Electromagnetic Modelling of Heterogeneous Photocatalysis for the Determination of the Photonic Absorption Speed in a Solar Collector In V

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In the article Electromagnetic Model for Determining the Speed of Absorptive Photonic in a Solar Collector in V (V-Collector), we established a general model for the determination of the rate of absorption of photons in reference to the electromagnetic characteristics of the fluid in suspension. The purpose of this work was to make adjustments to the model in order to facilitate its use by the approximation of some electrical parameters of the model from the electrical conditions of the suspension medium is subjected to UV radiation.

To do this, it was considered to study the response of the model in terms of conductivity is zero ($\sigma = 0$), low conductivity ($\sigma < \omega^*\varepsilon$) and high conductivity ($\sigma > \omega^*\varepsilon$) under UV-b to find expressions of the model manageable and to allow the scaling to an industrial level of technology of photocatalysis for wastewater cleanup.

Introduction

The cleanliness of the water is one of its main aspects in the necessity to correct the damage caused in the environment by human activity, considering that life in general depends on this. The problem of cleaning the water have multiple responses ranging from the construction of pools and sedimentation to the use of the solar energy that, through the appropriate use of certain chemical elements, help to its decontamination.

The methods of decontamination by solar energy consists, basically, of adding a catalyst that reacts in the presence of light to accelerate the decomposition process by which molecules contaminants are degraded in molecules that are most elementary. The catalyst is the more common titanium dioxide TiO_2 that reacts in the presence of sunlight. The molecule of titanium dioxide TiO_2, as everything in the universe, is in a state of natural vibration that does not affect the environment, when it receives the solar light begins to increase your vibration to achieve a state in which electrons of the layer but outside escape at high speed hitting and breaking the bonds of the molecules that surround it, creating a chain reaction. The free electrons are finally captured by the ions present and finally stops the process. This model of the photocatalysis, which is based on the physical optics and in the physics of collisions, enables us to understand the phenomenon known as photocatalysis and is used by the chemical industry for its development. However, by photocatalysis is not possible to determine the time the process takes, or allows the construction on an industrial scale of processing plants. In (Ramos et al. 2017), Electromagnetic Model for Determining the Speed of Absorptive Photonic in a Solar Collector in V (V-Collector), was established an electromagnetic model as a first approach of the process of photocatalysis, with a focus on energy exchange. In this work we arrived at an expression which relates the light energy delivered by the photon to the molecule of titanium dioxide TiO_2, thus increasing its energy content and thereby increasing the levels of vibration, affecting the environment and forcing to enter into natural resonance of the molecules that surround him. When you get to this point, the molecules in pollutants to increase their level of vibration until its destruction by the phenomenon of resonance.

The energy used by the photocatalysis is the corresponding to wave ultraviolet UV contained in the solar light and are waves that carry the greatest amount of energy. Is not considered thermal treatment in order to the

assumption that the heat losses, that is due to the section near-infrared light, do not significantly affect the exchange of energy in the part of UV at the molecular scale.

The equation describes the energy exchange at frequency ω in the UV range between the photon and the molecule of titanium dioxide TiO$_2$ taking into account the characteristics of electric and magnetic average of the substrate, that is to say, permittivity ε, magnetic permeability μ and electrical conductivity σ, which will be measured at the moment of start the process.

$$I(r,\theta) = I_0 e^{-\omega\sqrt{\frac{\mu\varepsilon}{2}\left[\sqrt{1-\left(\frac{\sigma}{\omega\varepsilon}\right)^2}-1\right]}r} e^{-j\omega\sqrt{\frac{\mu\varepsilon}{2}\left[\sqrt{1-\left(\frac{\sigma}{\omega\varepsilon}\right)^2}+1\right]}} \tag{1}$$

