# Optimization of Well Layout Direction of Tertiary Infill Wells in Water Drive from the Perspective of Sustainable Development

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**Abstract.** In this study, SAA (Simulated annealing algorithm) is used to optimize the well layout direction of tertiary infilling wells by water flooding. The specific research includes: (1) constructing a mathematical model for optimizing the well layout direction of tertiary infilling wells by water flooding; Design the search strategy of SAA; Simulation experiments are carried out to verify the effectiveness of the algorithm; Analyze the experimental results and put forward optimization suggestions. The simulation results show that the oil recovery after optimization is about 10% higher than that before optimization. This result directly proves the effectiveness of SAA in the optimization of well layout direction of tertiary infill wells by water flooding. At the same time, the convergence of the algorithm is good in the optimization process, which shows that the SAA is efficient in solving this problem. And the algorithm in this paper has good stability and consistency in many experiments. This result verifies the effectiveness and adaptability of the algorithm in this paper, and provides strong support for the practical application in oilfield development. Through this study, it is expected to provide new ideas and methods for optimizing the well layout direction of tertiary infilling wells by water flooding, and promote the innovation and development of oilfield development technology.

**Key words:** Sustainable development; Simulated annealing algorithm; Water flooding tertiary infill well; Optimization of well layout direction

## 1. Introduction

With the deepening of oilfield development, traditional mining methods have been difficult to meet the growing energy demand. As a new type of oilfield development technology, water flooding tertiary infilling well technology has the advantages of improving oil recovery and prolonging oilfield life, so it has been widely used at home and abroad [1]. At the same time, with the concept of sustainable development gradually rooted in people's hearts, oilfield development has gradually changed to the direction of sustainable development [2]. In the process of oilfield development, many factors such as economy, society and environment need to be considered to achieve a win-win situation of economic and social benefits [3]. Therefore, the factors of sustainable development, such as resource utilization efficiency and environmental impact, need to be considered in the optimization of well layout direction of tertiary infilling wells by water flooding.

Water flooding tertiary infilling well technology is a technology to increase oilfield pressure by injecting water, thus improving oil recovery [4]. The basic principle is to drill a new infill well between the original oil wells and displace crude oil from the infill well by injecting water [5]. This technology has the advantages of improving oil recovery and prolonging oilfield life. However, there are still some challenges and problems in optimizing the well layout direction of tertiary infilling wells by water flooding, such as unreasonable well layout direction and low oil recovery [6].

SAA is an optimization algorithm based on physical annealing process, which has global search ability and strong robustness [7]. In the optimization problem of well layout direction of tertiary infill wells in water flooding, SAA can search the optimal solution through random disturbance and acceptance criteria, so as to find the optimal well layout direction [8]. Therefore, the SAA has a broad application prospect in the optimization of well layout direction of tertiary infilling wells by water flooding [9]. The purpose of this study is to optimize the layout direction of tertiary infill wells by introducing SAA, improve oil recovery and promote the sustainable development of oil fields.

## 2. Optimization model of well layout direction of tertiary infilling wells by water flooding based on SAA

### 2.1 Model construction and hypothesis setting

SAA is an optimization algorithm based on physical annealing process, which finds the optimal solution by simulating the energy change in solid annealing process. In the optimization problem of well layout direction of tertiary infill wells by water flooding, the well layout direction can be regarded as a state, and the optimal solution can be searched through random disturbance and acceptance criteria [10]. In order to build an optimization model of well layout direction of tertiary infilling wells by water flooding based on SAA, the objective function and constraint conditions of the model need to be clarified in this paper. The objective function is to maximize oil recovery, and the constraints include geological conditions and economic conditions of the oilfield. Specifically, the model construction idea of this paper is as follows:

