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Foundation of the Reaction Mechanism of Deep Penetration and Low-Damage Acidizing Fluid

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Abstract

With the development of oil and gas resources to inefficient and multiple rounds measure reservoir development, with deep penetration characteristics of low-damage acid system acidification and acid fracturing technology more and more research is very important. "Deep penetration and low-damage Acidizing fluid" system has some advantage which a slower etch rate, etch depth, no secondary damage, reservoir reconstruction obvious effect, acid-rock reaction kinetics parameters such testing and etching acid system mechanism is the basis of the depth of acidification and acid fracturing work. With deep penetration and low-damage Acidizing fluid system formulation, through new experimental device for etching experiments carried reservoir core, on the basis of Hekim distributed parameter model is proposed the reaction mechanism of deep penetration and low-damage acidizing fluid in the reservoir. The key consideration during the construction of deep penetration and low-damage acidizing fluid in the formation of continuous hydrolysis HF, detailed derivation of the body acid, HF concentration distribution and concentration distribution of mineral mathematical models and numerical models.

Key words: The reaction mechanism of acidizing fluid; Acidification model; Concentration distribution model; Concentration distribution numerical model; Numerical analogue

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INTRODUCTION

Combined with microscopic scanning system for dissolution process and the rock face dissolution characterization quantitative analysis, identify the acid properties of acid-rock reaction mechanism parameters and related laws. The key consideration during the construction of deep penetration low damage acid in the formation of continuous hydrolysis HF. Detailed derivation of the main body of the acid, HF concentration distribution and concentration distribution of mineral mathematical models and numerical models. In this model, give full consideration to the deep penetration of low-harm release of HF acid in the formation rate, mineral again divided in accordance with the speed of its reaction with hydrofluoric acid to two basic minerals, that is the clay, feldspar and hydrofluoric acid react quickly divided into silicate minerals. The reaction with hydrofluoric acid slow minerals ingredients such as quartz into a quartz minerals, and taking into account the heterogeneity of the actual formation on vertical, will be pay formation in accordance with the permeability distribution layer is divided into different small layer. In the design calculations, with the permeability of injuries and damage radius to indicate the degree of formation damage[1].

1. EXPERIMENTAL

1.1 Establishing Reservoir Acid-Rock Reaction Kinetics Model, the Establishment of HF Acid Concentration Distribution and Mineral Concentration Distribution Model

1.1.1 The Assumptions of the Model

(a) Pore acid concentration at each point in the longitudinal direction does not change, and the acid concentration is higher than the pore wall;

(b) Ignoring its own acid molecule diffusion;

(c) Reservoir rocks and minerals can be divided into a limited number of mineral components, the acid to react with different rocks and minerals are in accordance with their mechanism equation;

(d) Acid flow in the reservoir pores showed a single phase radial flow, and meet Darcy's law;

(e) Note processing solution, it is assumed carbonate rocks minerals in reservoir have been dissolved away by the front of the hydrochloric acid solution, hydrochloric acid treatment solution no longer participate in the reaction.

1.1.2 Meshing

Let the well radius--r_w that axis with tubing center, that using block center grid, in the radial direction it is divided into N elements body area of each unit cell is $\pi(r_i^2 - r_{i-1}^2)$. Among them, $r_0 = r_w$, $r_i = \alpha \cdot r_{i-1}$ (i = 1,2,3,…,N), α is the geometric constant that greater than 1, which uses variable step grid system in the calculation. Divided infinitesimal body diagram shown in Figure 1, which suppose micro unit height is h, reservoir drainage radius is R_e.

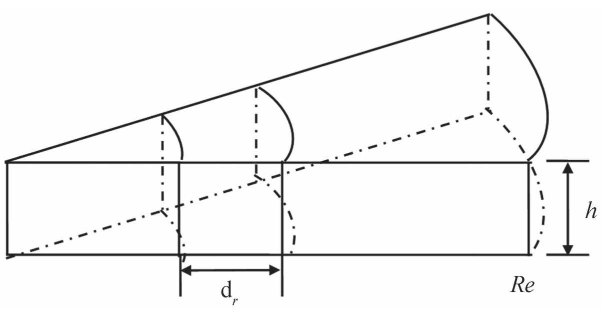

Figure 1
The Schematic of Micro Unit Division

According to the theory of chemical reactions to obtain:

$$R_h = R_s \cdot \sigma_s + R_q \cdot \sigma_q. \quad (1)$$

R_s and R_q denotes corresponding consumption rate of quartz and silicate class. R_h represents HF consumption rate. σ_s is a reciprocal that the chemical reaction coefficient of quartz minerals; σ_q is a reciprocal that the chemical reaction coefficient of silicate minerals.

