Research on Electrical Characteristics of Mixed Media Based on Computer Simulation Technology

Aorigele
Chifeng Institute of Industrial Technology. Chifeng 024000, Inner Mongolia

Abstract: Computer technology is mainly used to study the electrical characteristics of mixed media through calculation and analysis of its equivalent dielectric constant. Since the geometric distribution, content, and structural shape characteristics of different phases in the mixed media will affect the equivalent dielectric constant to varying degrees, we need to analyze the relevant factors. However, when analyzing the relationship between the geometric distribution characteristics of each phase and the equivalent permittivity in a mixed medium, the traditional hybrid formula analysis method cannot meet the actual needs of complex equivalent permittivity research. Therefore, we must adopt computer simulation technology and use relevant simulation software to realize the conversion between geometric distribution and correction factor. In addition, we can also modify the mixing formula through the porosity function to accurately understand the electrical properties of the mixed medium.

1. Introduction
In recent years, the rapid development of computer and network information technology in my country has made simulation technology an important direction for the development of computer technology. Moreover, as simulation technology continues to mature and improve, it has been widely used in various fields of production and life. Through the application of computer simulation technology, we can construct the corresponding system model according to actual problems. Besides, we can also use computer algorithms and corresponding tools to quantitatively analyze more complex problems, and at the same time provide ways to solve the problems. Because computer simulation technology is not restricted by environmental conditions, and its problem analysis is accurate and efficient, this technology has been widely used in the analysis of complex problems such as the study of electrical characteristics of mixed media. In addition, the application of computer simulation technology effectively solves the problem that the traditional mixing formula cannot accurately analyze the influence of geometric distribution characteristics on the equivalent dielectric constant of the mixed medium. It can not only realize the correction of the hybrid formula through the construction of the simulation model, but also compare and verify the solution value of the correction formula with the simulation value, thereby laying a technical foundation for the comprehensive and accurate analysis of the electrical characteristics of the mixed medium.

2. Overview of Computer Simulation Technology

2.1. COMSOL Multiphysics Software Technology of Computer Simulation
When using computer simulation technology to study the electrical properties of mixed media, we can use COMSOL Multiphysics software to solve partial differential equations through finite element algorithms, and realize the simulation analysis of the physical properties of mixed media. Computer
COMSOL Multiphysics simulation software is an advanced numerical software system widely used in many scientific research fields. It can not only simulate various physical projects, but also directly perform coupling analysis on multiple physical fields. Because it has better coupling analysis and calculation capabilities, it can significantly improve the accuracy of computer simulation, and is more suitable for simulation analysis of the more complex geometric distribution of multi-mixed media. At the same time, the foundation of COMSOL Multiphysics simulation software is still the finite element method, which can solve and calculate multi-field partial differential equations and single-field partial differential equations, so as to achieve the effect of simulation and simulation of real physical phenomena [1]. In addition, a variety of physics are preset in the COMSOL Multiphysics software, which provides favorable conditions for the rapid construction of simulation models. Moreover, the definition model in COMSOL Multiphysics simulation software also has high flexibility. It can not only use interpolation functions to represent measured data, but also use arbitrary variable functions and constants to set boundary conditions, material properties, or source terms. The COMSOL Multiphysics simulation software is also equipped with different functional modules, which can be expanded according to the actual simulation needs and provide convenience for users to customize the physics. Therefore, the research on the electrical properties of mixed media based on computer simulation technology has been more and more widely used.

2.2. Analysis of the Basic Process of Computer Simulation
When conducting research on the electrical properties of mixed media based on COMSOL Multiphysics simulation software, we should first set up the physical field. The AC/DC module of COMSOL Multiphysics simulation software contains various application modes such as electrostatic field. In this way, users can choose the corresponding mode according to the specific characteristics of the research problem they need, which provides convenience for the user's simulation and calculation analysis [2]. Later, we should make the choice of geometric space and geometric structure. After that, the user should also reasonably set the geometric distribution and excitation conditions, and clearly define the boundary conditions, so that the calculation and solution can be performed after the mesh is divided. When applying COMSOL Multiphysics simulation software to study the electrical properties of mixed media, we should first choose the electrostatic field as the physical field, and we should build the model in the three-dimensional geometric space.

