THE EFFECTS OF GEOMETRIC FACTORS ON THE BEHAVIOUR OF TWO ELECTRODES AND THREE ELECTRODES CONDUCTIVITY CELLS: A MODELLING AND SIMULATION SOFTWARE APPROACH

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Abstract: This paper presents a study of the effects of geometric factors on the behaviour of conductivity cells for water quality monitoring.

A modelling and simulation software tool has been used to study the variation of the current density near the cells and its influence on the value of the geometric factor as well as in the value of conductivity.

The effect of the number of electrodes and their relative positions in the value of geometric constant of cells are shown as well as several plots of electric field and current density for different values of conductivity and in the presence of conductive and non conductive objects to study their influence on the conductivity measurements.

Keywords: Water quality, conductivity cell, current density, geometric factor, simulation software.

1. INTRODUCTION

Water quality monitoring is an extremely important issue for a sustainable development.
Low cost sensors and measurement systems provides a very good tool for inexpensive and dissemination of water quality assessment.

One of the most measured parameters in water quality monitoring is electrical conductivity. This parameter is related with the quantity of salts dissolved in the water and it is measured on a vast field of applications from chemical industry to oceanography. In river estuaries the importance of water quality monitoring is directly related with the environmental sustainability and with biodiversity availability, e.g. in the aquaculture.

In the case of electrical conductivity sensors, modelling and simulation software provides a very good tool for the sensor development finding the best geometry and can be used to determine the geometric cell constant for the relevant electrical conductivity range.

With the dissemination of computer software capabilities, modelling and simulation software became a very important tool for the characterization and development of almost every kind of systems, from mechanical engineering to electrical engineering and also in experimental physics from high energy physics to solid state physics, using finite element analysis.

Modelling and simulation is of particular importance on medical applications in the field of tissue and radiofrequency ablation [1], [2].

In this paper, the modelling and simulation of electric field and current density of two electrodes and three electrodes conductivity cells are presented.

The influence of surrounding objects at the vicinity of each cell is studied. Conductive and non conductive objects can affect the conductivity measurements. This is an important issue regarding calibration and error handling for the cells.

The modelling and simulation software used on this work was the Maxwell SV 2D from Ansoft Corporation [3].

2. OBJECTIVES

The main objective of this work was to evaluate the influence of the geometric factors on the performance of electrical conductivity cells of two and three electrodes in the 0.1 S/m to 1 S/m range.

As a related issue to this main objective we were interested on the use of a software simulation and modelling tool to obtain the best geometry and geometric constant that fits the electrical conductivity range to be measured and also to study the behaviour of the electric field and current density within the surroundings of the cell.

Theoretical and experimental values of the geometric constant of the different cells were to be compared and related to the electric field and current density values.

The best cell geometry would give the closest result between theoretical and experimental values of geometric constant.

The electrical conductivity cell was integrated in a monitoring system with pH and temperature sensors to study the effect of temperature on other parameters [4].

3. METHODOLOGY

Electrical conductivity in liquid aqueous environments such as estuarine waters is a measure of the quantity of salts dissolved in the water and is expressed in Siemens per meter (S/m), in SI units.

Electrical conductivity is given by the following equation:

$$\sigma = \frac{K}{R} \qquad (1)$$

where σ is the electrical conductivity in S/m, K is the geometric factor of the cell in m^{-1} and R is the resistance between electrodes in Ω. So the electrical conductivity can be obtained by a measurement of the resistance of the volume of the liquid solution between electrodes.

On the other hand, the geometric factor K is given by:

$$K = \frac{d}{A} \qquad (2)$$

where d is the distance between electrodes and A is the surface area of the electrodes.

Several steps must be taken to compare the experimental value with the theoretical for the geometric constant:

The first step is to define the conductivity range, which is 0.1 S/m to 1 S/m for estuarine waters.

The second step is to define the resistance range, which for reasons of handling the measurements errors was chosen to be, e.g., from 100 Ω to 10000 kΩ.

From these values of σ and R and from (1) the theoretical geometric constant is 1000 m^{-1} [4].

From (2) it is possible to define, the distance between electrodes and the area of each electrode to get the proper value for the geometric constant.

The experimental value for the cell constant can be calculated from the experimental value of the conductivity and resistance measurements and this value can be compared with the theoretical one [5], [6].

The d, A and σ values as well as other items that we shall discuss below will be introduced as parameters for the software simulation.

Maxwell SV 2D can be parameterized on several aspects presented in the *executive commands* section. These a0re the following:

The *Define Model*, where it is possible to draw a model of the conductivity cell as well as the surroundings with dimensions in mm.