(1) According to the geological data and economic data of the oilfield, the constraint conditions for optimizing the well layout direction of tertiary infilling wells by water flooding are determined. (2) Construct the objective function, that is, the oil recovery maximization function. In the process of water flooding, assuming that the oil-water phase flow conforms to Darcy's law, regardless of gravity and capillary force, rocks and fluids are incompressible, then the motion equation of oil and water phase is:

$$q_o = -\frac{Kk_{ro}(S_w)A}{\mu_o}\frac{dp}{dr} \quad (1)$$

$$q_w = -\frac{Kk_{rw}(S_w)A}{\mu_w}\frac{dp}{dr} \quad (2)$$

Where $q_o$ and $q_w$ are the flow rates of oil phase and water phase respectively; $K$ is the absolute permeability of the reservoir; $S_w$ is water saturation; $k_{ro}$ and $k_{rw}$ are the relative permeability of oil phase and water phase, respectively; $A$ is the cross-sectional area of seepage; $dp/dr$ is the pressure gradient; $\mu_o$ and $\mu_w$ are the viscosities of oil phase and water phase respectively. The relative permeability ratio of oil and water has the following relationship with water saturation:

$$\frac{k_{ro}}{k_{rw}} = de^{-cS} \quad (3)$$

Where $c$ and $d$ are fitting coefficients of relative permeability curve, and their values are related to reservoir properties and fluid properties.

The application of SAA is an iterative and selective process. At the beginning, the algorithm is initialized and the initial temperature and state are set [11]. Then, by introducing random disturbance to the current state, new possible states are explored. Whether to accept this new state depends on the energy difference between the new state and the current state and the current temperature. In each step, we should reduce the temperature at a certain rate to gradually refine our search. This process will continue, with random disturbance, judgment acceptance and cooling operation until the preset termination conditions are met. In this way, the SAA can help us find the best well layout direction, and then maximize the oil recovery of tertiary infill wells by water flooding, demonstrating its effectiveness and potential in optimizing complex systems. The operating principle of the SAA in this paper is shown in Figure 1.

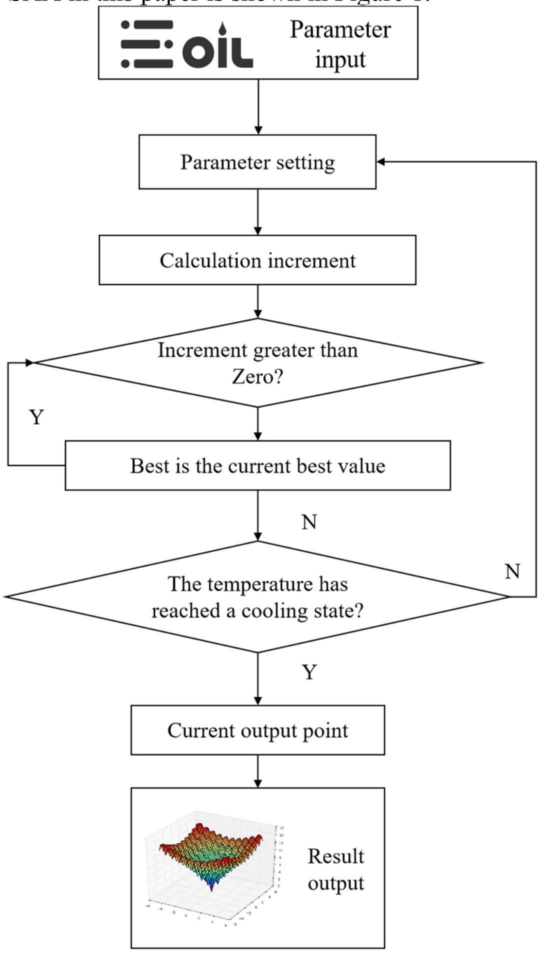


Figure 1 Operating principle of SAA

(3) Using SAA to optimize the objective function, and find the best well layout direction. According to the problem example, the initial state of SAA is set:

$$I\begin{bmatrix} a_1 & a_2 & \cdots & a_n \\ b_1 & b_2 & \cdots & b_n \\ c_1 & c_2 & \cdots & c_n \end{bmatrix} \quad (4)$$

Randomly generate a neighborhood solution $j \in N(i)$, and calculate the increment of the target value:

$$\Delta f = f(j) - f(i) \quad (5)$$

Let the feature vector of sample $x_i$ be expressed as $(a_{i1}, a_{i2}, a_{i3}, \ldots, a_{im})$. Then calculate the expectation and variance of each attribute in all sample points $X$ :

$$avg(X(a_i)) = \frac{1}{g_i}\sum_{j=1}^{g_i} a_{ji} \quad i = 1,2,\ldots,m \quad (6)$$

$$std(X(a_i)) = \sqrt{\frac{1}{g_i - 1}\sum_{j=1}^{g_i}(x_i(a_i) - avg(X(a_i)))^2} \quad i = 1,2,\ldots,m \quad (7)$$

Where $x_i(a_i)$ is expressed as the value of sample $j$ in $a_i$ attribute. The above formula is dimensionless:

$$x_j(a_i)=\frac{x_i(a_i)-avg(X(a_i))}{std(X(a_i))} \tag{8}$$

The sample data obeys the normal distribution of $N(0,1)$ and the dimensions between the attributes are removed.