The mixed medium used in this study is a three-phase medium. We use W to represent water, S to represent solid particles, and N to represent petroleum. Therefore, the geometric structure we selected mainly includes two types of structures, SWN and NWS. However, the geometric distribution pattern is set to 4 types. At the same time, we also determined 100V as the experimental voltage for this study in the excitation setting, and its pressure direction is Z direction. After completing the construction of the simulation model, we should add relevant materials to the mixed medium. In this mixed media study, the dielectric constant distribution was set to ~2 non-wetting phase, ~80 wetting phase, and ~4 solid particles. The boundary conditions are periodic boundaries. In addition, we should not only use tetrahedral free mesh as the mesh, but also reset the mesh parameters. Only in this way can we guarantee the research and analysis of the electrical properties of the mixed media in a relatively stable state. After completing the relevant settings, we can solve the differential equations. In the solution process, we can use COMSOL Multiphysics simulation software to directly calculate and analyze the parameters such as the set battery strength and power plant flux.

2.3. Analysis of Fitting Method of Computer Simulation Technology
When performing curve fitting, the least squares method is currently mainly used, which is also the main calculation method to solve the data matching problem. The so-called least square method can also be called the least square method. This is a kind of mathematical optimization technology, which is mainly used in scientific fields such as estimation error and uncertainty, prediction, identification system, etc. It is one of the more widely used mathematical tools. This mathematical optimization method mainly uses the minimization of the error square to achieve the best match with the data
function. Through the least square method, a simple linear regression model and estimated values of related parameters can be obtained based on sample data. However, whether the parameter estimated value can be close to the real measured value requires that the least squares formula has good linearity, unbiasedness and minimum variance. Among them, unbiased means that the estimated parameter value is the same as the real measured value, and the linear characteristic mainly refers to the linear combination of the observed value and the estimator [3]. The minimum variance mainly refers to that the variance of the estimated value compared with other solving methods is the best that is the smallest. Due to this characteristic of the least square method, the estimated value obtained by it is the best value compared with other solving methods. Therefore, the least square method cannot only be used to express optimization problems such as maximum entropy and minimization ability, but also a common method of curve fitting.

When applying the least squares method to find the best matching function, we should set the given data. For example, \{(xi, yi), i=1, 2, \ldots, n\}'s fitting function is set to \(\phi(x)\), in order to find the best matching function of the data that can make the measurement data error evenly divided. The least square method can not only realize the rapid solution to the unknown data, but also has a higher degree of fit between the obtained solution value and the actual value. Therefore, the fitted water cut must be able to accurately reflect the main changes in most of the data. However, the experiment does not require it to reflect all the data changes, so there will be a certain error between the actual measured value and the fitted function value. We can use \(E_i\) to represent the error value, and we should calculate and analyze \(E_i\) according to the following formula.

\[
E_i = \phi(x_i) - y_i, \quad i=1, 2, \ldots, n \quad (1)
\]

The square value of \(E\) should be the smallest, so that the fitted curve can more accurately reflect the actual change law of the data. The square value of \(E\) should be calculated according to the following formula:

\[
E^2 = \sum (\phi(x_i) - y_i)^2 \quad (2)
\]

The MATLAB software of the computer can be programmed and calculated according to the principle of the least square method, so as to minimize the square difference between the simulated numerical solution and the theoretical formula solution value. At the same time, we can also determine the set correction factor and porosity function, and then use other distributions to verify and analyze the geometric correction factor.

3. Research on Electrical Characteristics of Mixed Media Based on Computer Simulation Technology

3.1. Build Geometric Distribution Model of Mixed Media

Research on the electrical characteristics of mixed media based on computer simulation technology can use computer simulation technology to simulate and model different mixed solutions. In this study, the NW mixed medium S structure with rock particles wrapped in water and oil distributed around and the SWN mixed medium structure with oil wrapped in water and solid particles distributed around were selected, and modeled separately (the distribution model can be seen in Figure 1 and Figure 2). In the simulation model, mark the innermost ball with C, mark the composite ball with S, and mark the outer skeleton with m. At the same time, 4 different geometric distribution models of random distribution, simple distribution, face center distribution and body center distribution are set up, and they are represented by RD, SC, FC and BC.
3.2. Modification of the Mixed Formula for the Electric Characteristic of Mixed Media Based on Computer Simulation Technology