According to assumptions, and said mesh, the unit body selected which depending on the amount of acid substance conservation can be deduced mathematical model of HF concentration and mineral concentration distribution.

HF dissolution reaction mathematical model:

$$\phi\frac{\partial C_{HF}}{\partial t} + u\frac{\partial C_{HF}}{\partial r} = r_h + R_h. \quad (2)$$

HF reaction mathematical model in the formation:

$$\begin{cases} \phi\frac{\partial C_{HF}}{\partial t} + u\frac{\partial C_{HF}}{\partial r} = r_h + R_h \\ r_j = (1-\phi)\frac{\partial C_j}{\partial t} \\ R_h = R_s \cdot \sigma_s + R_q \cdot \sigma_q \\ r_j = -k_{rj} C_{HF}(C_j - C_{irj}) \end{cases}. \quad (3)$$

Initial and boundary conditions:

$$\begin{cases} C_{HF}(r,0) = 0, C_j(r,0) = C_{0j} \\ C_{HF}(r_w,t) = C_{HF0}, C_j(r_w,0) = 0 \\ C_{HF}(r > R_{ef},t) = 0, C_j(r > R_{ef},t) = C_{0j} \end{cases}. \quad (4)$$

C_{0j} is the initial concentration of the mineral; R_{ef} is the radius of etching; C_{HF0} is the initial concentration of HF.

1.2 Distribution Model of Deep Penetration of Low Damage Acid Concentration

Based on the above assumptions on, take a micro unit in the formation, and to consider the injection of acid hydrolysis process continuously out HF, in addition to considering the unit time from a radial inflow micro unit of HF, but also consider the hydrolysis of the HF in infinitesimal unit time.

The use of acid-rock reaction material balance, a mathematical model of acid concentration distribution to derive which is as follows:

(a) The acid mole number n_i which from a radial inflow micro unit per unit time:

$$n_i = 2\pi \cdot r \cdot h \cdot u \cdot C_{Hd}. \quad (5)$$

(b) The acid mole number n_{0d} which from a radial outflow micro unit per unit time:

$$n_{0d} = 2\pi（r + \mathrm{d}r)h(\mu + \frac{\partial\mu}{\partial r}\mathrm{d}r)(C_{Hd} + \frac{\partial C_{Hd}}{\partial r}\mathrm{d}r). \quad (6)$$

(c) The number of moles per unit time which consumed acid solution in the micro unit is n_{hd}:

$$n_{hd} = 2\pi \cdot r \cdot \mathrm{d}r \cdot h \cdot r_h. \quad (7)$$

(d) In the Equation, r_h is hydrofluoric acid production reaction speed.

$$n_{hd} = 2\pi \cdot r \cdot \mathrm{d}r \cdot h\phi\frac{\partial C_{Hd}}{\partial t}. \quad (8)$$

According to the amount of material conservation:

$$n_i - n_{0d} - n_{dh} = n_d. \quad (9)$$

The Equations (5) - (8) into (9), organize, eliminate second-order infinitesimal get:

$$\phi\frac{\partial C_{Hd}}{\partial t} + u\frac{\partial C_{Md}}{\partial r} = -r_h. \quad (10)$$

Equation (10) is the deep penetration and low-damage acidizing fluid concentration distribution mathematical model, the initial and boundary conditions are:

$$C_{Hd}(r,0)=0,\ C_{Hd}(rw,t)=C_{Hd0},\ C_{Hd}(r>R_{ef},\ t)=t\ . \quad (11)$$

In the formula: C_{Hd0} is the initial concentration of the acid; R_{ef} is the radius of etching.

