

# Influence Analysis of Calculation Error of Reservoir Numerical Simulation by Direction and Size of Grid

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**Abstract:** Grid direction and size influence calculation precision of reservoir numerical simulation and calculation cost. Influence of calculation result by grid direction and size is analysed by building concept model and changing grid direction and size. As example of Liang 35 Shengli Oil Field, adaptability of grid direction and size is discussed by building actual models in different grid size. Method of reducing effect of grid direction and size and principle of deviding grid are brought forward. The conclusion has some reference value and instruct significance.

**Key words:** Reservoir numerical simulation; Grid Direction; Grid Size; Fluidity Ratio; Error

## 1. Introduction

Reservoir numerical simulation is widely applied as a technical means to modify the geological model and forecast the remaining oil. The reservoir is gridded, nonlinear partial differential equation group reflecting the flow event of underground fluid is solved by computer, then filtration of oil, water and gas is simulationed<sup>[1]</sup>. Approximate numerical resolution is achieved by numerical method for true result is hardly got by analytical method<sup>[2]</sup>. A set of reservoir parameters is given to each grid, then pressure and saturation are calculated. Grid direction and size certainly influence calculation precision of reservoir numerical simulation. If five-point finite difference is applied in areal model, then flow firstly acts adjacent grids in the same line or row. But fluid in the reservoir can flow in any direction. So, how is the influence of grid direction determined? If the grid size is too large, the reservoir heterogeneity is hardly considered and huge calculation error is caused by truncation and numerical dispersion. If the grid size is too small, the scale of model is enlarged and the cost of calculation increases. And also computation time is prolonged owing to the non-convergent calculation<sup>[3]</sup>. So the size of grid is always the point of numerical simulation. This paper gives the answer by building conceptual model and actual reservoir model.

## 2. Building Conceptual Model

Besides grid direction and size, many factors influence the simulation results, such as reservoir structure, distribution of faults, fluid property and its filtration character, size of edge and bottom water and other reservoir heterogeneity. Considering different grid direction and size and remaining the other reservoir parameters, a high and middle-permeability reservoir conceptual model is built. The basic reservoir parameters are as follows: reservoir top depth is 2000m, thickness is 27m, porosity is 0.3, permeability is  $2000 \times 10^{-3} \mu\text{m}^2$ , the initial pressure is 20MPa, pressure coefficient is 1.0, surface oil density is  $0.87 \text{g/cm}^3$ , oil volume factor is 1.175, immobile water saturation is 0.306, residual oil saturation is 0.233, dissolved gas/oil ratio is  $51.0 \text{m}^3/\text{m}^3$ , rock coefficient of compressibility is  $4.0 \times 10^{-4} 1/\text{Mpa}$ , oil initially in place is  $314.0 \times 10^4 \text{m}^3$ . Five-spot water flooding pattern is applied and injector producer distance is 380m.

