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Research on the influence of bubbles on electromagnetic flow measurement

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Abstract

Bubble, a key factor in the electromagnetic measurement, is crucial to the research of the electromagnetic flowmeter due to its effects. In this paper, an analytical method is investigated for the weight function under radius variation and eccentricity of the bubble. To overcome the unfeasibility of analytic method, finite element simulation and moving mesh technology are used to analyze the radius variation and eccentricity of the bubbles along with the flowing of numerous bubbles in the tube, and the corresponding weight function distribution is obtained. Based on the analytic solutions and simulation analysis, two evaluation standards are proposed for the heterogeneous density and sensitivity of weight function under different situations. The results show that the bubble radius variation and its eccentricity along different electrode directions have a large influence on the weight function heterogeneous density, while the influence vertical to the electrode direction keeps constant. When many bubbles flow in the fluid, the bubbles closer to electrode crosscut have less voltage sensitivity, and the ones farther show greater voltage sensitivity. This research attaches great significance to the electromagnetic measurement of fluids with bubbles and can be spread to the measurement of double-phased flow electromagnetic measurement of insulation medium with solid particles.

Keywords

Electromagnetic, bubbles, flowmeter.

1. Introduction

Double phased flow is widely applied in the field of petroleum, metallurgy, chemical engineering, power and dynamics, the parameter measurement of which is attached great significance to the production process. However, the double-phased flow has complex features and extremely great difficulty of parameter detection [1-2]. Speed, an important parameter in the measurement of double-phased flows, is important for analyzing fluid state in the tube. Methods of mechanics, optics, acoustics, heat, nuclear magnetic resonance, and relevance can be applied to measure the speed of double-phased fluids. Electromagnetic flowmeter is an instrument that is based on Faraday electromagnetic conduction law, used in the measurement of average speed of the conducted fluids. The result of measurement is not related to working pressure, temperature, viscosity, and conductivity, etc., therefore the electromagnetic flowmeter is widely used in single-phase as well as double-phased flow measurement. However, there still exist many problems for the measurement of double-phased flow. When bubbles exist inside the measurement tube, the weight function of electromagnetic flowmeter varies due to the bubbles acting as the insulating dielectric. Virtual current, with a varying distribution due to insulated medium, is especially determined by electrical features, and incapable of penetrating insulated medium like bubble. In order to study the influence of the insulating medium on electromagnetic measurement, scholars from home and abroad have implemented researches from different aspects.

As for the double-electrode electromagnetic flowmeter, Zhang et al. solved the weight function of electromagnetic flowmeter by Laplace equations using an alternating iteration method,and the distribution of electromagnetic flowmeter current density was obtained [5]. Wang et al. used finite element software ANSYS to study the influence of the electromagnetic flowmeter to oil and water double phased crosscut response characteristics[6]. Shi et al. designed arc electrode electromagnetic flowmeter to realize gas and water double phased flow measurement, elucidated the excellent linear relationship between the conduction voltage and fluid parameters of arc electrodes and optimized the degree of 2 arc electrodes [7-8]. Du et al. carried out a relevant simulation analysis of triple phased fluid of water, oil, and gas [9]. Ma et al. combined two tomographic scanning systems (Magnetic induction tomography and electromagnetic velocity tomography), mostly used in the measurement of water phase crosscut volume fraction and partial axial velocity [10].Cha et al. studied the flow output phase and amplitude of fluid metal double phased [11]. Wang et al. used finite element simulation modelling to study the feature of electromagnetic flowmeter of multi-phased flow, and the result of the simulation showed that electromagnetic flowmeter is possibly a new way to measure the axial velocity distribution of conductive continuous phased [12-13]. Li et al. used value simulation to study the effect of a single bubble on electromagnetic virtual current density [14]. Wang et al. developed a capacitance electromagnetic, used to measure oil and water double-phased flow and proved that the feature of capacitance electromagnetic flowmeter has a better performance than electrode electromagnetic flowmeter [15].

Currently, as for the influence of double-phased flow on electromagnetic measurement, researchers mainly study the insulated substances, which have an impact on weight function. Virtual current density is an important quantity in the theory of electromagnetic flow measurement, which has a direct relationship with the weight function vector while the research on the influence of bubbles on virtual current density and weight function is relatively less. Moreover,simulation research is mainly focused on single bubbles or multiple bubbles with fixed positions. When bubbles in revelation simulation are motionless, with stable simulation results, it is difficult to realize the real-time display of the weight function of bubbles flowing inside the pipe. Therefore, this research is mainly focused on the effect of bubbles on virtual current density and weight function of electromagnetic flowmeter, where mobile network and finite element simulation are applied to analyze and evaluate the effect of flowing bubbles on weight function.