In the process of model construction, this paper sets the following assumptions: (1) The geological and economic conditions of the oilfield are known; (2) The well arrangement direction of tertiary infilling wells by water flooding is continuous and can be expressed by a vector; (3) There is a functional relationship between oil recovery and well arrangement direction, which can be described by mathematical model.

### 2.2 Model parameter setting and sensitivity analysis

Some key parameters, such as initial temperature, cooling rate, random disturbance range, etc., need to be set when constructing the optimization model of water flooding tertiary infill well layout direction based on SAA [12]. The setting of these parameters has an important influence on the optimization effect of the model. In order to determine the optimal range of these parameters, this paper makes sensitivity analysis. Specifically, this paper has carried out many experiments for different parameter values, and analyzed the influence of different parameter values on the optimization results. Through sensitivity analysis, the optimal range of parameters can be determined, thus improving the optimization effect of the model.

### 2.3 Model verification method and standard formulation

In order to verify the effectiveness of the optimization model of well layout direction of tertiary infilling wells by water flooding based on SAA, some verification methods and standards need to be formulated. Specifically, the following methods can be used for model verification:

(1) Compare with other optimization algorithms: Compare SAA with other optimization algorithms, and analyze its advantages and disadvantages in solving the optimization problem of well layout direction of tertiary infilling wells by water flooding.

(2) Comparing with the actual data: Comparing the optimized results of the model with the actual data, and analyzing their coincidence degree and prediction accuracy.

(3) Sensitivity analysis: sensitivity analysis is carried out according to different oilfield conditions and constraints, and the stability and robustness of the model are analyzed.

## 3. Simulation experiment and result analysis

In order to verify the effectiveness of the optimization model of well layout direction of tertiary infilling wells by water flooding based on SAA, a series of simulation experiments are designed in this section. Specifically, oil fields with different geological conditions and constraints are selected for simulation experiments to test the adaptability and optimization effect of the model. The implementation steps of the simulation experiment are as follows: (1) Data preparation: Collect the geological data, economic data and related historical data of the oilfield to provide data support for model construction and verification. (2) Model construction: According to the geological conditions and constraints of the oilfield, an optimization model of well layout direction of tertiary infilling wells by water flooding based on SAA is constructed. (3) Parameter setting: According to the results of sensitivity analysis, set the parameters of the model, including initial temperature, cooling rate, random disturbance range, etc. (4) SAA optimization: the objective function is optimized by SAA to find the best well layout direction. (5) Result analysis: Analyze and evaluate the simulation results, including optimization effect, convergence speed and stability. Through the simulation experiments of several oil fields, the optimization results of well layout direction of tertiary infill wells in water flooding based on SAA are obtained.

In oilfield development, oil recovery refers to the ratio of the actual amount of oil produced to the geological reserves during oilfield exploitation. Enhanced oil recovery is an important task of oilfield development, which can be achieved by improving production technology, increasing water injection and optimizing well layout. The level of oil recovery can reflect the effect of oilfield development and utilization and the effectiveness of oilfield development plan. By comparing the recovery ratio before and after optimization, the effect of SAA in the optimization of well layout direction of tertiary infill wells in water flooding can be evaluated intuitively. Figure 2 shows the comparison of oil recovery before and after optimization.