## 3. Influence of Grid Direction

### 3.1 Quantitative analysis on influence of grid direction

The flow of reservoir fluid has definite orientation owing to the pressure difference, permeability and its direction. Although it is considered to be consistent with the major permeability direction, the grid direction equal to the filtration direction can hardly attain. So the grid direction influences the simulation result. What's more, influence of grid direction is related with oil/water mobility ratio and grid size<sup>[4]</sup>. Different cases based on conceptual model are as follows: grid size is 90m, 30m, 10m, grid direction is diagonal and parallel grid(diagonal that is the angle between grid direction and the injection/production direction is 45°, parallel that is the angle between grid direction and injection/production direction is 0°), mobility ratio is 1:1(no gas cap), 1:1(gas cap), 10:1, 100:1. Each case forecasts twenty-year development index. The result (Fig1, Fig2) shows: (1) Grid direction apparently influences the development index. On the condition of same oil/water mobility ratio and grid size, parallel grid direction model has faster water breakthrough and large water cut escalating rate in earlier stage, almost accordant at the last stage. Provided the oil/water mobility ratio is 1(no gas) and grid size is 90m, water breakthrough comes 2 years later in the diagonal grid model than in the parallel grid model. Water breakthrough comes in May,2011 in the parallel grid model whereas in April,2013 in the In the parallel grid model. After 20 years, in the parallel grid model water cut reaches 0.788, degree of reserve recovery is 38.1%, while in the diagonal grid model water cut is 0.808, degree of reserve recovery is 41.5%. The difference of reserve recovery degree between two models is 3.4%, Relative error is 8.19%. (2) Influence of grid direction is related with oil/water mobility ratio. If the Oil/water mobility ratio is 1, grid direction has the most apparent influence. As the Oil/water mobility ratio increases or a gas cap is being, influence by the grid direction becomes less. For example, provided the oil/water mobility ratio is 1 and grid size is 90m, water breakthrough comes 2 years earlier in the parallel grid model than in the diagonal grid model. Water breakthrough comes almost at the same time when the oil/water mobility ratio is 100 and grid size is 90m. The difference of reserve recovery degree between two models is only 0.74%. If there is a gas cap, as the pressure decrease, gas dissolves out, gas/oil ratio ascends abruptly, immobile water partly becomes movable for the reduction of pore volume. So water is produced as soon as a well is put into production, but not injected water. Water cut curve of different grid sized model almost coincides in the early stage also demonstrate that influence by the grid direction becomes less when there is gas. (3) Influence of grid direction is also related with grid size. The bigger the grid size, the more apparent the influence. If the oil/water mobility ratio is 10 and grid size is 90m, water breakthrough comes 4 months earlier in the parallel grid model than in the diagonal grid model. The difference of reservoir recovery degree between two models is 2.1%. Relative error is 8.82%, whereas the grid size is 10m, water breakthrough comes 1 month earlier in the parallel grid model than in the diagonal grid model. The difference of reservoir recovery degree between two models is only 0.1%. Relative error is 0.4%.

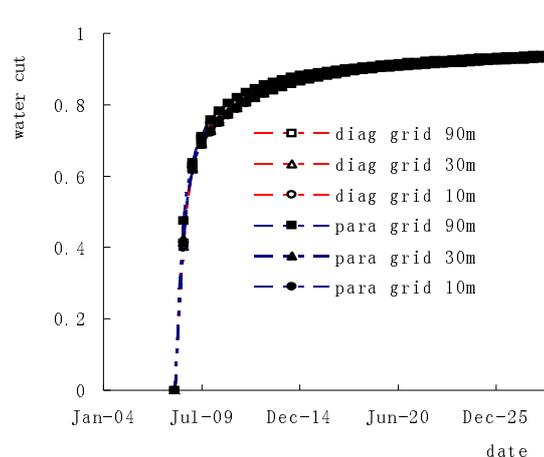
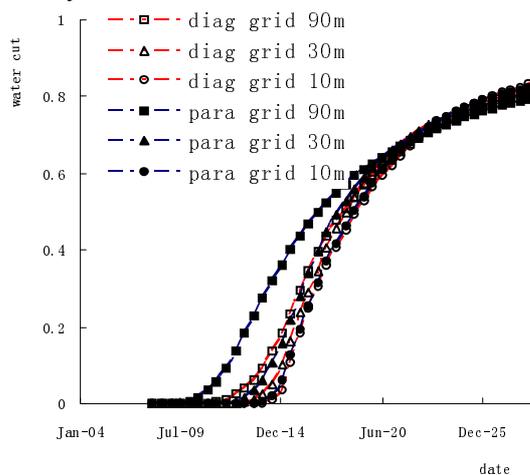


Figure 1 WCUT change (fluidity ratio=1 . No gas cap) Figure 2 WCUT change (fluidity ratio=100)

### **3.2 Approach of lessening the influence of grid direction**

Since the influence by grid direction is hardly avoided, how to lessen the influence is considered as follows: (1) the forward analysis shows that the smaller the grid size, the less apparent the influence. Smaller grid should be used or grid near the well should be refined especially when oil/water mobility ratio is 1. Nine-point difference method can lessen the influence by grid direction. The flow between adjacent diagonal grids is calculated in the nine-point difference method, which reflects the flow event of underground fluid, but traditional five-point difference method can't do that. The result also shows that, if the oil/water ratio is 1, water cut curves between nine-point difference and five-point difference has apparent difference, whatever it's a diagonal or parallel grid model. Water cut curves between diagonal grid and parallel grid nine-point difference model are closer. The difference between reservoir recovery degree is 2.1% whereas the difference of reserve recovery degree between diagonal grid and parallel grid five-point difference model is 3.4%. Nine-point difference apparently lessens the difference between diagonal and parallel grid.