This paper is mainly scoped within the effect of bubbles on electromagnetic flow measurement. The following contents are arranged as follows: in the second part, the analytical method is used to Figure out the analytical solutions of the bubble radius variation and eccentricity. In the third part, finite element simulation and moving mesh technology are applied to simulate bubble radius variation, bubble eccentricity and flowing situation in the tube to obtain the corresponding weight function distributions. The fourth part analyzes the variation of uneven density and sensitivity of weight function. The fifth part is the summarization of the work.

2. Theoretical Research on Effect of Bubbles on Electromagnetic Flow Measurement

2.1. Weight Function Theorem Foundation

Basic equations of an electromagnetic flowmeter can be Figured out according to Maxwell equations and assumptions. Currently, the integration formula given by Bevir [16] in 1970 is mostly used as:

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$$U_2 - U_1 = \int_A \vec{W} \cdot \vec{v} dA \tag{1}$$

Where $U_2 - U_1$ is the difference of electrodes, A is the integration in the whole space, $\vec{v}$ is the fluid speed, $\vec{W}$ is the vector weight function, which is determined by its own structure. The expression is:

$$\vec{W} = \vec{B} \times \vec{j} \tag{2}$$

Where $\vec{j}$ is the virtual current density, determined by the electrode structure. Vector $\vec{B}$ is the magnetic conduction intensity. If the measured fluid does not have the source of electricity and magnetism $\vec{j}$ and $\vec{B}$ can be expressed by potential. G and F are potential of $\vec{j}$ and B, which satisfies Laplace Equations.

2.2. Effect Of Bubbles on Weight Function

As for air-water two-phase flow, when the bubble is located on the central axis of the electromagnetic flowmeter measurement tube, the double dimensional model is shown in Figure 1. Based on the weight function theory, the weight function of an electromagnetic flowmeter with point electrodes and uniform magnetic field in a two-dimensional concentric ring is solved.

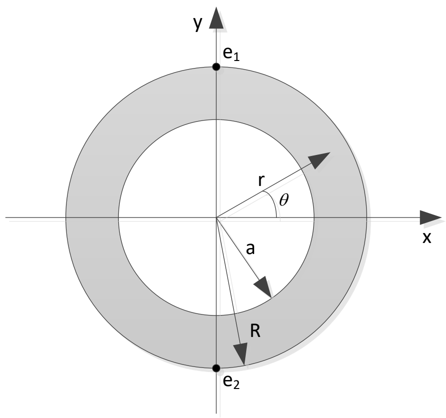

Figure 1. Electromagnetic flow system crosscut with only one bubble

Where a is the radius of bubbles, two electrodes (e_1, e_2) are on y axis, the measurement tube has a radius of R. The boundary value of virtual current potential G under polar coordinate is:

$$\frac{\partial}{\partial r}\left(r\frac{\partial G}{\partial r}\right) + \frac{1}{r} \cdot \frac{\partial^2 G}{\partial \theta^2} = 0 \tag{3}$$

$$\begin{cases} \left.\dfrac{\partial G}{\partial r}\right|_{r=a} = 0 \\ \left.\dfrac{\partial G}{\partial r}\right|_{r=R} = \begin{cases} \dfrac{\delta(\theta - \frac{\pi}{2})}{R} \\ \dfrac{-\delta(\theta + \frac{\pi}{2})}{R} \end{cases} \end{cases} \tag{4}$$

The general solution of G is:

$$G(r,\theta) = C_0 + D_0 \ln r + \sum_{n=1}^{\infty} (C_n r^n + D_n r^{-n})(A_n \cos n\theta + B_n \sin n\theta) \tag{5}$$

By substituting the boundary condition, it can be obtained that

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$$\begin{cases} G_1 = \dfrac{1}{\pi}\displaystyle\sum_{n=1}^{\infty} \dfrac{\left(\dfrac{r}{R}\right)^n + \left(\dfrac{a}{R}\right)^{2n}\left(\dfrac{R}{r}\right)^n}{n\left[1-\left(\dfrac{a}{R}\right)^{2n}\right]} \cos n(\theta + \dfrac{\pi}{2}) \\ G_2 = \dfrac{1}{\pi}\displaystyle\sum_{n=1}^{\infty} \dfrac{\left(\dfrac{r}{R}\right)^n + \left(\dfrac{a}{R}\right)^{2n}\left(\dfrac{R}{r}\right)^n}{n\left[1-\left(\dfrac{a}{R}\right)^{2n}\right]} \cos n(\theta - \dfrac{\pi}{2}) \end{cases} \tag{6}$$