1.3 Establishing Numerical Model of Acid Concentration Distribution and Concentration Distribution

Implicit numerical model which from deep penetration and low-damage acidizing fluid concentration distribution is:

$$\begin{cases} CC_i^{\ n} C_{Hdi-1}^{\ \ n+1} + AA_i^{\ n} C_{Hdi}^{\ \ n+1} + BB_i^{\ n} C_{Hdi+1}^{\ \ n+1} = DD_i^{\ n} \\ C_{Hdi}^{\ \ 0} = 0 (\text{Boundary conditions}) \\ C_{Hd\,0}^{\ \ n+1} = C_{0j} (\text{Within the boundary conditions}) \\ C_{Hd\,N2}^{\ \ n+1} = 0 (\text{Outer Boundary Conditions}) \\ C_{Hd\,i>N2}^{\ \ n+1} = 0 (i=1,2,\ldots,N_2; n=1,2,\ldots) \end{cases} \quad .(12)$$

Differential implicit numerical model which from HF acid concentration distribution is:

$$\begin{cases} CC_i^{\ n} C_{HFi-1}^{\ \ n+1} + AA_i^{\ n} C_{HFi}^{\ \ n+1} + BB_i^{\ n} C_{HFi+1}^{\ \ n+1} = DD_i^{\ n} \\ C_{HFi}^{\ \ 0} = 0 (\text{Boundary conditions}); C_{HF\,i>N}^{\ \ n+1} = 0 \\ C_{HF\,0}^{\ \ n+1} = C_{0j}; C_{HF\,N}^{\ \ n+1} = 0 (\text{Boundary conditions}) \end{cases} \quad .(13)$$

$$\left(i=1,2,\ldots,N; n=1,2,\ldots\right)$$

Mineral concentration distribution numerical model:

$$\begin{cases} (1-\phi_i^n)\dfrac{C_{ji}^{n+1}-C_{ji}^n}{\Delta t_{n+1}} = r_{ji}^n \\ -r_{ji}^n = k_{rji}^n C_{HFi}^n (C_{ji}^n - C_{irj}) \\ C_{ji}^0 = C_{rj0} (\text{Initial conditions}) \\ C_{j0}^{n+1} = 0 (\text{Within the boundary conditions}) \\ C_{jN2}^{n+1} = C_{rj0} (\text{Outer Boundary Conditions}) \end{cases}$$

$$\left(j=s,q; i=1,2,\ldots,N\right)$$

1.4 Solving Numerical Model

HF acid concentration distribution model for solving matrix:

The coefficient matrix of Equations (14) and (15) is diagonal tridiagonal matrix, so it can catch up method to solve. Specific algorithm is: First, according to the initial condition with deep penetration and low-damage acidizing fluid kinetic equation get the of generated the reaction rate of HF, using Equation (1) is calculated with the reaction rate of mineral acid, then find the coefficient matrix above two equations based on the initial and boundary conditions. The last the deep penetration and low-damage acidizing fluid concentration distribution and concentration of the acid HF and the effective radius of action can be obtained by catch method.

$$\begin{pmatrix} AA_1 & BB_1 & & & & \\ CC_2 & AA_2 & BB_2 & & & \\ & \cdots & \cdots & \cdots & & \\ & & CC_i & AA_i & BB_i & \\ & & & \cdots & \cdots & \cdots \\ & & & & CC_{N-1} & AA_{N-1} \end{pmatrix} \begin{pmatrix} C_{Hd1}^{n+1} \\ C_{Hd2}^{n+1} \\ \cdots \\ C_{Hdi}^{n+1} \\ \cdots \\ C_{MH\,N-1}^{n+1} \end{pmatrix} = \begin{pmatrix} DD_1 \\ DD_2 \\ \cdots \\ DD_i \\ \cdots \\ DD_{N-1} \end{pmatrix} . \quad (14)$$

$$\begin{pmatrix} AA_1 & BB_1 & & & & \\ CC_2 & AA_2 & BB_2 & & & \\ & \cdots & \cdots & \cdots & & \\ & & CC_i & AA_i & BB_i & \\ & & & \cdots & \cdots & \cdots \\ & & & & CC_{N2-1} & AA_{N2-1} \end{pmatrix} \begin{pmatrix} C_{HF1}^{n+1} \\ C_{HF2}^{n+1} \\ \cdots \\ C_{HFi}^{n+1} \\ \cdots \\ C_{HF\ N_2-1}^{n+1} \end{pmatrix} = \begin{pmatrix} DD_1 \\ DD_2 \\ \cdots \\ DD_i \\ \cdots \\ DD_{N2-1} \end{pmatrix} . \quad (15)$$

1.5 Model Simulation

In order to visually analyze the changes of the role of acid in the distance and acid concentration with etching radius, the above model was simulated by Comsol software.

