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COMSOL Multiphysics Modelling for Measurement Device of Electrical Resistivity in Laboratory test cell

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Abstract:

Leachate recirculation is a key process in the scope of operating municipal waste landfill as bioreactor which aims to increase the moisture content to optimize degradation in landfills. Given that liquid flows exhibit a complex behaviour in very heterogeneous porous media in situ monitoring methods are necessary.
Surface electrical resistivity tomography is usually proposed, but the interpretation of resistivity data variation is not easy. For this reason, a laboratory approach is developed for a better understanding of electrical resistivity variation of waste. The aim of this paper is to determine if Comsol Multiphysics can help to improve the characterisation and measurements of laboratory test cell. Electromagnetic module (EM) in COMSOL Multiphysics is used to study a model of sensor systems.
In the first part, numerical measurements on homogenous media can highlight errors on resistivity measurement from electrodes position in the test cell. The results show that the difference between modelling and measurement is very close to 3%.
In the second part we demonstrate at the laboratory scale that is necessary to take into account in the inversion process the electrode shape, by considering an equivalent point node position where the geometrical factor is the same.

1. Introduction.

The bioreactor landfill process is studied and tested since 1970. Many studies have pointed out the potential benefit of the bioreactor for a quicker stabilisation of organic matter (Pacey et al., 1999). In bioreactor, leachate recirculation allows improving the biodegradation of the waste body by the water optimization.
This water optimization process is controlled by an optimum and a homogenous distribution of water content in the deposit cell. Therefore, measuring and controlling water content in waste landfills is a key issue and a real challenge for operators to monitor bioreactor degradation process (Imhoff et al., 2007).

Most of studies have shown that Electrical Resistivity Tomography (ERT) can be a suitable method to study relative water content variation using 2D or 3D representations (Clément et al., 2011; Guérin et al., 2004; Moreau et al., 2003). ERT is based on non-intrusive and non-destructive resistivity measurements. Electrical resistivity is influenced by many physical and chemical parameters of the medium studied and no single relationship with volumetric water content was yet established for Municipal Solid Waste (MSW). MSW scale is not adapted to control physical parameters of waste body and study their influence on resistivity laws. To achieve this goal, laboratory test were started using cylindrical test cells (Figure 1-a). Before carrying out surveys in laboratory test cell, metrological evaluation of resistivity device is necessary with numerical modelling approach using Comsol Multiphysic 4.1.

2. **Electrical Resistivity Tomography.**

ERT method is well described in the geophysical literature (for example Chapellier, 2000). The apparent resistivity (ρ_{app} in ohm.m) is calculated from a quadripole composed with 2 injected current electrodes (I in ampere) and 2 others electrodes to measure a potential difference (ΔV_{mn} in volt) (Figure 1). The electrodes position is taken into account in, the equation with the geometrical factor (**k**) (equation 1 and figure 1).

$$\rho_{app} = \frac{k \times \Delta V_{MN}}{I} \qquad \textbf{(1)}$$

Based on several apparent resistivity data measured, interpreted resistivity distribution is derived from inversion algorithm software. In the inversion process several tools consider the electrodes as a point node but the electrode geometry could not considered like punctual in our test cell. Rucker and Guenther (2011) showed that this approximation induced some errors for calculation of **k**. To estimate the value of **k** two methods can be use in your case:

- Carry out an experiment on homogenous medium in laboratory test.
- Use numerical computation with Comsol Multiphysics 4.1.

3. Test cell and electrical resistivity device.

The test cell is a circular High-Density Polyethylene (HDPE) tank, with a waterproof fixed bottom and a moving top platen test. The cylindrical cell has an internal diameter of 150 mm, a height of 170 mm and an approximate volume of 0.003 m^3. Resistivity device is composed by 16 steel electrodes (8 mm diameter and 60 mm long) allowing 124 quadripoles configuration to record apparent resistivity. Electrodes position and shape are described in Figure 2. The electrode length in contact with waste medium studied is equal to 10 mm. The HDPE laboratory test cell is considered as an electrical insulator with a conductivity of 10^{-14} S/m. The conductivity of the steel electrodes is 10^6 S/m.