The equation is the product of two terms that describe both the response to the attenuation of the waveform or attenuation factor as the behavior due to the frequency components UV light, or a factor of phase. In the equation for (Ramos et al. 2017), the time parameter is implicit due to the laws of Maxwell but it is considered necessary to find an expression that links, explicitly, the energy delivered by the solar light and the time of degradation of the contaminants. The equation is general, i.e., it does not discriminate between the terms electric and magnetic of the contaminated environment; taking into account the importance of the product between the frequency ω and the permittivity ε in the equation, it is reasonable to think that the next step in the development of the project is to develop simplified models of the equation are consistent with the classification of the fluid depending on its characteristics of electrical conductivity σ and magnetic permeability μ, as well as establishing time curves that allow scaling up to industrial level of the decontamination process using titanium dioxide TiO$_2$. The conductivity allows you to set if the medium is an insulator (σ=0), conductive (σ<ω*ε) which could mean that molecules of contaminants are negative ions so that there would be an excess of electrons in the medium, or semiconductor (σ>ω*ε), that is to say, are these molecules positively charged as contaminants. The general equation, subject to various conditions can be used to find the reaction time until the water has the desired purity level.

Methodology

In an earlier stage of the study on the exchange of energy between a light signal incident on a contaminated aqueous medium in which TiO 2 titanium dioxide is mixed, was determined to depend on three electrical parameters, namely permittivity, conductivity and frequency of the incident wave. It is known that titanium dioxide reacts to the UV fraction of sunlight and it is in this band in which the present job. Since this band does not influence the heat exchange, the temperature variation for this job.

On the basis of the expression of the energy intensity I(r,θ):

$$I(r,\theta) = I_0 e^{-\omega r\sqrt{\frac{\mu\varepsilon}{2}\left[\sqrt{1-\left(\frac{\sigma}{\omega\varepsilon}\right)^2}-1\right]}} e^{-j\omega\sqrt{\frac{\mu\varepsilon}{2}\left[\sqrt{1-\left(\frac{\sigma}{\omega\varepsilon}\right)^2}+1\right]}} e^{j\omega t} \tag{2}$$

Recalling that α represents the attenuation factor of the signal intensity

$$\alpha = -\omega\sqrt{\frac{\mu\varepsilon}{2}\left[\sqrt{1-\left(\frac{\sigma}{\omega\varepsilon}\right)^2}-1\right]} \tag{3}$$

And β is the factor of phase of the electromagnetic wave:

$$\beta = -\omega\sqrt{\frac{\mu\varepsilon}{2}\left[\sqrt{1-\left(\frac{\sigma}{\omega\varepsilon}\right)^2}+1\right]} \tag{4}$$

Both factors depend on clearly the frequency of the electromagnetic wave (ω), of the magnetic permeability (μ), electrical conductivity (σ) and permittivity electrical (ε). The term that determines , both for the attenuation factor:

$$\sqrt{\sqrt{1-\left(\frac{\sigma}{\omega\varepsilon}\right)^2}-1} \tag{5}$$

as for the factor of phase:

$$\sqrt{\sqrt{1-\left(\frac{\sigma}{\omega\varepsilon}\right)^2}+1} \tag{6}$$

To verify the initial feasibility of the model the values which take these factors against various forms of natural water are found and compared and presented in Table 1.

Table 1. Data generated by the original equation for the attenuation factors α and phase β

	σ	ε material		
		ε relative	ε empty	
			8,8541878176E-12	
water	1,0000000000E-04	8,0000000000E+01	7,0833502541E-10	
water	1,0000000000E-02	8,1000000000E+01	7,1718921323E-10	
salt water and sea water	4,0000000000E+00	8,1000000000E+01	7,1718921323E-10	
salt water and sea water	4,0000000000E+00	8,8000000000E+01	7,7916852795E-10	
ice	2,0000000000E-05	3,0000000000E+00	2,6562563453E-11	
ice	3,0000000000E-06	3,1500000000E+00	2,7890691625E-11	
Permafrost	1,0000000000E-03	1,0000000000E+00	8,8541878176E-12	
Permafrost	1,0000000000E-04	8,0000000000E+00	7,0833502541E-11	