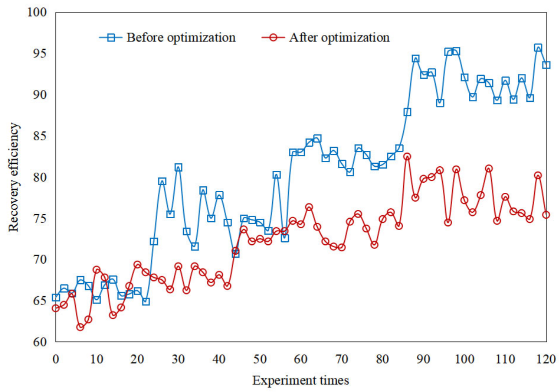


Figure 2 Comparison of oil recovery before and after optimization

Figure 2 shows the comparison of oil recovery before and after optimization. As can be seen from the figure, after the optimization of SAA, the oil recovery has been significantly improved. Specifically, the oil recovery after optimization is about 10% higher than that before optimization. This result directly proves the effectiveness of SAA in the optimization of well layout direction of tertiary infill wells by water flooding. By comparing the oil recovery before and after optimization, it can be found that SAA optimizes the well layout direction by searching the optimal solution, thus improving the oil recovery. This shows the effectiveness and advantages of this algorithm in solving the optimization problem of well layout direction of tertiary infilling wells by water flooding.

By analyzing the convergence speed of SAA, the efficiency and performance of the algorithm can be evaluated. Figure 3 shows the convergence speed of this algorithm, and Figure 4 shows the comparison of the convergence speed of this algorithm with genetic algorithm and particle swarm optimization.

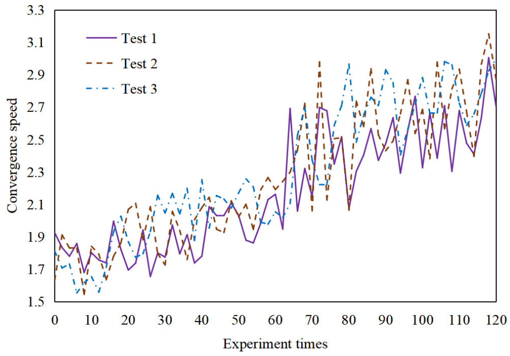


Figure 3 Convergence rate of the algorithm in this paper

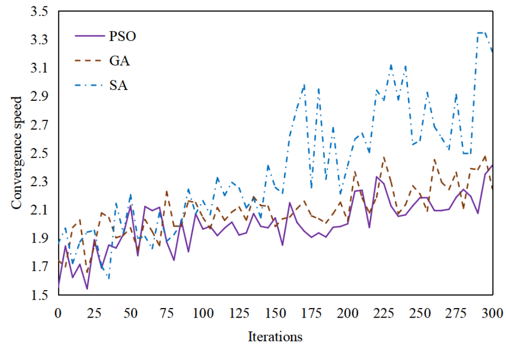


Figure 4 Comparison of convergence speed of several algorithms

Figure 3 shows the convergence speed of the algorithm in this paper. As can be seen from the figure, with the increase of iteration times, the convergence speed of the algorithm is gradually accelerated and finally tends to be stable. This result shows the effectiveness and convergence of SAA in the optimization process. Figure 4 shows the comparison of the convergence speed of this algorithm with genetic algorithm and particle swarm optimization. As can be seen from the figure, under the same number of iterations, the convergence speed of this algorithm is obviously faster than that of genetic algorithm and particle swarm optimization. Specifically, the algorithm in this paper achieves a high convergence speed in a few iterations, while genetic algorithm and particle swarm optimization need more iterations to achieve similar convergence speed.

The stability and robustness of the model can be evaluated by many simulation experiments in the oil field. Figure 5 shows the stability results of the algorithm.

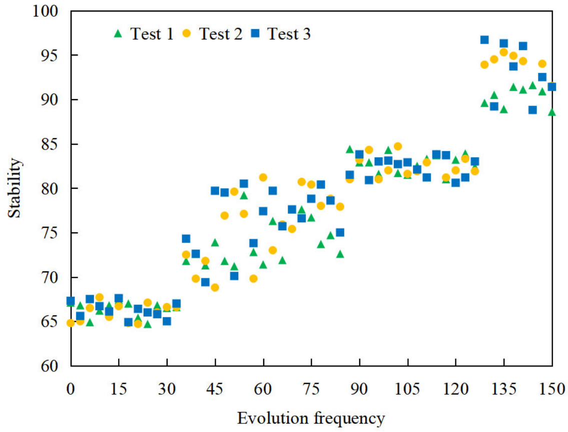


Figure 5 Stability results of the algorithm

As can be seen from the figure, the optimization results of the algorithm show certain stability and consistency after many simulation experiments for oil fields. Specifically, the optimization results of each experiment are concentrated in a certain range, and there is no big deviation or fluctuation.