4. Use of COMSOL Multiphysics for resistivity measurement

The advantage of Comsol Multiphysic 4.1, those electric field distributions can be modelled using full 3D modelling and the potential difference due to injected current can be evaluated easier. To do that, seven modelling steps are conducted:

1. Choosing the mode in the EM module.
2. Drawing the laboratory cell geometries.
3. Generating the mesh.
4. Set electrical properties in the domains.
5. Set the boundary conditions.
6. Solve and find the field distribution.
7. Use the post-processing capabilities in COMSOL to compute voltages

Electric field distributions is built using AC/DC module (quasi-stationary electromagnetic field with the theory of electromagnetic field) to evaluate the potential difference induced by the injected current. The geometry design (electrode and cylindrical cells) is real challenging for ERT modelling. Cylindrical cell with 16 complete electrodes embedded (0.01 m) is designed using FEM Comsol tool (Figure -a).

Homogeneous resistivity model of 20 ohm.m is created with electrical insulation at the boundaries and virtual ground node (point) is placed at the centre of the test cell. To simulate the current injection we apply: An intensity of 1 A on the electrode of injection "A" and -1A on the electrode injection "B".

With the model carried out, we simulated:

- The distribution of the potentials resulting from the of current injection point between A and B (figure 3-b)
- The distribution of the current density (figure 4-b)

At the end of simulation, potentials (expressed in volt) at the electrodes M and N are estimated and the potential difference calculated. Knowing the resistivity of the medium, the intensity of the injected current and the potential difference, the geometrical factor can be estimated for each quadripole using equation 1.

The next result part of this paper is articulated in two steps:

- The first steps allow comparison of geometric factor K results between Comsol multiphysics software and laboratory experiment.
- The second steps, geometrical coefficients are modelled for point node electrode and complete electrodes to take into account inversion specification.

5. Result

5.1 Comsol Multiphysics model validation.

A	B	M	N	Simulated geometrical factor	Measured geometrical factor	Standard deviation
1	13	5	9	0.127	0.125	1.92
5	6	7	8	0.581	0.596	2.58
5	8	9	12	0.279	0.286	2.48
5	6	11	12	0.888	0.906	1.96

Table 1 comparison between simulated geometrical factor with Comsol Multiphysics 4.2 and measured geometrical factor in laboratory.

To validate the electrical model obtained with Comsol, experience is performed using the laboratory test cell illustrated. In our laboratory cell, water of known electric resistivity (20 ohm.m) is used and measurements are carried out to control the

known injection current and record the potential voltage.
The values of measured geometrical factor and the value of geometrical factor obtained with Comsol Multiphysics 4.1 are reported in Table 2.

Table 1 summarizes all the results for four selected quadripole configuration according to typical electrode arrays, vertical (1.13.5.9), horizontal (6.5.7.8), on two levels (5.8.9.12) and cross on two levels (6.5.11.12) (Figure 2). For the four quadripoles, we observe that the values of the simulated geometrical factor with Comsol 4.1 and measured in laboratory are in the same order of magnitude with a deviation included between 1.9% and 2.5%. According to that result, the model is considered as realistic. Thereafter document, we will carry out the same model while varying electrode shape, and we will estimate the impact on geometrical factor for the four quadripole,

5.2 Comparisons between complete electrodes and point electrodes.

As proposed in the article of Carsten et al. 2011, we compare the influence of complete electrodes with a point source current. (Figure 3-a and 3-b). The real inversion algorithm can't take into account the electrode shape. Carsten et al. (2011) proposed to find a position where the geometrical factor calculated for complete electrode and point node is equivalent.
The geometrical factor calculated for the four quadripole with the complete electrodes in the first step is compared with data obtained from models with variant point node position; the point radius position point varies between 0.066 and 0.075 inside the laboratory cylindrical test cell. Figure 4 shows the relative geometrical factor error for the four selected quadripole, between the point node and the complete electrode expressed by:

$$\xi = \left(1 - \frac{K_{CE}}{K_{PN}}\right) \times 100 \qquad (2)$$

Where:
ξ, the error in percentage**,**
$K_{CE,}$ the geometrical factor for the complete electrode,
$K_{PN,}$ the geometrical factor for the point node source,

For the quadripole 1 13 5 9, ξ varies in a range between 0.4% and 3.7%. The minimal error value is located at the abscise 0.07 at the centre of the buried part of the electrode.