Simulated of reservoir thickness is 15 m, porosity is 26%, permeability is 875 × 10^{-3} μm^2; reservoir quartz minerals accounted for 58%, silicate minerals accounted for 42%. The injection of acid rate is 4 m^3/min, the total amount of acid injection is 110 m^3. Simulation the deep penetration and low-damage acidizing fluid concentration distribution and concentration of the acid HF and the effective radius of action after injection of acid at different time points, as shown in Figures 1 to 8.

Figures 1 to 4 are analog obtained variation of acid concentration of deep penetration and low-damage acidizing fluid with the radius of action after acid injection at different times. From the simulation results can be seen: H^+ can continue for a long time to distant spread. The role of acid in distance, and deep penetration effect is obvious.

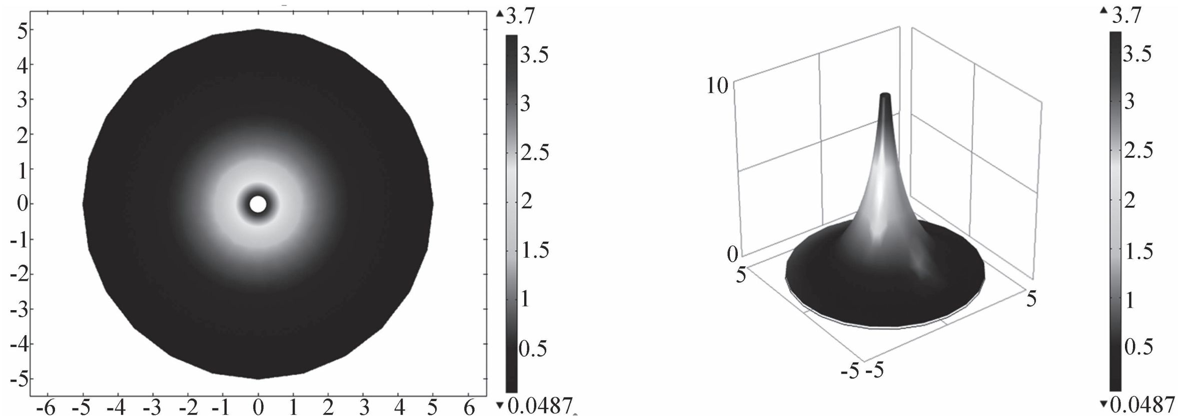

Figure 1
The Simulation Diagram of Concentration Change of the Deep Penetration and Low-Damage Acid After 10 Minutes of Injection

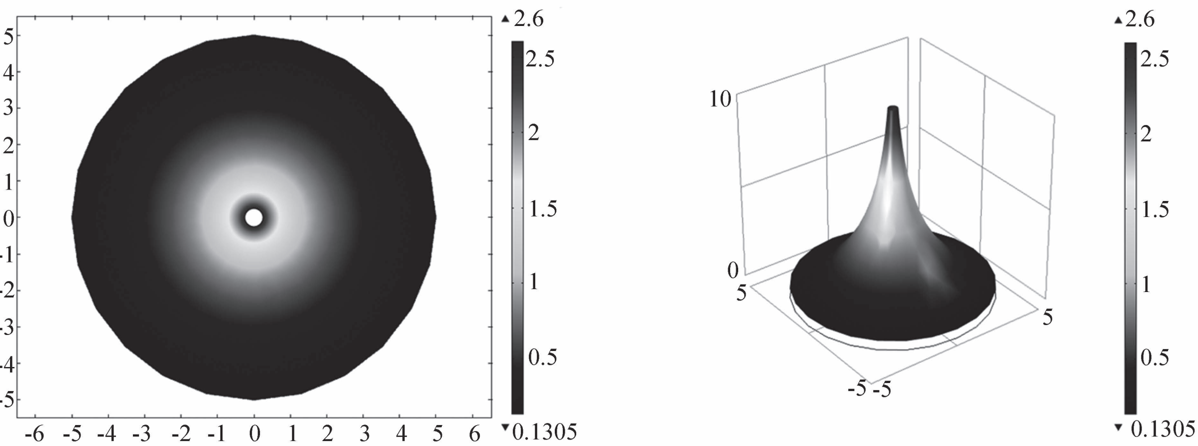

Figure 2
The Simulation Diagram of Concentration Change of the Deep Penetration and Low-Damage Acid After 20 Minutes of Injection