Through the analysis and evaluation of the simulation experiment results, the following conclusions can be drawn: (1) The optimization model of well layout direction of tertiary infilling wells based on SAA can effectively improve oil recovery, which proves the effectiveness of SAA in this problem. (2) The SAA has a fast convergence speed, which shows that the algorithm has a high efficiency in solving the problem of optimizing the well layout direction of tertiary infilling wells by water flooding. (3) The model has good stability under different constraints, which shows that the model has strong adaptability and robustness.

## 4. Suggestions on optimization strategy of well layout direction from the perspective of sustainable development

### 4.1 Optimization strategy formulation of well layout direction based on simulation experiment results

According to the results and analysis of the simulation experiment, the following optimization strategies of well layout direction can be formulated:

Data-driven decision-making: Using advanced geological exploration technology and data analysis methods, the geological conditions and reserve distribution of the oilfield can be predicted and evaluated more accurately, providing scientific basis for the selection of well layout direction.

Combination of algorithm and practice: When the SAA is applied to optimize the well layout direction, it is necessary to set reasonable parameters and constraints according to the actual situation of the oilfield, including geological conditions, economic conditions and technical conditions.

Flexible adjustment of well layout strategy: according to the different stages of oilfield development and the

changes of actual situation, flexibly adjust the well layout direction and strategy to meet the needs of oilfield development.
Strengthen technical innovation: strengthen technical research and innovation, promote the application of new well layout technology and equipment, and improve well layout efficiency and oil recovery.

### 4.2 Suggestions on adjustment of well layout direction based on sustainable development

From the perspective of sustainable development, it is necessary to consider the balance of economic, social and environmental benefits of oilfield development. Therefore, this paper puts forward the following suggestions for adjusting the well layout direction:
Efficient utilization of resources: in the process of well layout, priority should be given to efficient utilization of resources to avoid waste and destruction. By optimizing the well layout direction and strategy, the oil recovery is improved and the development life of the oilfield is prolonged.
Eco-environmental protection: In the process of oilfield development, we should pay attention to eco-environmental protection to avoid damage to the eco-environment. When choosing the direction of well layout, we should try to avoid ecologically sensitive areas and protected areas.
Fulfillment of social responsibility: Oilfield development enterprises should actively fulfill their social responsibilities, strengthen communication and cooperation with local communities, and jointly promote the sustainable development of oilfields. When choosing the direction of well layout, we should consider the needs and interests of local communities.

## 5. Conclusions

In this paper, an optimization method of well layout direction of tertiary infilling wells by water flooding based on SAA is proposed, which solves the limitations of traditional methods in dealing with complex constraints and optimization objectives. Through the research, we can draw the following conclusions: the algorithm in this paper has advantages in convergence speed, can find the solution of the optimization problem faster, and improves the optimization efficiency. Compared with genetic algorithm and particle swarm optimization, this algorithm has better performance in solving the optimization problem of well layout direction of tertiary infilling wells by water flooding. By comparing the experimental and analytical results, the advantages of this algorithm in convergence speed and the comparison results with other algorithms are verified. These experimental results prove the effectiveness and superiority of this algorithm in solving the optimization problem of well layout direction of tertiary infilling wells by water flooding.
SAA can search the global optimal solution by randomly disturbing the well layout direction, thus avoiding falling into the local optimal solution. At the same time, the algorithm can also control the progress of the search process by accepting criteria, so as to ensure the search efficiency and avoid premature convergence to inferior solutions. Therefore, the SAA has high application value and potential in optimizing the well layout direction of tertiary infilling wells by water flooding. At the same time, this paper also notes that there are still some problems and shortcomings in the simulation experiment. For example, in some cases, the optimization effect of the model is not ideal, which may be caused by unreasonable model parameters or complicated constraints. Therefore, in the future research, we can further explore how to improve the model parameter setting and constraint processing methods to improve the optimization effect and adaptability of the model.

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