The *Setup Materials*, where it is possible to choose and define the types of materials for the cell and its surroundings. On this subsection it is also possible to define values for relative permittivity and electrical conductivity.

The *Setup Boundaries/Sources* where are defined the magnitudes of the sources on this case the electrodes potential.

It is also possible to choose the frequency of the stimulus, the solver residual and the number of passes for convergence to be achieved.

After that, the software solves the equations and proceeds to the *post process* section. In this section it is possible to plot several parameters including the electric field and the current density lines between the electrodes.

Let us consider two electrodes conductivity cell and three electrodes conductivity cell with the following geometries for current density analysis.
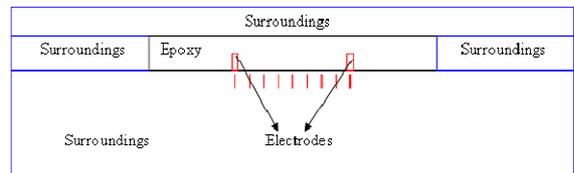

Fig. 1 – Cut view of two electrodes cell.

In Fig. 1 it is shown a cut view of a two electrodes cell. The cell is parameterized as follows:

The body is epoxy with zero conductivity;

The electrodes are stainless steel with a 10^6 S/m conductivity;

The surroundings are salt water with conductivity varying in the range of interest.

The small red segments are the lines for integration of the current density J. The integral of J in one dimension gives the Magnetic Field Force in A/m.
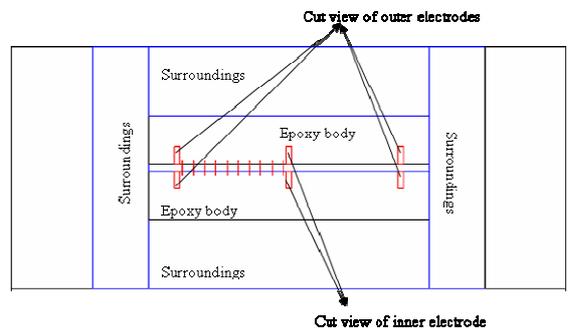

Fig. 2 – Cut view of three electrodes cell.

In Fig. 2 is represented a cut view of a three electrode cell.

The parameterization is the same as for the two electrodes cell except for the number of electrodes and their relative positions.

The outer electrodes are at ground potential and the inner electrode is at a potential of 2 Volt.

The frequency of the stimulus was set to 50 kHz.

The surroundings of the cells were parameterized in order to study the influence of the presence of conducting and non conducting objects near the electrodes.

On one case an epoxy object with zero conductivity was set to be parallel to the body of the cell at a distance of 5 mm and all along the body. On the other case a lead object with the same dimensions and 5×10^6 S/m conductivity was set. The Fig. 3 shows the geometry of this setup.
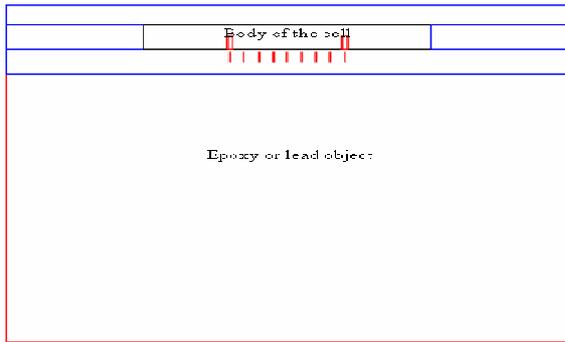
Fig. 3 – 2 electrodes cell in the presence of an object.

4. RESULTS

Let us now look at the field in the surroundings of each cell given by the *post process* tool of the software.

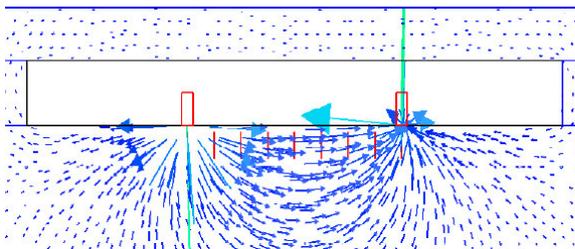In Fig. 4 it is shown the current density lines in the surroundings of the two electrodes cell.

Fig. 4 – Two electrodes cell – Current Density Lines (Zoom).