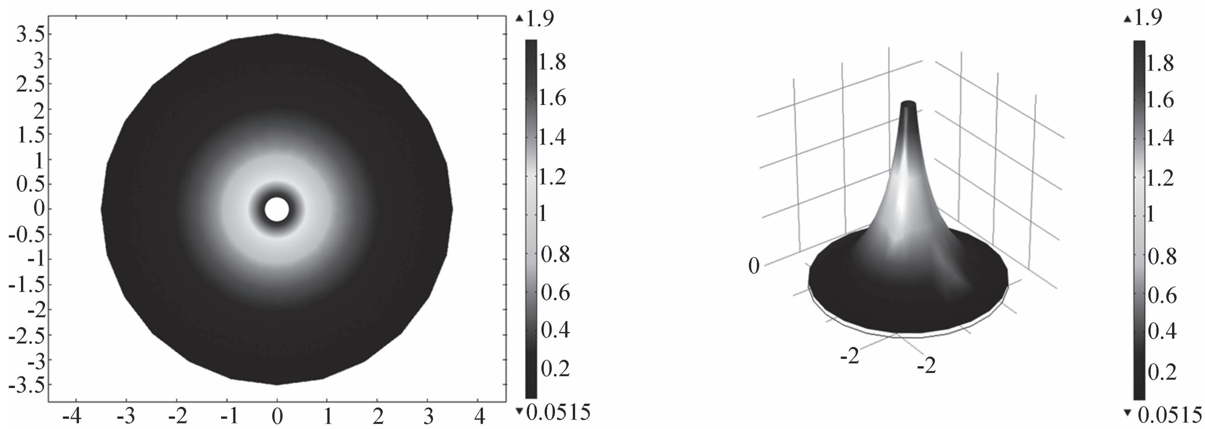

Figure 3
The Simulation Diagram of Concentration Change of the Deep Penetration and Low-Damage Acid After 30 Minutes of Injection

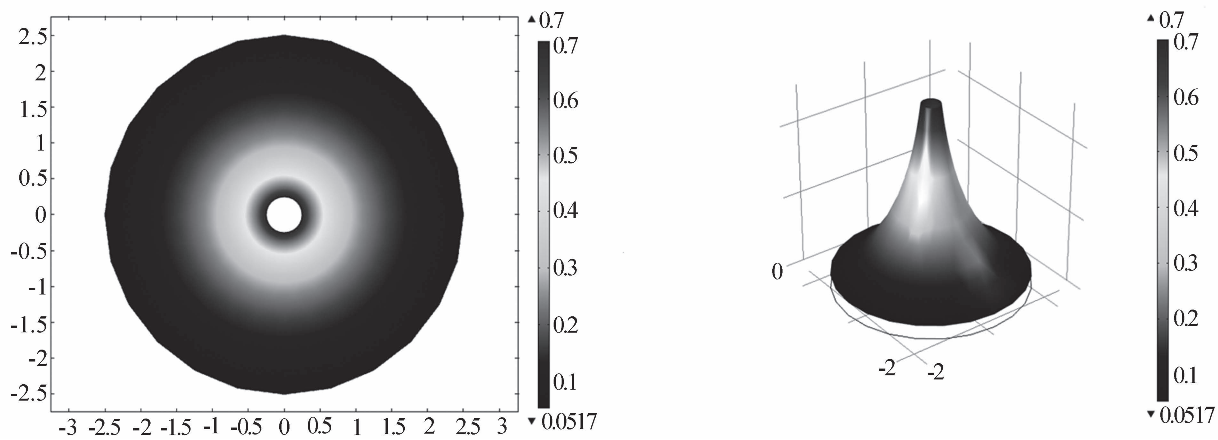

Figure 4
The Simulation Diagram of Concentration Change of the Deep Penetration and Low-Damage Acid After Acid Injection 50 Minutes