G is the sum of G_1 and G_2

$$G = G_1 + G_2 = \frac{2}{\pi}\sum_{n=1,3,5,\ldots}^{\infty} \frac{\left(\frac{r}{R}\right)^n + \left(\frac{a}{R}\right)^{2n}\left(\frac{R}{r}\right)^n}{n\left[1-\left(\frac{a}{R}\right)^{2n}\right]} \cos n(\theta - \frac{\pi}{2}) \tag{7}$$

The expression of weight function can be obtained based on the weight function theory of equation (2)

$$\begin{aligned} W(r,\theta) &= B_0\frac{\partial G}{\partial r}\sin\theta + B_0\frac{\partial G}{r\partial\theta}\cos\theta \\ &= \frac{2B_0}{\pi R}\sum_{n=1,3,5,\ldots}^{\infty}\frac{1}{1-\left(\frac{a}{R}\right)^{2n}} \bullet \\ &\left\{\left(\frac{r}{R}\right)^{n-1}\sin\left[(n-1)\theta - n\frac{\pi}{2}\right] + \left(\frac{a}{R}\right)^{2n}\left(\frac{R}{r}\right)^{n+1}\sin\left[(n+1)\theta - n\frac{\pi}{2}\right]\right\} \end{aligned} \tag{8}$$

2.3. Effect of Bubble Eccentricity on Weight Function

Bubble size is an important factor affecting the weight function, but when bubbles flow in the pipeline, bubbles do not necessarily lie in the center of the cross-section of the pipeline. In most cases, the center of the bubbles does not coincide with the center of the cross-section of the pipeline. This kind of eccentric boundary condition is complex, and the eccentric ring region is solved by conformal transformation first. Mapping to a concentric ring, as shown in Figure 2, assuming the bubble radius be a.

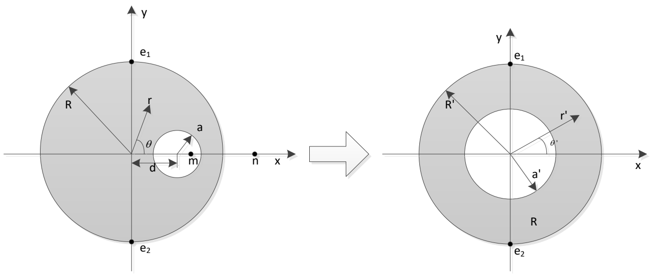

Figure 2. Mapping from Eccentric to Concentric Rings

Assuming m, n as two symmetric points on the circle of plane z, the coordinates of which are x_1 and x_2:

$$x_1 x_2 = R_1^{\,2},\ (x_1 - d)(x_2 - d) = R^2 \tag{9}$$

The coordinates of points m and n are:

$$x_1 = \frac{\left(d^2 + R^2 - a^2\right) - \sqrt{\left(d^2 + R^2 - a^2\right)^2 - 4R^2d^2}}{2d}, \quad x_2 = \frac{\left(d^2 + R_1^2 - R_2^2\right) + \sqrt{\left(d^2 + R^2 - a^2\right)^2 - 4R^2d^2}}{2d} \tag{10}$$

Performing fractional linear transformation to eccentric circulation region

$$w(z) = \left(z - x_1\right) / \left(z - x_2\right) \tag{11}$$

In this case, points m and n on plane z are both mapped on plane w, original point and ∞. Then two concentric circles whose radii are R' and r' respectively circle center distance d are mapped to w plane by two eccentric circles.

$$\begin{cases} R' = \left[(d+R)^2 - a^2 - \sqrt{(d^2-R^2-a^2)^2 - 4R^2a^2} \right] \\ \quad / \left[(d+R)^2 - a^2 + \sqrt{(d^2-R^2-a^2)^2 - 4R^2a^2} \right] \\ a' = \left[(d+a)^2 - R^2 + \sqrt{(d^2-R^2-a^2)^2 - 4R^2a^2} \right] \\ \quad / \left[(d+a)^2 - R^2 - \sqrt{(d^2-R^2-a^2)^2 - 4R^2a^2} \right] \\ r' = \sqrt{\dfrac{r^2 - 2rx_1\cos\theta + x_1^2}{r^2}}, \theta' = \mathrm{arctg}\dfrac{(x_1-x_2)\rho\sin\theta}{r^2 + R_1^2 - r\cos\theta(x_1+x_2)} \end{cases} \tag{12}$$