In Fig. 5 it is shown the same lines for the three electrodes cell. Fig. 6 is a zoom of the three electrodes cell.
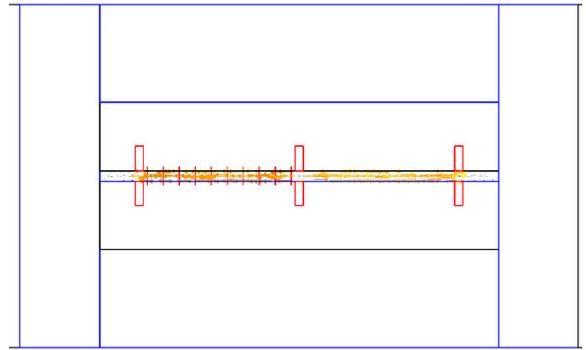

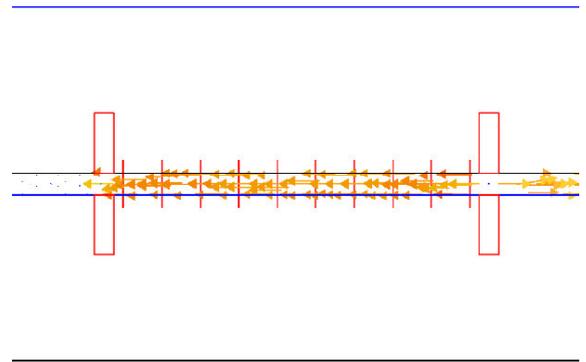Fig. 5 – Three electrodes cell – Current Density Lines.

Fig. 6 – Three electrodes cell – Current Density Lines (half cell zoom).

In the case of the two electrodes cell there is no confinement of the current density lines.

In the case of the three electrodes cell all the current density lines are confined to the space between the electrodes and in the volume defined by the electrodes where the conductivity is to be measured.

In the graphic of Fig. 7 it is shown the variation of the Magnetic Field Force (MMF) with the relative position between electrodes. For the two electrodes cell the positions between electrodes were chosen to be closest to the body of the cell where the field is more flat. For the three electrodes cell the lines are in the inner part of the cell where the conductivity is to be measured.
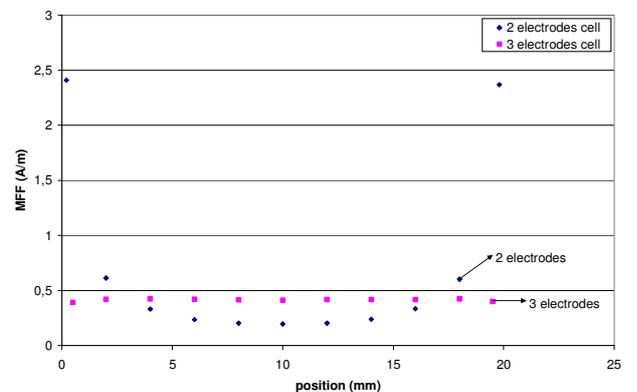

Fig. 7 – Variation of the MMF (A/m) with the relative position between electrodes for 2 electrodes and 3 electrodes cells.

The losses in the current density lines measured in percentage of MMF are around 26%. This type of losses is reported in some other texts [7] regarding the behaviour of conductivity sensors for oceanography.

Looking closer to the two electrodes cell behaviour in the presence of conductive and non conductive objects the results for the variation of the MMF with the distance to the objects in the surroundings of the cell are shown in Fig. 8. The values were taken from the middle position between electrodes.
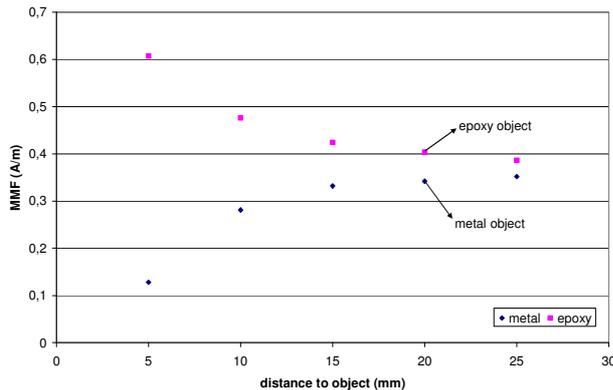

Fig. 8 – Variation of MMF with the distance to the conductive and non conductive objects for the same value of conductivity of water solution.

The objects are located parallel to the body of the cell. The metal object is lead.

It is observed that for a metallic object like lead the value of MMF increase with the distance to the object. On the other hand for a non conductive material like epoxy the MMF value decreases with distance to the object.