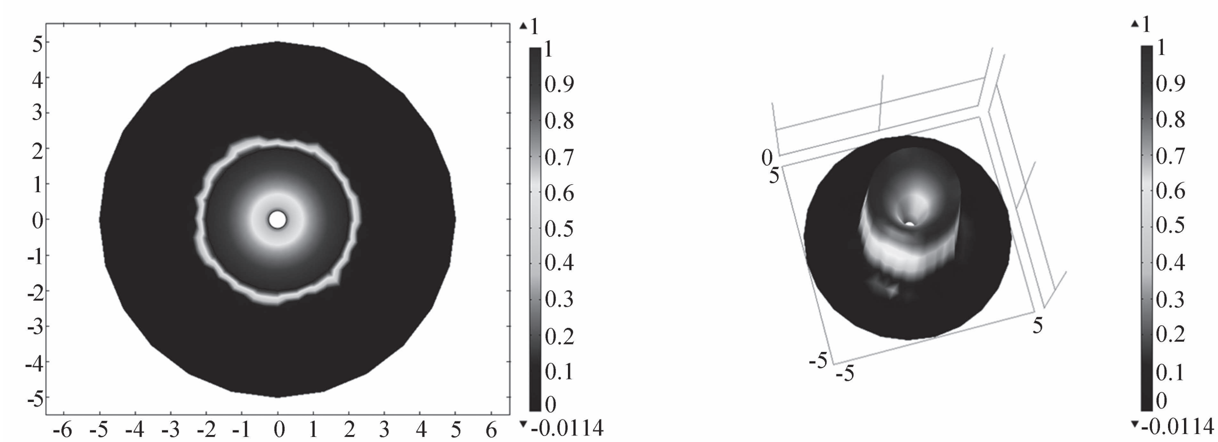

Figure 5
The Simulation Diagram of Concentration Change of HF Acid After 0 Minutes of Injection

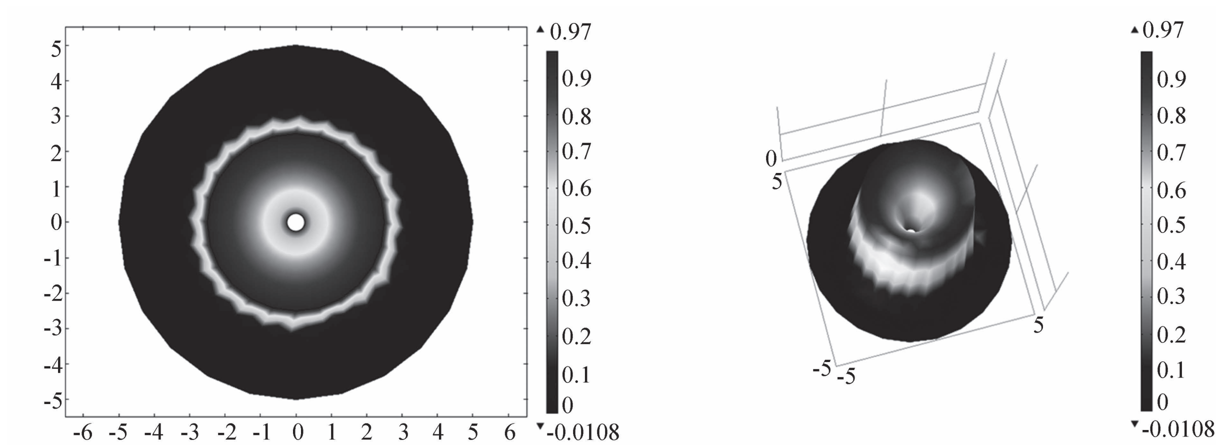

Figure 6
The Simulation Diagram of Concentration Change of HF Acid After 20 Minutes of Injection

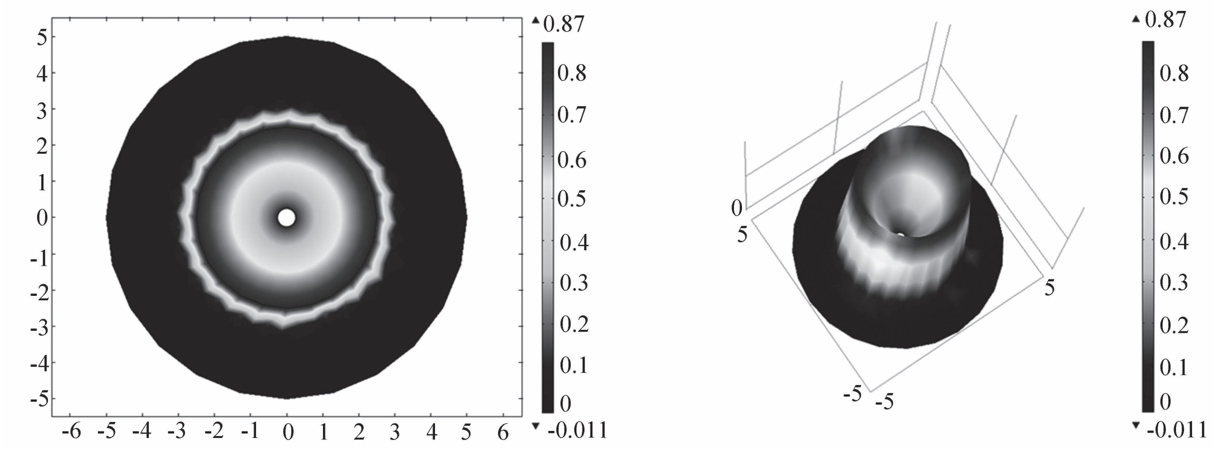

Figure 7
The Simulation Diagram of Concentration Change of HF Acid After 30 Minutes of Injection