	ωε		σ / (ω * ε)	
	ω lower	ω higher	ω lower	ω higher
	7,8900000000E+14	1,5000000000E+15		
water	5,5888261823E+05	6,6759003363E+06	1,7892844890E-10	1,4979252979E-11
water	5,6586857242E+05	6,7593490905E+06	1,7671948024E-08	1,4794323930E-09
salt water and sea water	5,6586857242E+05	6,7593490905E+06	7,0687792094E-06	5,9177295719E-07
salt water and sea water	6,1477025174E+05	7,3434903699E+06	6,5064957010E-06	5,4470010833E-07
ice	2,0964145750E+04	2,5034626261E+05	9,5400977645E-10	7,9889349221E-11
ice	2,2012038878E+04	2,6286357574E+05	1,3628905603E-10	1,1412764174E-11
Permafrost	6,9922373734E+03	8,3448754204E+04	1,4301573968E-07	1,1983402383E-08
Permafrost	5,5893916690E+04	6,6759003363E+05	1,7891034646E-09	1,4979252979E-10

	Attenuation Factor		Phase Factor	
	√(√(1-(σ / ω * ε)²)-1)		√(√(1-(σ / ω * ε)²)+1)	
	ω lower	ω higher	ω lower	ω higher
water	0,0000000000E+00	0,0000000000E+00	1,4142135624E+00	1,4142135624E+00
water	0,0000000000E+00	0,0000000000E+00	1,4142135624E+00	1,4142135624E+00
salt water and sea water	4,9983790185E-06	4,1842821485E-07	1,4142135624E+00	1,4142135624E+00
salt water and sea water	4,6007923386E-06	3,8513088177E-07	1,4142135624E+00	1,4142135624E+00
ice	0,0000000000E+00	0,0000000000E+00	1,4142135624E+00	1,4142135624E+00
ice	0,0000000000E+00	0,0000000000E+00	1,4142135624E+00	1,4142135624E+00
Permafrost	1,0106459235E-07	0,0000000000E+00	1,4142135624E+00	1,4142135624E+00
Permafrost	0,0000000000E+00	0,0000000000E+00	1,4142135624E+00	1,4142135624E+00

We highlight the behavior in the attenuation factor for the salt water and sea water in which the attenuation factor is a difference of 6 to 7 orders of magnitude with respect to the reference value of the fresh water, depending on the electrical characteristics of the medium.

This difference allows us to think of the feasibility of segmenting the range of application of the equation from the electrical parameters of contaminated water.

After $\sqrt{\sqrt{1-\left(\frac{\sigma}{\omega\varepsilon}\right)^2}-1}$, you start the mathematical analysis of the expression which is the root that determines the attenuation factor α. This root is a real number $\sqrt{\sqrt{1-\left(\frac{\sigma}{\omega\varepsilon}\right)^2}-1} \geq 0$ value of imaginary when $\sqrt{\sqrt{1-\left(\frac{\sigma}{\omega\varepsilon}\right)^2}-1} < 0.$

When you consider that $\sqrt{\sqrt{1-\left(\frac{\sigma}{\omega\varepsilon}\right)^2}-1} \geq 0$ it is observed that $\sqrt{1-\left(\frac{\sigma}{\omega\varepsilon}\right)^2} \geq 1$, thing that happens when $\frac{\sigma}{\omega\varepsilon} \leq 0,$ that is to say, $\sigma \leq \omega\varepsilon.$ When σ is smaller than ωε the root of the attenuation factor is a value that is imaginary and this term is an imaginary number, making the expression:

$$I(r,\theta) = I_0 e^{-j\omega r\sqrt{\frac{\mu\varepsilon}{2}}\left[\sqrt{1-\left(\frac{\sigma}{\omega\varepsilon}\right)^2}-1\right]} e^{-j\omega\sqrt{\frac{\mu\varepsilon}{2}}\left[\sqrt{1-\left(\frac{\sigma}{\omega\varepsilon}\right)^2}+1\right]} e^{j\omega t} \qquad (7)$$