The mapped concentric circulation region is solved by separating the variables method.

$$G(r',\theta') = \sum_{n=1}^{\infty} A'_m \cos m\theta' \left(r'^m + a'^{2m} r^{+m} \right) \tag{13}$$

Where

$$m = 2n-1, \quad A'_m = 4\sin\frac{m\theta'_0}{2} / \left[m^2 \pi \theta'_0 \left(R'^m - a'^{2m} R'^{-m} \right) \right] \tag{14}$$

The weight function equation in partial circular current can be obtained based on the weight function theory in equation (2),

$$W(r,\theta) = B_0 \left[\left(\frac{\partial G}{\partial r'}\frac{\partial r'}{\partial r} + \frac{\partial G}{\partial \theta'}\frac{\partial \theta'}{\partial r} \right)\cos\theta - \left(\frac{\partial G}{\partial r'}\frac{\partial r'}{\partial \theta} + \frac{\partial G}{\partial \theta'}\frac{\partial \theta'}{\partial \theta} \right)\frac{\sin\theta}{r} \right] \tag{15}$$

The analytical solutions of the weight function under the conditions of bubble diameter variation and bubble eccentricity are obtained. In actual flow measurement, the size and position of bubbles are random, and bubbles of different sizes can be characterized by radius variation, different positions can be characterized by eccentricity, the combination of which presents the random distribution of bubbles. However, the boundary conditions of several bubbles of different sizes and positions are extremely complex, and it is difficult to solve the analytical solution.

3. Method and Simulation Model

3.1. Moving Mesh Technology

The theoretical derivation of a single bubble is rather complicated, and the theoretical analytical solutions for multiple bubbles can not be obtained. However, the traditional Lagrange method and Euler method have some defects. Although the Lagrange method has the advantage of distinguishing material interface accurately, the intersection of meshes caused by large deformation will lead to interruption of calculation. In Euler method, although the geometric shape of meshes is better, the problems of interface tracking, hybrid meshes, and reconstruction at boundary are more difficult to deal with [19-20]. In order to solve this problem, the finite element method can be used by computer simulation technology. In order to simulate the influence of bubbles on the weight function more truly, the mobile grid technology can be introduced into the simulation study. As a kind of adaptive grid, mobile grid technology was first proposed by Liao et al. in 1992. Later, it was widely used in the field of partial differential equations by some scholars and achieved better results.

The key and most difficult point of the mobile grid method is to find a grid mapping or grid transformation that satisfies a certain jump. Harmonic mapping was proposed by Fuller in the 1940s. It was widely used in the fields of mathematical physics and the adaptive grid. Harmonic mapping was defined as follows [21-22]:

For two n-dimensional regions D_p and D_L, a smooth mapping is given: $\xi : D_P \to D_L$, the power density of which is:

$$e(\xi)(x) = \frac{1}{2}\left|d\xi\right|^2(x),\ \ x \in D_P\ , e(\xi) \in C^\infty(D_P) \tag{16}$$

The power of mapping ξ is the integration of power density:

$$E(\xi) = \int_{D_P} \frac{1}{2}\left|d\xi\right|^2(x)dx \tag{17}$$

Where D_p and D_L are physical area and logical area of calculation

Energy functional: the boundary point $E : C^\infty(D_P、D_L) \to R$ is called harmonic mapping. The Lagrange Euler equation of energy functional is

$$\Delta\xi^k + G^{ij}\Gamma^k_{\alpha\beta}\frac{\partial\xi^\alpha}{\partial x^i}\frac{\partial\xi^\beta}{\partial x^j} = 0 \tag{18}$$

Where Δ is Lagrange Beltrimi operator, G^{ij} is Rieman measurement of partial coordinate x^n, $\Gamma^k_{\alpha\beta}$ is the contact function of D_P.

Mobile grid technology is widely used in the case of large deformation and dynamic boundary. Electromagnetic measurement of the fluid itself is a dynamic process. When measuring the fluid containing bubbles, the dynamic process is more complex. If static grid is still used, it will bring huge errors and can not really reflect the influence of electromagnetic measurement on bubble pairs in the dynamic process. Therefore, the moving grid can simulate the flow of bubbles and fluids in the pipeline more realistically, and get the influence of bubbles on the weight function in the dynamic process.

