant of low saline water in combination with diesel has been carried out using waveguide cell with shift in minima method in 5.3 and 13.4 GHz. Tests are conducted with samples of different salinity of water with various amount of diesel oil. The amount of salinity is 5, 10 and 15 kppm and the amount of diesel contamination is from 40 to 280 percent with the interval of 80 percent for Cj band (5.3 GHz) and 40 to 160 percent with the interval of 40 percent for Ku band (13.4 GHz). The estimation of emissivity and scattering coefficient have been done for incident angles varying from 10 to 80 degree with the interval of 5 degree for both horizontal and vertical polarization. The value of Brewster angle has been calculated and the values of emissivity and scattering coefficient for three look angles (45, 50 and 55) degree is presented which are useful for designing space borne active and passive sensors. Furthermore, this database is useful for detecting oil spills in low saline water.

Keywords: Microwave remote sensing, Emissivity, Scattering coefficient, Diesel contaminated water, Low saline water

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1 Introduction

The essence of remote sensing is the measuring and recording of the electromagnetic radiation emitted or reflected by the earth's surface and its features. Diagnosis of water contamination by diesel in any region is an essential pre-requisite to plan a water reclamation project. Diagnosis with conventional techniques has been a time consuming and laborious exercise. With the advent of remote sensing, diagnostic procedures have been made easier and cheaper. In spite of this progress, it was found that an appropriate investigation for the identification and diagnosis of diesel oil contamination in low saline water has been lacking.

Annually, fuels account for 48% of the total oil spilled into the sea worldwide, while crude oil spills account for 29% of the total1. Tanker accidents contribute with 5% of all pollution entering into the sea2. Moreover, numerical models are being used to predict the drift and dispersion of oil following an accident3. Between 1988 and 2000, there were 2,475 spills which released over 800,000 liters of oil in Toronto and surrounding regions4. The impact of not monitoring oil spills is presently unknown, but the main environmental impact is assumed to be seabirds mistakenly landing on them and the damage to the coastal ecology as spills hit the beach5.

Recent research shows that even if the operators go through extensive training to learn manual oil spill detection they can detect different slicks and give them different confidence levels6, so a laboratory research has been made to measure the dielectric constant of diesel and then estimating the scattering coefficient and emissivity of low saline water contaminated by diesel and calculation of Brewster angle as well for better detection of diesel oil contaminated low saline water.

Although the vast majority of seawater has salinity in the range 3.1-3.8%, seawater is not uniformly saline throughout the world. Where mixing occurs
with fresh water runoff from river mouths or near melting glaciers, seawater can be substantially less saline. Unfortunately, in case of low salinity (brackish water), there is very small amount of investigations. Thus, this paper presents the result of emissivity and scattering coefficient estimation as well as Brewster angle in low water salinity contaminated by diesel. The measurement works well because diesel and water have dissimilar dielectric properties; the value of dielectric constant for diesel is 1.7 for Ku band and 2.3 for Cj band. The water has a typical value of 80. So, in other words, water is capable of storing much more energy per volume unit than the average oil. There is a special classification for the amount of salinity, which is presented in Table 1.

### 2 Methodology

Tests have been conducted with samples having 5, 10 and 15 kppm salinity and the diesel contamination from 40 to 280 percent with the interval of 80 percent for Cj band and 40 to 160 percent with the interval of 40 percent for Ku band (13.4 GHz). The estimation of emissivity and scattering coefficient have been done for incident angles varying from 10 to 80 degree with the interval of 5 degree for both horizontal and vertical polarization. The value of Brewster angle has been calculated and the values of emissivity and scattering coefficient for three look angles (45, 50 and 55) degree has been presented, which are useful for space borne active and passive sensors.