## **4. Influence of Grid Size**

### **4.1 Quantitative analysis on influence of areal grid size**

The forward result shows that, (1) Grid size in some degree influences the calculation result. The bigger the grid size, the earlier the water cut breakthrough comes and the smaller the water cut escalating rate. On the contract, the smaller the grid size, the later the water cut breakthrough comes and the bigger the escalating rate. As the time goes on, the difference of water cut among different grid sized model becomes smaller. Water cut at the last stage is almost accordant. For example, if the oil/water ratio is 1 (no gas) and parallel grid is determined in the model, water breakthrough comes 2 years earlier in 90m grid model than in the 10m grid model. The difference of reservoir recovery degree is 5.1%. (2) Influence of grid size is related with oil/water mobility ratio. Grid size brings the most influence when the oil/water ratio is 1. As the grid becomes bigger or smaller, the influence becomes weaker. For example, when oil/water ratio is 100 and grid size is 10m, water cut breakthrough comes in Feb, 2008, 1 month later than 10m grid size. The difference of reservoir recovery degree is 1.14%. Error becomes smaller compared with the model that oil/water ratio is 1.

### **4.2 Quantitative analysis on influence of vertical grid size**

The former result based on a areal model which has only one layer. What is the result when the 3D model has many layers? Different cases are given as follows: diagonal grid model and grid size is 30m, 3 or 9 or 27 layers in the vertical direction and vertical permeability is 0.05 times larger than areal permeability. The result shows: (1) The result shows great difference after reservoir subdivision. Water cut breakthrough comes earlier in a subdivided reservoir than a non-subdivided one. Water cut increases slowly after reservoir subdivision. The more the subdivided layers, the slower the water cut increases. Different regular pattern segments which are equal to the number of subdivided layers display on the water cut curve. For example, water cut reaches 0.813 after 20 years in a non-subdivided model. The degree of recovery is 42.2%. Water cut reaches 0.818 after 20 years in a 3-subdivided layers model and degree of recovery is 52.8%. Water cut reaches 0.610 after 20 years in a 27-subdivided layers model and degree of recovery is 56.0%. The difference of recovery degree between the non subdivided model and the 27-subdivided layers model is 13.8%. Relative error reaches 32.7%. The result is considered to be brought by the gravitational differentiation. Since the density of oil and water is different, injected water firstly goes into bottom of the reservoir and flows to the production well. Water firstly flooded at the bottom of the oil well, and as the injected water gradually flows in, then the middle of the oil layer floods out, collision displays on the water cut curve. So different regular pattern segments displays on the water cut curve. (2) Vertical permeability acts a lot in the calculated result. Little difference is made when the vertical permeability is 0.005 times larger than areal permeability. The difference of recovery degree between a non-subdivided model and a 27-subdivided layers model is 0.05%. Relative error reaches 0.12%. Thus, Vertical permeability is the most important factor of fluid flow and division of remaining oil. Subdivision of reservoir, especially barrier and interbed effect on vertical permeability

should be the key point of remaining oil research and case forecast.