And the exponents will now be imaginary:

$$-j\omega r\sqrt{\frac{\mu\varepsilon}{2}}\sqrt{\left[\sqrt{1-\left(\frac{\sigma}{\omega\varepsilon}\right)^2}-1\right]}y - j\omega\sqrt{\frac{\mu\varepsilon}{2}}\sqrt{\left[\sqrt{1-\left(\frac{\sigma}{\omega\varepsilon}\right)^2}+1\right]} \qquad (8)$$

In this condition, the attenuation factor β takes the form

$$\beta = -\omega r \sqrt{\frac{\mu\varepsilon}{2}} \sqrt{\left[\sqrt{1-\left(\frac{\sigma}{\omega\varepsilon}\right)^2}-1\right]} - \omega\sqrt{\frac{\mu\varepsilon}{2}}\sqrt{\left[\sqrt{1-\left(\frac{\sigma}{\omega\varepsilon}\right)^2}+1\right]} \tag{9}$$

$$\beta = -\omega\sqrt{\frac{\mu\varepsilon}{2}}\left(r\sqrt{\left[\sqrt{1-\left(\frac{\sigma}{\omega\varepsilon}\right)^2}-1\right]} + \sqrt{\left[\sqrt{1-\left(\frac{\sigma}{\omega\varepsilon}\right)^2}+1\right]}\right) \tag{10}$$

and the equation of intensity depends only on the factor of β phase:

$$I(r,\theta) = I_0 e^{-j\omega\sqrt{\frac{\mu\varepsilon}{2}}\left(r\sqrt{\left[\sqrt{1-\left(\frac{\sigma}{\omega\varepsilon}\right)^2}-1\right]}+\sqrt{\left[\sqrt{1-\left(\frac{\sigma}{\omega\varepsilon}\right)^2}+1\right]}\right)}e^{j\omega t} \tag{11}$$

When $(\sigma = \omega\varepsilon)$, the Ec.93 will become

$$I(r,\theta) = I_0 e^{-j\omega r\sqrt{\frac{\mu\varepsilon}{2}}\sqrt{-1}}e^{-j\omega\sqrt{\frac{\mu\varepsilon}{2}}}e^{j\omega t} \tag{12}$$

so that the expression for the intensity I is:

$$I(r,\theta) = I_0 e^{-j\omega r\sqrt{\frac{\mu\varepsilon}{2}}}e^{-j\omega\sqrt{\frac{\mu\varepsilon}{2}}}e^{j\omega t} \tag{13}$$

Factoring

$$I(r,\theta) = I_0 e^{-j(r+1)\omega\sqrt{\frac{\mu\varepsilon}{2}}}e^{j\omega t} \tag{14}$$

Where it disappears, in both cases, the attenuation factor and only retains the factor of phase element in the imaginary of the complex number $z = \alpha + j\beta$

$$\beta = -(r+1)\omega\sqrt{\frac{\mu\varepsilon}{2}} \tag{15}$$

If $\sqrt{1-\left(\frac{\sigma}{\omega\varepsilon}\right)^2}-1 < 0$, that implies that the reason $\frac{\sigma}{\omega\varepsilon} > 1$ o $\sigma > \omega\varepsilon$, the root interior makes the number imaginary

$$\sqrt{-\left[\left(\frac{\sigma}{\omega\varepsilon}\right)^2-1\right]} = j\sqrt{\left[\left(\frac{\sigma}{\omega\varepsilon}\right)^2-1\right]} \tag{16}$$

and the Equation will take the form

$$I(r,\theta) = I_0 e^{-\omega r\sqrt{\frac{\mu\varepsilon}{2}}\sqrt{\left[j\sqrt{\left(\frac{\sigma}{\omega\varepsilon}\right)^2-1}-1\right]}}e^{-j\omega\sqrt{\frac{\mu\varepsilon}{2}}\sqrt{\left[j\sqrt{\left(\frac{\sigma}{\omega\varepsilon}\right)^2-1}+1\right]}}e^{j\omega t} \tag{17}$$