#### Table 1—Classification of various amount of salinity in water

<table>
<thead>
<tr>
<th></th>
<th>Fresh water</th>
<th>Brackish water</th>
<th>Saline water</th>
<th>Brine</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt; 0.05 %</td>
<td>0.05 – 3 %</td>
<td>3 – 5 %</td>
<td>&gt; 5 %</td>
</tr>
<tr>
<td>Salinity</td>
<td>&lt; 0.5 ppt</td>
<td>0.5 – 30 ppt</td>
<td>30 – 50 ppt</td>
<td>&gt; 50 ppt</td>
</tr>
</tbody>
</table>

**2.1 Measurement of dielectric constant**

There are four methods of measurement of dielectric constant, viz. transmission line method, resonant cavity method, wave guide cell method and free space method. This study covers the estimation of emissivity and scattering coefficient in Cj band as well as Ku band. The data of dielectric constant, which is already measured using waveguide cell with shift in minima method, has been implemented for this purpose. The dielectric constant was measured for different water salinity and different weight percentage of diesel in Cj band as well as Ku band in the laboratory.

**2.2 Microwave emission model**

Various theoretical models have been developed to estimate microwave emission of materials. These models include zero order non-coherent radiative transfer mode, first order non-coherent radiative transfer model, coherent model and emissivity model. Table 2 gives comparative depiction of the four models. The estimation of emissivity using the available data of dielectric constant and emissivity model is presented in this paper.

#### 2.2.1 Estimation of emissivity using emissivity model

The emission of microwave energy is proportional to the surface temperature and the surface emissivity, which is referred to as the microwave brightness temperature ($T_B$). Thus, the brightness temperature of an emitter of microwave radiation is related to the physical temperature of the source through the emissivity:

$$T_B = (1-R) \times T_{eff}$$

where, $R$, is the hemispherical-directional reflectivity from the surface; $T_{eff}$, the effective physical temperature.
of the surface; and \( e = (1-R) \), the emissivity, which depends on the dielectric constant of the medium. This model is the simplest to use with reasonable accuracy for the radiation within a range close to the surface.

Reflectivity is described by the Fresnel equation that defines the behaviour of electromagnetic waves at a smooth dielectric boundary. For horizontal (H) and vertical (V) at non-nadir incidence \( \theta \), the Fresnel reflectivity may be derived from electromagnetic theory as:

\[
R(H, \theta) = \left( \frac{\cos \theta - \sqrt{\varepsilon_H - \sin^2 \theta}}{\cos \theta + \sqrt{\varepsilon_H - \sin^2 \theta}} \right)^2
\]

...(2)

and

\[
R(V, \theta) = \left( \frac{\varepsilon_V \cos \theta - \sqrt{\varepsilon_V - \sin^2 \theta}}{\varepsilon_V \cos \theta + \sqrt{\varepsilon_V - \sin^2 \theta}} \right)^2
\]

...(3)

where, \( \varepsilon_p \) is the polarization-dependent dielectric constant of the emitter; and \( \theta \), the angle of observation. The emissivity can be calculated using Eqs (2) and (3) and then the brightness temperature can be obtained using Eq. (1).

2.3 Backscattering behaviour of the surfaces

When a target is moist or wet, scattering from the topmost portion (surface scattering) is the dominant process taking place. The type of reflection (ranging from specular to diffuse) and the magnitude will depend on how rough the material appears to the radar. If the target is very dry and the surface appears smooth to the radar, the radar energy may be able to penetrate below the surface, whether that surface is discontinuous (e.g. forest canopy with leaves and branches), or a homogeneous surface (e.g. soil, sand or ice). For a given surface, longer wavelengths are able to penetrate further than shorter wavelengths.

If the microwave does manage to penetrate through the topmost surface, then volume scattering may occur. Volume scattering is the scattering of radar energy within a volume or medium, and usually consists of multiple bounces and reflections from different components within the volume.

2.3.1 Scattering models for different surfaces

Depending upon the surface pattern, three different models are used for the estimation of scattering coefficient. These models are:

1. Perturbation model
2. Physical optics model
3. Geometric optics model

The perturbation model is appropriate for slightly rough surface where both the surface standard deviation and correlation length are smaller than the wavelength, thereby, this model has been implemented for estimating the scattering coefficient of low saline water in combination with diesel. Selecting a model for computation for a particular surface will depend upon the validity of a model for the surface concerned. The validity condition for each model is given in Table 3.