For the quadripole 5 8 9 12, ξ varies in a range between 0.3% and 3.2%. The minimal error value 0.4 % is located at the abscise 0.07 m at the centre of the buried part of the electrode.

For the quadripole 5 6 11 12, ξ varies in a range between 0.1% and 1%. The minimal error value 0.4% is located at the abscise 0.072 m at the centre of the buried part of the electrode.

For the quadripole 5 6 7 8, ξ varies in a range between 0.1% and 1%. The minimal error value 0.4% is located at the abscise 0.072 m at the centre of the buried part of the electrode.

The following result shows that ξ for different quadripole is not the same and that the point node position has an important impact on *K* value. The error is in a range between 0.1% to 4% for 10 mm variations of the point node position. ξ is more important for quadripoles 1 13 5 9 and 5 8 9 12 . For the quadripole 5 6 11 12 and 5 6 7 8 ξ is lower than 1% and it is thus negligible. For inversion process with these data recorded with laboratory test cell, the position of 0.07 is we retained. This result shows that the position of the point node electrode has to be calculated to avoid errors in the inversion process.

6. Conclusions

First, results of numerical computation with Comsol Multiphysics 4.1 allowed us to compare the influence of complete electrodes with a point source current. We undertook a research of the position of the injection point. Electrodes representations were computed as points and the others as complete electrodes. Eight positions were tested for each quadripole. ξ is different in function of quadripole use. Results lead us to situate our equivalent injection point at 50% of the length of the electrode inside the cell when we inverse the data set.

From the result obtained with numerical modelling, Comsol opens some perspective in term of electrical resistivity tomography in laboratory. Many configurations of electrode array will be tested to improve electrical resistivity measurement, and to evaluate different shape of electrode to reduce the uncertainty. The robustness of the inversion algorithm could be estimate using synthetic model and apparent resistivity calculated with Comsol Multiphysics 4.1.

In conclusion, the simulation of electric field distributions in insulating structures is very interesting when designing ERT laboratory equipment. The use of Comsol Multiphysics 4.1 FEM Electromagnetic analysis in evaluating electrical resistivity laboratory sensor systems greatly improves the confidence on measurement and opens news geophysical perspectives.

7. References

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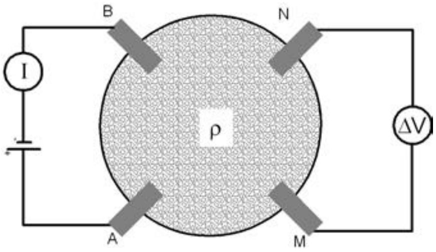

Figure 1: Electrical resistivity measurement with quadripole, A and B injection current electrodes, N and M potential difference measurement.

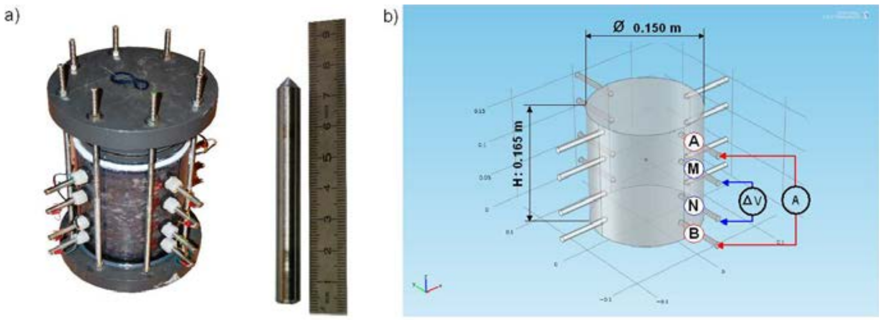

Figure 2: a) Test cell and electrodes; b) Electrical resistivity measurements principle (AB, current injection electrodes; MN electric potential electrodes).