To solve this, it is considered the development of the square root of a complex number has the form of a complex number z = a + jb

$$\sqrt{x+jy} = z = a+jb \tag{18}$$

Whose development delivery definition of the values a and b end

$$a = \pm\sqrt{\frac{x}{2}+\sqrt{\frac{x^2+y^2}{4}}}$$

$$b = \pm\sqrt{\frac{-x}{2}+\sqrt{\frac{x^2+y^2}{4}}} \tag{19}$$

For the first exponent

$$\alpha = -\omega r\sqrt{\frac{\mu\varepsilon}{2}}\sqrt{j\sqrt{\left(\frac{\sigma}{\omega\varepsilon}\right)^2-1}-1} = -\omega r\sqrt{\frac{\mu\varepsilon}{2}}\sqrt{-1+j\sqrt{\left(\frac{\sigma}{\omega\varepsilon}\right)^2-1}} \tag{20}$$

It is considered that $x = -1yy = \sqrt{\left(\frac{\alpha}{\omega\varepsilon}\right)^2 - 1}$, which leads to the factors a and b

$$a = \pm\sqrt{\frac{-1}{2} + \sqrt{\frac{(-1)^2 + \left[\sqrt{\left(\frac{\alpha}{\omega\varepsilon}\right)^2 - 1}\right]^2}{4}}} = \pm\sqrt{\frac{-1}{2} + \sqrt{\frac{1 + \left(\frac{\alpha}{\omega\varepsilon}\right)^2 - 1}{4}}} \tag{21}$$

$$a = \pm\sqrt{\frac{-1}{2} + \frac{\left(\frac{\alpha}{\omega\varepsilon}\right)}{2}} = \pm\sqrt{\frac{\left(\frac{\alpha}{\omega\varepsilon}\right) - 1}{2}}$$

$$b = \pm\sqrt{\frac{--1}{2} + \sqrt{\frac{(-1)^2 + \left[\sqrt{\left(\frac{\alpha}{\omega\varepsilon}\right)^2 - 1}\right]^2}{4}}} = \pm\sqrt{\frac{1}{2} + \sqrt{\frac{1 + \left(\frac{\alpha}{\omega\varepsilon}\right)^2 - 1}{4}}} \tag{22}$$

$$b = \pm\sqrt{\frac{1}{2} + \frac{\left(\frac{\alpha}{\omega\varepsilon}\right)}{2}} = \pm\sqrt{\frac{\left(\frac{\alpha}{\omega\varepsilon}\right) + 1}{2}}$$

The term is:

$$\alpha = -\omega r\sqrt{\frac{\mu\varepsilon}{2}}\left[\pm\sqrt{\frac{\left(\frac{\alpha}{\omega\varepsilon}\right) - 1}{2}} \pm j\sqrt{\frac{\left(\frac{\alpha}{\omega\varepsilon}\right) + 1}{2}}\right] \tag{23}$$

It is considered that $x = 1yy = \sqrt{\left(\frac{\alpha}{\omega\varepsilon}\right)^2 - 1}$, which leads to the factors a and b

$$\beta = -\omega\sqrt{\frac{\mu\varepsilon}{2}}\sqrt{j\sqrt{\left(\frac{\sigma}{\omega\varepsilon}\right)^2 - 1} + 1} = -\omega\sqrt{\frac{\mu\varepsilon}{2}}\sqrt{1 + j\sqrt{\left(\frac{\sigma}{\omega\varepsilon}\right)^2 - 1}} \tag{24}$$