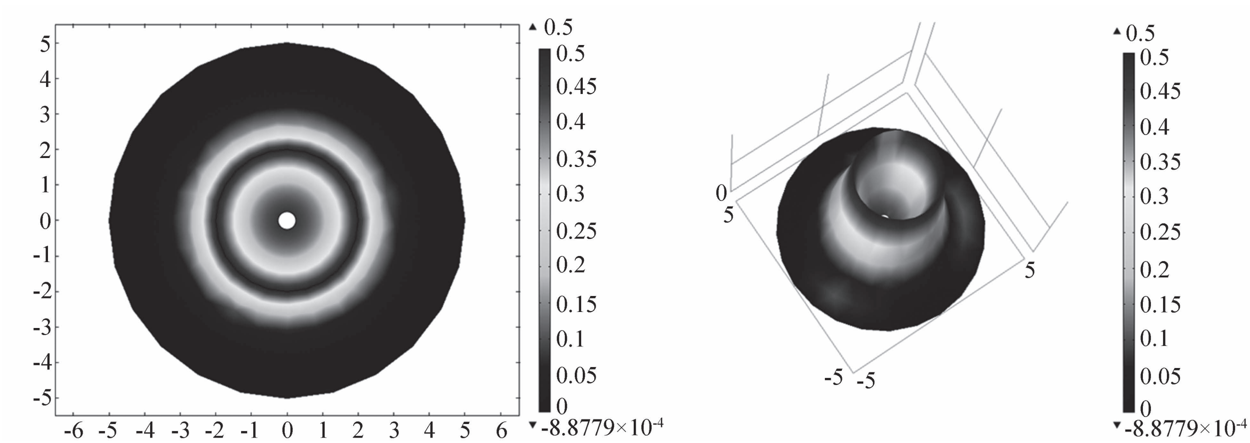

Figure 8
The Simulation Diagram of Concentration Change of HF Acid After 50 Minutes of Injection

Figures 5 to 8 are analog obtained variation of the concentration of HF with the radius of action after acid injection at different times. From the simulation results can be seen: HF effective role of distance reached 2.5 to 3 m which compared with ordinary acid 0.5 to 0.8 m radius of action is increased by 4 to 6 times, the use of such acid system for plugging operation can achieve low-damage and deep acidification purposes.

CONCLUSION

Deep penetration and low-damage acidizing fluid reaction order minimum which only half of the mud acid. That is, even at very high temperature it will not change with the overall acid concentration caused by acid rock reaction rate accelerated, acid system control active capability of H^+ that is outstanding, it has slowed the rate of acid-rock reaction role. Acid can effect a long time with the formation rock and growth increased etching pores and improve the effect of acid stimulation and injection.

This paper considers the deep penetration and low-damage acidizing fluid reaction mechanism feature of acid-rock, and establishes a model that compound acid concentration distribution of compound acid and generation of secondary acid along the radial direction of the reservoir and the mineral concentration distribution. At the same time using the method of numerical analysis to establish the corresponding numerical model for each model.

From the simulation results of the variation of the concentration of deep penetration and low-damage acidizing fluid and HF with the radius of action after acid injection at different times can be seen: (a) Deep penetration and low-damage acidizing fluid reaction is slow, acid-rock reaction is soft and harmful effects is small for the near wellbore rock skeleton; H^+ can uninterrupted to distant spread, acid role of distance and deep penetrating effect is obvious. (b) The process of continue action and generating HF substantial control the active properties of H^+ and reducing the intensity of acid-rock reaction, it effectively controls the secondary sedimentation and insoluble matter generation and reducing the secondary damage; In addition, HF effective role of distance can reach 2.5 to 3 m which compared with ordinary acid 0.5 to 0.8 m radius of action is increased 4-6 times. The use of such acid system for plugging operation can achieve low-damage and deep penetrating purposes.

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