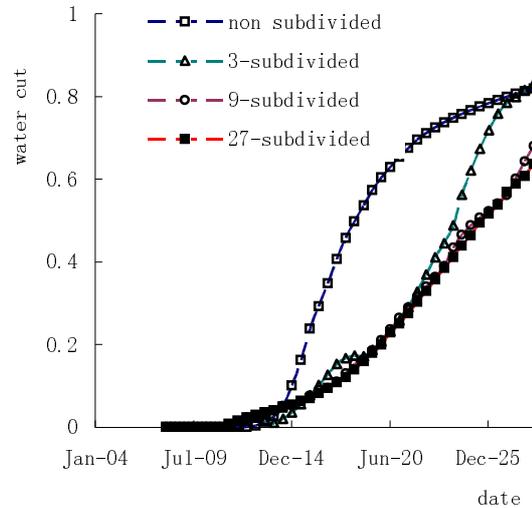


Figure 3 WCUT change of model of subdivision in a layer

#### 4.3 Theoretical analysis on calculation error by grid size

In reservoir numerical simulation, system error, such as truncation error and round off error can't be avoided since the continuous partial differential equation is replaced the finite difference equation. The error related grid size influences the calculation stability. Truncation error is caught by truncated Taylor series expansion replacing the time derivative and special derivative. Theoretical equation derivation shows:  $e_L = o[(\Delta x)^2] + o(\Delta t)$ ,  $e_L$  is local truncation error,  $o$  is the order of error,  $\Delta x$  is grid size,  $\Delta t$  is time step. Local truncation error is related with grid size and time step. The smaller the  $\Delta x$ , the less the truncation error. But as the  $\Delta x$  becomes smaller, the number of grids becomes more and calculated amount increases, so that round off error increases proportionally. So lessen the grid size may not increase the calculated accuracy. Determination of grid size should consider the concordancy of truncation error and round off error<sup>[5]</sup>.

### 5. Adaptability of Grid Size on an Actual Model

As an example of Liang 35 Shengli Oil Field, influence of grid size is discussed. Liang 35 is a middle porosity and middle permeability unsaturated light oil reservoir. Sha 3 Zhong is the main oil containing formation. The reservoir has big edge and bottom water. The mean permeability is  $235 \times 10^{-3} \mu\text{m}^2$ , and the mean porosity is 0.16. The oil/water ratio is 3:1. Injector producer distance is 300m or so. Four different grid sized 3D geological model are built: grid size 25m with subdivided layers, and other grid size 25m, 50m, 100m without subdivided layers. The average relative error<sup>[6]</sup>, which reflects degree of deviation between calculated and actual value is used to make comparison of calculated results of different models. The result shows that: (1) Generally speaking, influence by grid size for actual model is less than conceptual model. Water cut curves of different model has a little difference in number but the same tendency. For example, the difference of field water cut between 25m and 100m grid sized model is 0.5%. (2) Comparatively speaking, more influence is made by reservoir subdivision, not areal grid size. Little difference is caught especially when areal grid size is less than 50m. For example, the relative error of water cut brought by reservoir subdivision and non-subdivision is 0.3% when areal grid size is 25m, whereas relative error is 0.1% when areal grid size is 50m. Why does grid size make a more apparent influence on a conceptual model than an actual model? The reason can be considered: conceptual model is a homogeneous formation, which has simple structure, less oil in place and wells. Truncation error, round off error and numerical dispersion is relatively enlarged. While

actual model is a heterogeneous formation, which has complex structure, more oil in place and wells, each type of error by grid size is concealed in some extent. However, production index of some wells still gives large difference by grid size.

Thus it can be seen, in practical application, determination of grid direction and size should be as follows: (1) Grid direction is consistent with major permeability orientation so that less error is made by grid direction and difference method. (2) In the areal direction, small grid size should be used in the area which is large well spacing density, complex structure or microtectonics and fluid properties of wide variation range and reservoir properties. Grid size must be less than 50m when a reservoir is on production at a middle or later stage. In the vertical direction, subdivision by thickness or in proportion should be made according to your interest for rhythmic thick reservoir and bottom water coning reservoir and high heterogeneous reservoir, so that distribution of reservoir property, barrier and interbed, intermediate zone and filtrational resistance by various permeability are described clearly.

## 6. Conclusions

Following conclusions are gotten through research described above: On the conceptual model, (1) Grid direction has apparent influence. Parallel grid model has earlier water cut breakthrough. As the oil/water ratio increases or a gas cap is being, influence by the grid direction becomes less. Small grid size and nine-point difference method can lessen the influence; (2) The bigger the grid size, the earlier the water cut breakthrough comes. As time goes on, water cut difference among different grid sized model becomes less. As the ratio becomes bigger or smaller, influence by grid size gradually drop off; (3) The result gives apparent difference after vertical subdivision of reservoir, and also vertical permeability acts a lot. On the actual model, (4) Influence by grid size is smaller. So, determination of grid size is given out:(5) the grid direction is better to be consistent with major permeability orientation. Areal grid size is less than 50m and thick oil reservoir should be subdivided in the vertical direction; (6) History matching should be carried on by stages. Large grids are used to make the production index reasonable in a range at the rough history matching stage. Smaller grids are used to match the individual well production index at the accurate history matching stage.

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