3.2. Weight Function Simulation of Electromagnetic Flowmeter With Bubbles

In the actual engineering flow measurement process, bubbles will inevitably exist in the pipeline, and the movement of the bubble has a great influence on the electromagnetic measurement method, which is mainly reflected in the fact that the virtual current cannot pass through the bubble, so the existence of the bubble should be considered for the electromagnetic flow measurement process. . In the second part of the thesis, the influence of bubbles on the weight function in two dimensions is theoretically deduced, while the actual bubbles are three-dimensional geometry. Since the bubble flows with the fluid, it not only affects the weight function when the bubble passes through the electrode cross-section. In fact, the influence of the bubble on the weight function before and after passing through the electrode cross-section is cumulative. Therefore, by applying the moving grid technology to the electromagnetic flowmeter finite element simulation, it is possible to simulate the influence of the more realistic bubble movement on the weight function.

1) Electromagnetic Flowmeter Simulation with Single Bubble

Fig. 3 shows the three-dimensional simulation model of the electromagnetic flowmeter with a single bubble. The light blue area is water, the red part is electrodes, the orange part is coils, and the blue part is a bubble. The diameter of the pipe is 0.1m, the length of the pipe is 0.5m, the coil is circular, the inner diameter of the coil is 5cm, the outer diameter of the coil is 4cm, and the radius of the electrode is 1cm.

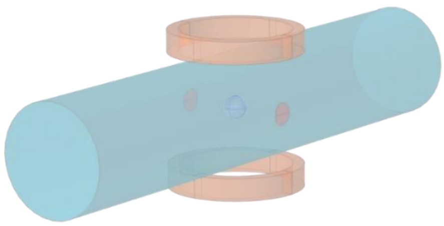

Figure 3. Three dimensional simulation model of electromagnetic flowmeter with single bubble

In the three dimensional model, the bubble is insulated, the excitation coil generates magnetic conduction intensity, and the virtual current density is formed at the two ends of electrodes. The vector product of magnetic intensity and virtual current density is weight function. In this model, the influence of bubble radius variation and eccentricity on weight function is studied separately by parameter scanning.

2) Electromagnetic Flowmeter Simulation With Multiple Bubbles

In actual flow measurement, there is more than one bubble in the fluid, and in most cases there are multiple bubbles. Therefore, in order to simulate the influence of bubbles on the weight function more realistically, the moving mesh technology is introduced to simulate the distribution of the weight function of multiple bubbles when they flow with fluid. Fig. 7 shows the three-dimensional simulation model of electromagnetic flowmeter with multiple bubbles.

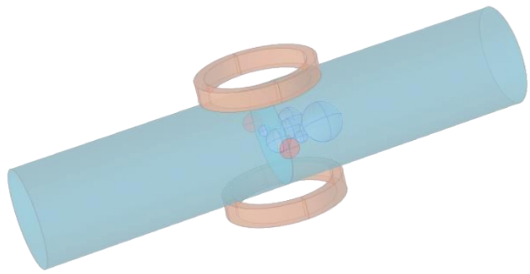

Figure 4. Three dimensional model of electromagnetic flowmeter with multiple bubbles

4. Results and analysis

4.1. Simulation Results of The Influence of Single Bubble Radius Variation on Weight Function

The influence of different sizes of bubbles on the distribution of weight function is studied by parameter scanning. The distribution of weight function is shown in Figure 5 below when the radius of bubbles increases gradually from 5 mm to 30 mm.

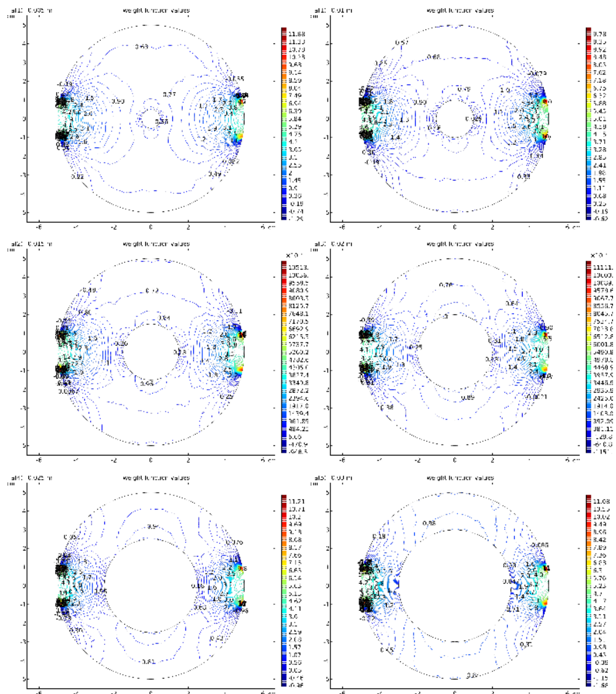

Figure 5. Weight function distribution with bubble radius ranging from 5mm to 3cm