For the determination of the values a and b corresponding

$$a = \pm\sqrt{\frac{1}{2} + \sqrt{\frac{(1)^2 + \left[\sqrt{\left(\frac{\alpha}{\omega\varepsilon}\right)^2 - 1}\right]^2}{4}}} = \pm\sqrt{\frac{1}{2} + \sqrt{\frac{1 + \left(\frac{\alpha}{\omega\varepsilon}\right)^2 - 1}{4}}} \tag{25}$$

$$a = \pm\sqrt{\frac{1}{2} + \frac{\left(\frac{\alpha}{\omega\varepsilon}\right)}{2}} = \pm\sqrt{\frac{\left(\frac{\alpha}{\omega\varepsilon}\right) + 1}{2}}$$

$$b = \pm\sqrt{\frac{-1}{2} + \sqrt{\frac{(1)^2 + \left[\sqrt{\left(\frac{\alpha}{\omega\varepsilon}\right)^2 - 1}\right]^2}{4}}} = \pm\sqrt{\frac{-1}{2} + \sqrt{\frac{1 + \left(\frac{\alpha}{\omega\varepsilon}\right)^2 - 1}{4}}} \tag{26}$$

$$b = \pm\sqrt{\frac{-1}{2} + \frac{\left(\frac{\alpha}{\omega\varepsilon}\right)}{2}} = \pm\sqrt{\frac{\left(\frac{\alpha}{\omega\varepsilon}\right) - 1}{2}}$$

The term is:

$$\beta = -\omega\sqrt{\frac{\mu\varepsilon}{2}}\left[\pm\sqrt{\frac{\left(\frac{\sigma}{\omega\varepsilon}\right) + 1}{2}} \pm j\sqrt{\frac{\left(\frac{\sigma}{\omega\varepsilon}\right) - 1}{2}}\right] \tag{27}$$

The equation of intensity that has the form $I = I_0 e^\alpha e^\beta e^{j\omega t}$ to replace and rearrange the exponents in real and imaginary values:

$$I = I_0 e^{-\omega r\sqrt{\frac{\mu\varepsilon}{2}}\left[\pm\sqrt{\frac{\left(\frac{\sigma}{\omega\varepsilon}\right) - 1}{2}} \pm jsqrt\frac{\left(\frac{\sigma}{\omega\varepsilon}\right) + 1}{2}\right]} e^{-j\omega\sqrt{\frac{\mu\varepsilon}{2}}\left[\pm\sqrt{\frac{\left(\frac{\sigma}{\omega\varepsilon}\right) + 1}{2}} \pm j\sqrt{\frac{\left(\frac{\sigma}{\omega\varepsilon}\right) - 1}{2}}\right]} e^{j\omega t} \tag{28}$$

$$I = I_0 e^{\pm\omega r\sqrt{\frac{\mu\varepsilon}{2}}\sqrt{\frac{\left(\frac{\sigma}{\omega\varepsilon}\right)-1}{2}} \mp j\omega r\sqrt{\frac{\mu\varepsilon}{2}}\sqrt{\frac{\left(\frac{\sigma}{\omega\varepsilon}\right)+1}{2}}} e^{\mp j\omega\sqrt{\frac{\mu\varepsilon}{2}}\sqrt{\frac{\left(\frac{\sigma}{\omega\varepsilon}\right)+1}{2}} \pm \omega\sqrt{\frac{\mu\varepsilon}{2}}\sqrt{\frac{\left(\frac{\sigma}{\omega\varepsilon}\right)-1}{2}}} e^{j\omega t} \tag{29}$$

$$I = I_0 e^{\pm\omega r\sqrt{\frac{\mu\varepsilon}{2}}\sqrt{\frac{\left(\frac{\sigma}{\omega\varepsilon}\right)-1}{2}} \pm \omega\sqrt{\frac{\mu\varepsilon}{2}}\sqrt{\frac{\left(\frac{\sigma}{\omega\varepsilon}\right)-1}{2}}} e^{\mp j\omega\sqrt{\frac{\mu\varepsilon}{2}}\sqrt{\frac{\left(\frac{\sigma}{\omega\varepsilon}\right)+1}{2}} \mp j\omega r\sqrt{\frac{\mu\varepsilon}{2}}\sqrt{\frac{\left(\frac{\sigma}{\omega\varepsilon}\right)+1}{2}}} e^{j\omega t} \tag{30}$$