For the other position between electrodes the variation of the value of MMF with the distance to the objects tends to decrease as it is shown in graphics of Fig. 9 and Fig. 10.
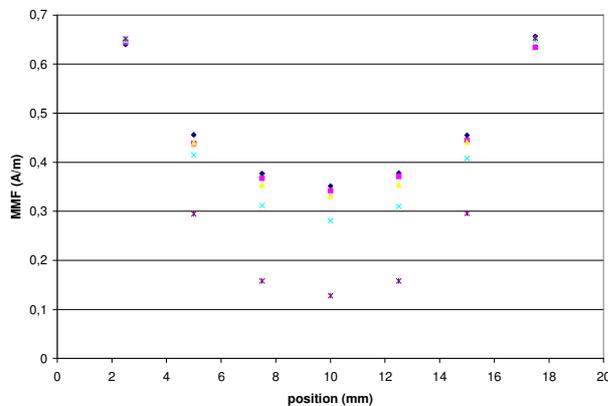

Fig. 9 - Variation of MMF with the position between electrodes for several distances to a conductive metallic object in the surroundings of electrodes cell.
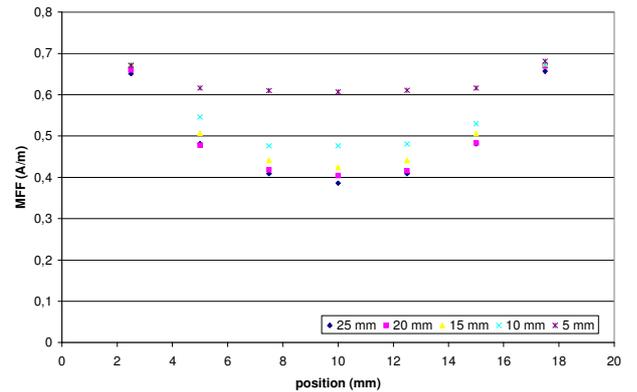

Fig. 10 – Variation of MMF with the position between electrodes for several distances to a non conductive epoxy object in the surroundings of electrodes cell.

5. DISCUSSION

From the results it is clear that the three electrodes cell shows current density confinement and it isn't affected by the presence of any objects in the surroundings of the electrodes.

On the other hand the two electrodes cell shows loss of current density lines which affect the accuracy of conductivity measurements and also that it is affected by the presence of conductive and non conductive object in its surroundings which affect the conductivity measurements and calibration.

The graphic of Fig. 10 indicates that we get a better conductivity measurement if we confine the field.

Considering the variation of the value of the conductivity sigma between 0.1 and 1 S/m the results for the variation of the value of MMF as a function of sigma for 2 and 3 electrodes cells with and without objects surrounding the cell are shown in the graphic of the Fig. 11.
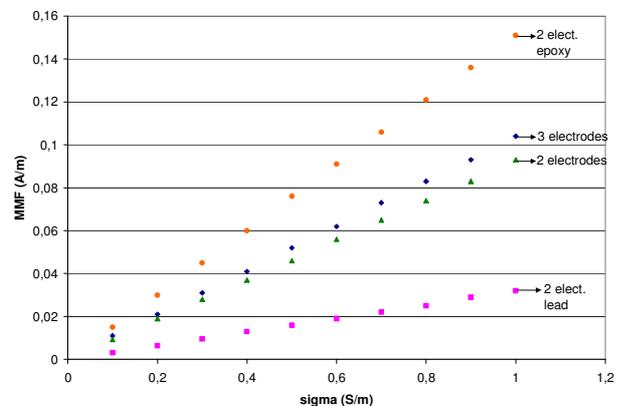

Fig. 11 – Variation of MMF as a function of sigma for 2 and 3 electrodes cells with conducting and non conducting objects in the surroundings of the cell.

The two electrodes cell shows a difference of about 10% from the three electrodes cell.

If we take a conductive object like lead near the two electrodes cell the difference drops about 70% and with an epoxy object increases about 30%.

All the values were taken for the middle position between electrodes.

6. CONCLUSION

Two electrodes cells have great dependency of surrounding objects.

The three electrodes cell is the best geometry for conductivity measurements since it has current density confinement.

The confinement of the field gives good results for conductivity measurements. Considering comparative results between a three electrodes cell and a commercial conductivity sensor the accuracy is less than 3.5% [4].

Since the value of conductivity is taken from the value of the current density in the volume defined by the electrodes the error in the measurement of conductivity is directly related with the current density losses, i.e, about 20%. In the same way the value of experimental geometric factor, K, varies according to those same losses for each different setup.

7. REFERENCES

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