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4.2. Simulation Results of Single Bubble Eccentricity on The Weight Function

In order to study the influence of bubble eccentricity on the weight function, the distribution of the weight function was simulated when the bubble eccentricity along the electrode direction and perpendicular to the electrode direction. The eccentricity of the bubble center to the center of the pipe section was 0 to 4 cm and the bubble radius was 5 mm by parameter scanning. Fig. 5 shows the distribution of the weight function when the bubbles are eccentric along the electrode direction. Fig. 6 shows the distribution of the weight function when the bubbles are eccentric perpendicular to the electrode direction.

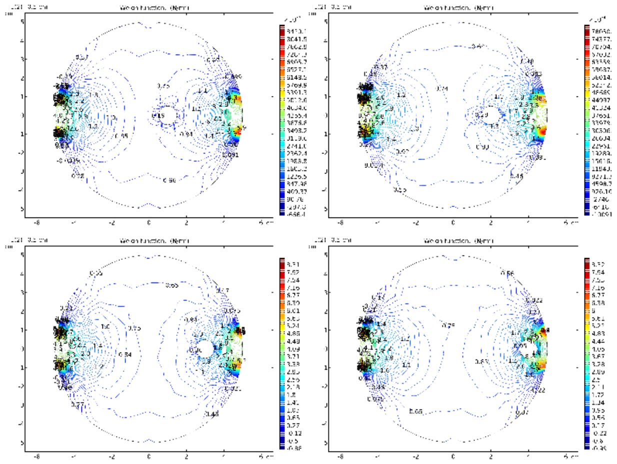

Figure 6(a). bubble eccentricity (electrode direction)

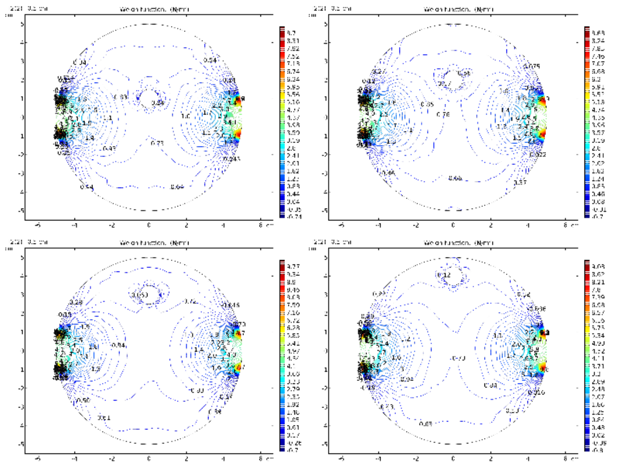

Figure 6(b). bubble partiality (perpendicular to electrodes)

4.3. Simulation Result of Multiple Bubbles Flow on The Weight Function

In order to study the distribution of weight function of multiple bubbles flowing in pipes, a moving mesh technique was introduced to simulate the flow of multiple bubbles. In this three-dimensional simulation model, there are six bubbles of different sizes. Bubbles flow from one end of the pipe to the other end. The length of the pipe is fifty centimeters, and the velocity of the bubbles is 0.02m/s. Figure 7 shows the isogram of the weight function at different times.