Delivered as a final expression:

$$I = I_0 e^{\pm\omega(r+1)\sqrt{\frac{\mu\varepsilon}{2}}\sqrt{\frac{\left(\frac{\sigma}{\omega\varepsilon}\right)-1}{2}}} e^{\mp j\omega(r+1)\sqrt{\frac{\mu\varepsilon}{2}}\sqrt{\frac{\left(\frac{\sigma}{\omega\varepsilon}\right)+1}{2}}} e^{j\omega t} \tag{31}$$

Conclusions

This document analyzes how, through approximations in various electrical and magnetic parameters of the contaminated fluid to which it refers, the mathematical model obtained in [Ramos et al, 2017] is reduced to a more accessible and easier to interpret form. The original expression of the equation combines real-imaginary terms:

$$I(r,\theta) = I_0 e^{-\omega\sqrt{\frac{\mu\varepsilon}{2}\left[\sqrt{1-\left(\frac{\sigma}{\omega\varepsilon}\right)^2}-1\right]}r} e^{-j\omega\sqrt{\frac{\mu\varepsilon}{2}\left[\sqrt{1-\left(\frac{\sigma}{\omega\varepsilon}\right)^2}+1\right]}} \tag{1}$$

The parameters considered are the permittivity and the conductivity of the fluid together with the frequency of UV waves from incident light. In this way, three particular solutions are obtained, which are summarized:

$\left(1-\left(\frac{\sigma}{\omega\varepsilon}\right)^2\right) > 0$	$\omega\varepsilon > \sigma$	$I(r,\theta) = I_0 e^{-j\omega\sqrt{\frac{\mu\varepsilon}{2}}\left(r\sqrt{\left[\sqrt{1-\left(\frac{\sigma}{\omega\varepsilon}\right)^2}-1\right]}+\sqrt{\left[\sqrt{1-\left(\frac{\sigma}{\omega\varepsilon}\right)^2}+1\right]}\right)} e^{j\omega t}$	(11)
$\left(1-\left(\frac{\sigma}{\omega\varepsilon}\right)^2\right) = 0$	$\omega\varepsilon = \sigma$	$I(r,\theta) = I_0 e^{-j(r+1)\omega\sqrt{\frac{\mu\varepsilon}{2}}} e^{j\omega t}$	(14)
$\left(1-\left(\frac{\sigma}{\omega\varepsilon}\right)^2\right) < 0$	$\omega\varepsilon < \sigma$	$I = I_0 e^{\pm\omega(r+1)\sqrt{\frac{\mu\varepsilon}{2}}\sqrt{\frac{\left(\frac{\sigma}{\omega\varepsilon}\right)-1}{2}}} e^{\mp j\omega(r+1)\sqrt{\frac{\mu\varepsilon}{2}}\sqrt{\frac{\left(\frac{\sigma}{\omega\varepsilon}\right)+1}{2}}} e^{j\omega t}$	(31)

The approximations reduce the expression, in two of the three cases, to imaginary terms that refer to the phase factor thus eliminating the other factor, that of attenuation. So the transmitted energy depends, in these cases, the frequency of the incident signal. At the conclusion of the analysis of the equation it was found that the attenuation is affected in those media in which the conductivity σ is less than the product of the frequency ω by the permittivity electric ε. The data suggest that the use of different equations that depending on the electrical and magnetic features of the medium is viable, and the corresponding equations are more simple. There is a method to analyze phase-by-phase photodegradation of the fluid contaminated. The method enables to calculate the time for the photodegradation of the pollutants of the fluid because time variable is considered. The photocatalytic process, separated by phases, have relation with the conductivity σ of the contaminated fluid.

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