2.3.2 Perturbation model

In the perturbation model, the standard deviation should be at least 5% less than that of the electromagnetic wavelength. In addition to this, the slope of the surface should be of the same order of magnitude as the wave number times the surface standard deviation.

In the present paper, the wavelength is 5.66 cm for C\textit{j} band and 2.66 cm for Ku band, so the standard deviation should be less than 0.3 mm (ref. 8).

Mathematically,

\[
k\sigma < 0.3 \quad \text{and} \quad (2\varepsilon \sigma / l) \leq 0.3
\]

where, \( K = \frac{2\pi}{\lambda}; \sigma = \text{r.m.s. surface height}; l = \text{correlation length}; \text{and} \ M = \text{r.m.s. surface slope.}

The backscattering coefficient is given by:

\[
\sigma_{0 \, \text{ppm}} (\theta) = 8k^4 \sigma^4 \cos^4 \theta \alpha_{pp} \theta l^2 W (2k \sin \theta)
\]

...(4)

<table>
<thead>
<tr>
<th>Table 3—Validity conditions for different models</th>
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<tbody>
<tr>
<td>Model</td>
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<tr>
<td>Physical optics model (Kirchoffs’ model with scalar approximation)</td>
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<tr>
<td>Geometric optics model (Kirchoffs’ model with stationary phase approximation)</td>
</tr>
<tr>
<td>Perturbation model</td>
</tr>
</tbody>
</table>

Note: \( K = 2\pi/\lambda; \sigma = \text{r.m.s. surface height}; l = \text{correlation length}; M = \text{r.m.s. surface slope.} \)
where, \( p = \) polarization; \( v = \) vertical polarization; and \( h = \) horizontal polarization. Also \( \alpha_{nn}(\theta)^2 = \Gamma_n(\theta) \) is the Fresnel reflection coefficient. The value for Fresnel reflection coefficient for horizontal polarization is given by:

\[
\alpha_{hh}(\theta) = \frac{\cos \theta - (\varepsilon_s - \sin^2 \theta)^{1/2}}{\cos \theta + (\varepsilon_s - \sin^2 \theta)^{1/2}} \quad \ldots (5)
\]

For vertical polarization, the Fresnel coefficient \( \sigma_{vv} \) is given by:

\[
\alpha_{vv}(\theta) = (\varepsilon_s - 1) \frac{\sin^2 \theta - \varepsilon_s (1 + 2 \sin^2 \theta)}{[\varepsilon_s \cos \theta + (\varepsilon_s - \sin^2 \theta)^{1/2}]^2} \quad \ldots (6)
\]

where, \( \varepsilon_s \), is the dielectric constant of emitter; and \( \theta \), the angle of incident. \( W(2k \sin \theta) \) 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 \( \rho(\xi) = \exp \left( -\xi^2 / l^2 \right) \), the normalized roughness is given by:

\[
W(2k \sin \theta) = 1/2 \left( k \sin \theta \right)^2 \exp \left[ -(k \sin \theta)^2 \right] \quad \ldots (7)
\]

### 3 Results and Discussions

The amount of change in dielectric constant of combination of low saline water and diesel has been done around 25.74, 24.67 and 23.46 for 1% change in weight percentage of diesel in low saline water for 5, 15 and 25 kppm, respectively in Cj band. On the other hand the amount of change in dielectric constant of combination of low saline water and diesel has been around 29.9, 29.85 and 29.69 for 1% change in weight percentage of diesel in low saline water for 5, 15 and 25 kppm, respectively in Ku band.