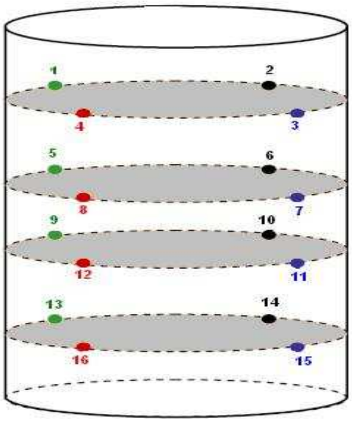

Figure 3: Electrodes numbers and positions.

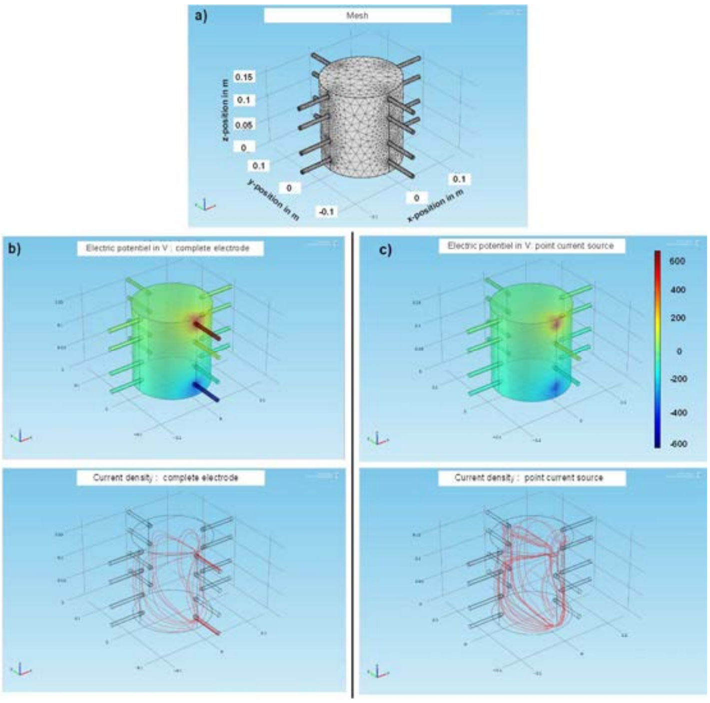

Figure 4: a) Test cell mesh used for calculation, b) electric potential and current density for complete electrode, c) electric potential and current density for point node electrode.

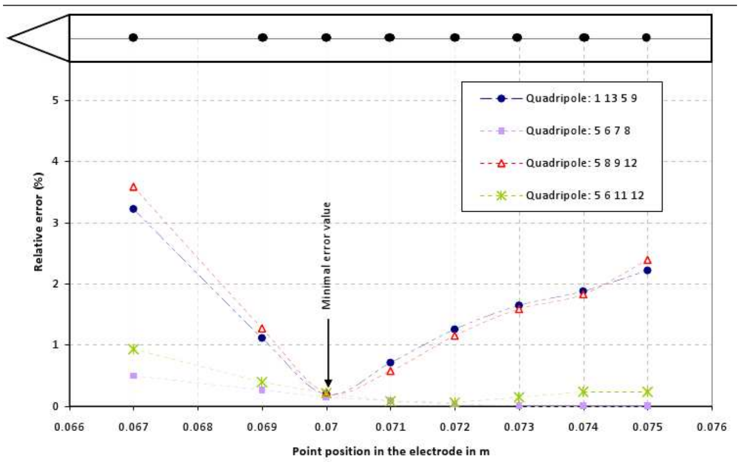

Figure 5: Relative geometrical factor error induce on the resistivity value by the use of a complete electrode for the measurement and node point for the inversion process.