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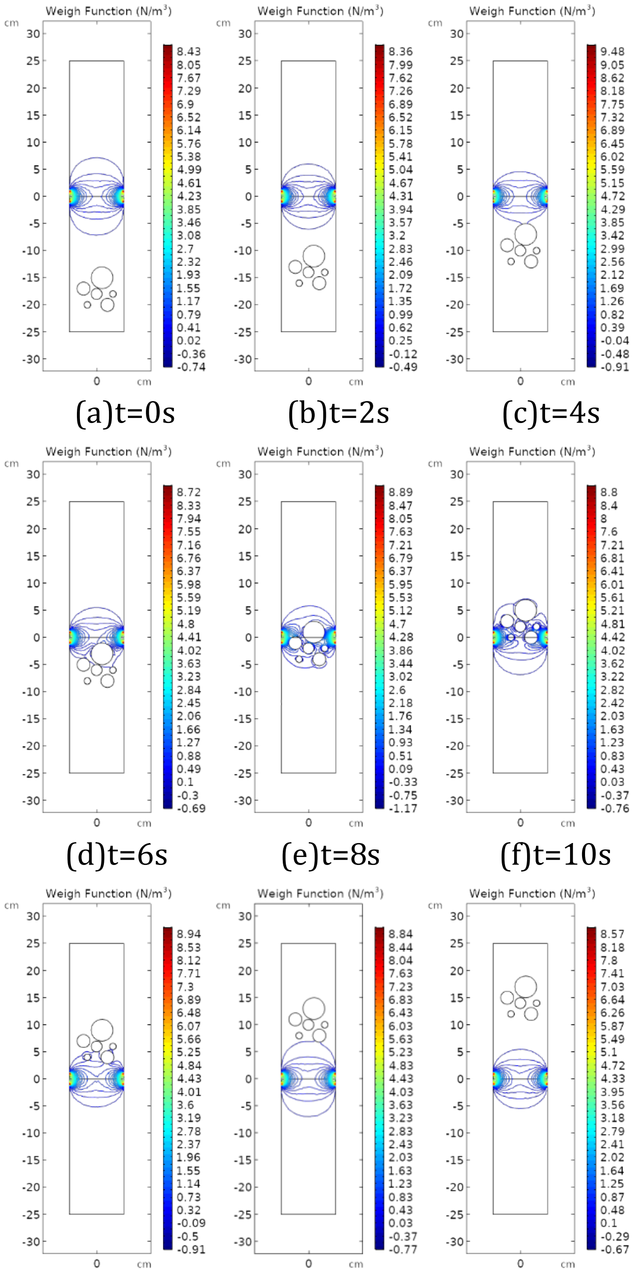

(a)t=0s (b)t=2s (c)t=4s

(d)t=6s (e)t=8s (f)t=10s

(g)t=12s (h)t=14s (i)t=16s

Figure 7. Contour map of 0-18s weight function

4.4. Result Evaluation and Analysis

1) EVALUATION AND ANALYSIS OF UNEVEN DENSITY BASED ON VECTOR WEIGHT FUNCTION

In order to evaluate the proportion of uniformity of vector weight function value distribution in important areas of the annular channel, an evaluation index of non-uniformity density is proposed. The formula of this index is as follows (19). Among them, W (x, y) is the vector weight function value of any finite element in the central section of the annular channel electrode; it is the average value of the vector weight function; P is the non-uniform density.

$$\frac{|W_{(x,y)}-\bar{W}|}{W}\times 100\% \le P\% \tag{19}$$

The larger the non-uniform density is, the more non-uniform the weight function of the current region is. From Figure 7 it can be seen that the non-uniform density increases gradually with the increase of bubble radius, and the non-uniform degree of the whole electrode cross-section increases from 50% to 80%. This shows that the size of the bubble has a great influence on the weight function of the whole cross-section.

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When the bubbles are eccentric along the x-axis, it means that the closer the bubbles are to the electrodes at both ends, the distribution of the weight function will also be affected. Fig. 10 shows the variation of non-uniform density when the bubble is eccentric along the electrode direction. It can be seen from the Figure that when the bubble is far away from the electrode, the non-uniform density of the whole region does not change much, but when the bubble is closer to the electrode, the non-uniform density of the whole region decreases gradually. This means that the bubbles around the electrodes have a great influence on the distribution of the weight function. The closer the bubbles are to the electrodes, the lower the non-uniform density of the weight function in the whole region is. When the bubbles are eccentric perpendicular to the direction of the electrode, it can be seen from Fig. 11 that the influence of bubbles on the non-uniform density of the weight function of the whole region is basically constant.

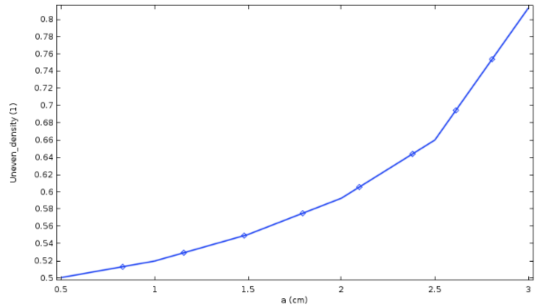

Figure 8. uneven density（radius variation range: 5mm~30mm）

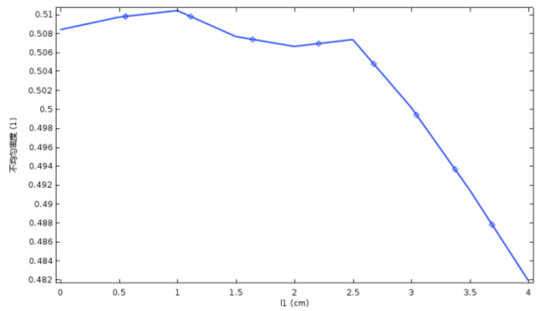

Figure 9. uneven density (eccentric along electrode)