3.2.1. Using Computer Simulation Technology to Transform Geometric Correction Factors

After completing the simulation calculation, a comparison analysis should be made with the obtained simulation COMSOL Multiphysics results according to the LLCM hybrid classic formula. The so-called LLCM formula is the abbreviation of the Lorentz-Lorenz-Clausius-Mossitt classic mixed formula. Through the analysis of the simulation value and analytical curve under the porosity between 0.03 and 0.96, we can find that the simulation value and analytical formula result will not fit when the porosity continues to increase and exceeds a certain range. Therefore, we need to modify the analytical formula [4]. The correction parameter added to the LLCM formula can be represented by $\mu$. Since the correction parameter $\mu$ in this study mainly refers to the geometric distribution of different phases in the mixed medium, $\mu$ in this article represents the geometric correction factor.

3.2.2. Modified Analysis of Least Squares Formula in the Study of Electric Properties of Mixed Media

When using computer simulation technology for simulation programming, the simulation data set should be determined according to the different characteristics of the geometric distribution model. For example, in the SC geometric distribution model, the porosity and equivalent permittivity should be used as the simulation data set when programming through MATLAB software due to the large changes in its porosity. At the same time, we should set the variation range of $\mu$ between 0.01 and 0.1. Then, the simulation results of the SC geometric distribution type are imported into the LLCM correction formula. In addition, we can also use the least square method to select the geometric correction factor under the condition that the difference between the simulation result and the solution value of the LLCM correction formula is the smallest. After that, the relationship between porosity and $\mu$ is determined by curve fitting. Finally, we should also use other distributions to verify the correction formula [5]. Among them, the LLCM correction formula is:
The calculation formula of porosity is:

\[
\frac{\varepsilon_{sc} - \varepsilon_s}{\varepsilon_{sc} + 2\varepsilon_s + \mu_1(\varepsilon_{sc} - \varepsilon_s)} = f \frac{\varepsilon_c - \varepsilon_s}{\varepsilon_c + 2\varepsilon_s + \mu_1(\varepsilon_c - \varepsilon_s)}
\]

\[
\frac{\varepsilon_{eff} - \varepsilon_m}{\varepsilon_{eff} + 2\varepsilon_m + \mu_2(\varepsilon_{eff} - \varepsilon_m)} = \phi \frac{\varepsilon_{sc} - \varepsilon_m}{\varepsilon_{sc} + 2\varepsilon_m + \mu_2(\varepsilon_{sc} - \varepsilon_m)}
\]

\[\mu = 1890.1 \phi^6 - 4989.3 \phi^5 + 4956.6 \phi^4 - 2304.1 \phi^3 + 512.3 \phi^2 - 49 \phi + 1.5\]  \(\text{(3)}\)

The calculation formula of porosity is:

\[\phi = \frac{V_{\text{Pore Volume}}}{V_{\text{Total Capacity}}} = \frac{V_o + V_z}{V_o + V_z + V_H}\]  \(\text{(4)}\)

Similar to the simulation calculation method of SC distribution, the relationship curve between porosity and \(\mu\) under the condition of NWS structure can also be obtained by using computer simulation technology. See Figure 3 for details.

![NWS-SC](image)

Figure 3: Schematic Diagram of the Relationship Between Porosity and \(\phi_2\) Value Under NWS and SWN Structure Conditions

### 3.2.3. Compare and Analyze the Corrected Formula Solution Value and the Solution Value Based on Computer Simulation Technology

After completing the construction and simulation calculation of four different geometric distribution models of the two mixed media, SWN and NWS, respectively, we should compare and analyze the solutions of their LLCM correction formulas. The comparative analysis results can be seen in Figure 4 and Figure 5.
4. Conclusion
When analyzing the electrical characteristics of mixed media, we can build different simulation models through the application of computer simulation technology in order to accurately grasp the relationship between the geometric distribution of each phase and the equivalent dielectric constant. In addition, we can also use computer simulation software such as COMSOL Multiphysics to try to calculate and analyze the equivalent dielectric in different distribution models. Moreover, we can also determine the geometric correction factor based on the calculation result to correct the least squares formula. Through the comparison and analysis of the simulation calculation results and the solution value of the correction formula, we can find that after the correction of the mixed formula, the equivalent permittivity of the mixed dielectric under various geometric distribution conditions can be
accurately calculated. This provides important technical support for the study of the electrical properties of mixed media.

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