The variations of emissivity of low saline water in combination with different weight percentage of diesel are presented in Figs 1 and 2 in different look angles from 10 to 80 degrees with the interval of 5 degree for both horizontal and vertical polarization in Cj band and Ku band, respectively. These figures indicate that the variation follows a polynomial curve of third order for horizontal polarization and fourth order for vertical polarization. The observable fact in Figs 1 and 2 is that the value of emissivity for horizontal polarization is decreasing as the look angles increase and the minimum values for all the curves take place at 80 degree for both horizontal and vertical polarization. On the other hand, the values of vertical polarization are always greater than the values of horizontal polarization and are highest at Brewster angle.

Figure 3 represents the emissivity at three different special angles (45°, 50° and 55°) for 15 kppm which are desirable for space borne remote sensing sensors, such as NIMBUS, AMSRE, SSMI and MSMR as well as QuikSCAT and OSCAT (India’s first scatterometer).
Fig. 1—Variation of emissivity of low saline water: (a) 5 kppm; (b) 15 kppm; and (c) 25 kppm with respect to different look angles in Cj band.

Fig. 2—Variation of emissivity of low saline water: (a) 5 kppm; (b) 15 kppm; and (c) 25 kppm with respect to different look angles in Ku band.

Fig. 3—Variation of emissivity of low saline water with respect to weight percentage of diesel in water in 15 kppm for three look angles (45, 50 and 55 degree) in: (a) Cj band; and (b) Ku band.

Figures 4 and 5 show the variation in scattering coefficient of low saline water with different weight percentage of diesel with respect to different look angles ranging from 10 to 80 degrees for slightly rough surface and for both horizontal and vertical polarization at 5.3 and 13.4 GHz, respectively. From the figures, it is observed that the scattering coefficient for slightly rough surface decreases as the look angle increases for horizontal polarization. From the figures, it is observed that the values of
scattering coefficient for VV polarization are higher than the values for HH polarization. It can be seen that as the weight percentage of diesel in low saline water increases, the value of scattering coefficient for both horizontal and vertical polarization decrease.

Figure 6 shows the variation of backscattering coefficient with respect to different weight percentage of diesel in low saline water for three different look angles (45°, 50° and 55°) for 15 kppm, which are desirable for space borne sensors.

Figure 7 represents the Brewster angle of low saline water contaminated by diesel at different percentages ranging 0-280% in Cj band and 0-160% in Ku band, respectively. It can be seen that as the percentage of diesel contamination in low saline water increases, the Brewster angle decreases.

It may be concluded from this study that the scattering coefficient decreases with increase in the weight percentage of diesel in low saline water whereas the emissivity increases with increase in the weight percentage of diesel in low saline water for both horizontal and vertical polarization at a specific look angle. Furthermore, emissivity and scattering coefficient for vertical polarization is higher than that for horizontal polarization. On the other hand, emissivity and scattering coefficient decreases with increase in the value of look angles for horizontal polarization. There is a peak value for vertical polarization for emissivity and scattering coefficient for both Cj and Ku band. With increase in the weight percentage of diesel in low saline water, the maximum values of vertical polarization shifts towards lower look angles. Emissivity and scattering
coefficient for vertical polarization is higher than that for horizontal polarization.

4 Summary and Conclusions

This paper presents the estimated emissivity and scattering coefficient at Ku band (13.4 GHz) and Cj band (5.3 GHz) frequency and for different samples of low saline water contaminated by diesel. The data obtained suggest the following:

1. Scattering coefficient decreases with increase in weight percentage of diesel in low saline water at a specific look angle.
2. Emissivity increases with increase in weight percentage of diesel in low saline water for a particular look angle.
3. Scattering coefficient and emissivity decrease with increase in look angle for horizontal polarizations and the value of scattering coefficient for horizontal polarization is less than that for vertical polarization.

Clearly, the problems associated with water pollution have the capabilities to disrupt life on our planet to a great extent. The database of this study will help in determining the behaviour of low saline water contaminated by diesel all over the world. The study will provide good results in designing microwave sensors for remote sensing of low saline water and the water bodies with low salinity. An extensive study on this subject is required for monitoring the spatial and temporal variations of contamination of low saline water.

References