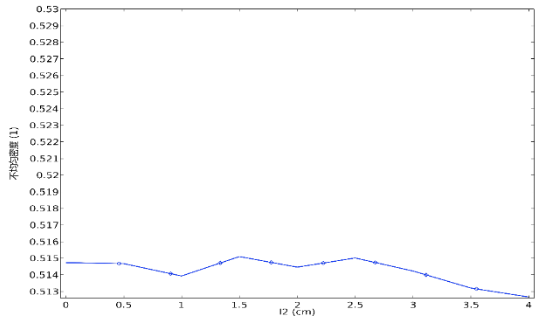

Figure 10. uneven density (eccentric perpendicular to electrode)

2) Evaluation And Analysis Based on Output Voltage Sensitivity

Output voltage sensitivity refers to the sensitivity of the electromagnetic flow measurement system, which is expressed by the ratio of the output voltage variation of the system to the variation of the measured parameters causing these changes. In this study, in order to study the sensitivity of the measurement system when bubbles flow through different positions of the pipeline, the sensitivity of the output voltage is taken as the index of analysis. It is assumed that the system output voltage change caused by the constant coil current and the fluid inflow velocity change of 0.02m/s is taken as the output voltage sensitivity.

$$S = \frac{U}{BLv} \tag{20}$$

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Where the potential difference between the two ends of the electrode, the magnetic field strength of the cross-section of the electrode, the diameter of the pipe and the average velocity of flow are considered. The output voltage sensitivity curve from 0s to 18S is shown in the Figure.

As can be seen from Fig. 12, when the bubble moves from one end of the pipeline to the other end, the sensitivity of the output voltage decreases continuously during the period of 0-9 s when the bubble moves from one end of the pipeline to the cross-section of the electrode; at 9-18 s, the bubble begins to move away from the cross-section of the electrode, and the sensitivity of the output voltage increases continuously. Therefore, when the bubble is close to the electrode section, the closer the bubble is to the electrode section, the lower the sensitivity of the output voltage will be.

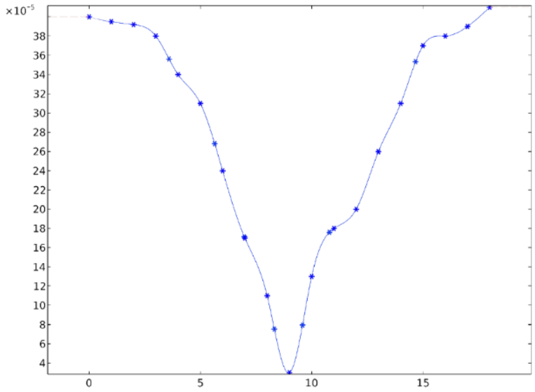

Figure 11. voltage sensitivity of output voltage of 0-18s

5. Conclusion

The electromagnetic flowmeter has been widely used in the measurement of single-phase flow, and the measurement of single-phase flow has reached a high accuracy, but the measurement of multi-phase flow is not yet mature. In the process of industrial fluid measurement, bubbles and solid particles are often produced, which will affect the flow measurement. Bubbles and solid particles belong to the insulators class, and their material properties are similar. Therefore, this paper mainly simulates the influence of bubbles on the measurement of electromagnetic flowmeter. The main contributions of this paper are as follows:

(1) Based on Bevir's vector weight function theory, this paper deduces the partial differential equation of electromagnetic measurement system with a single bubble, and compares the theoretical deduction with the simulation, thus verifying the feasibility of the simulation.

(2) Through finite element simulation, the influence of single bubble size and eccentricity on the weight function of the electromagnetic measurement system is analyzed. It is eventually concluded that the bubble size has a great influence on the weight function, and the larger the bubble size, the lower the uniformity of the weight function; when the bubble is eccentric along the electrode direction, the closer the bubble is to the electrode, the lower the uniformity of the weight function; when the bubble is eccentric perpendicular to the electrode direction, the uniformity of the weight function is almost unchanged, and the influence is small.

(3) Based on the moving mesh technology, the three-dimensional flow model of the electromagnetic measurement system with multiple bubbles is established, and the weight function distribution of thecross-section of the pipeline at different times and the sensitivity curve of the measurement system at different time are obtained. The sensitivity of the output voltage decreases when the bubble approaches the electrode section from one end of the pipe, but increases when it is far away from the electrode section.

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Conflict Of Interests

The authors declare that there is no conflict of interests regarding the publication of this article.

Data Availability Statement

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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