Numerical simulation of gas wells in different types of carbonate reservoirs

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Abstract. The geological conditions of carbonate reservoirs are complex, and there are multi-media of pores, vuggy, and fractures with different scales. The macroscopic Heterogeneity of carbonate reservoirs is very strong, and the difference between wells is very large, which leads to the great difference in the production of different types of reservoirs and the difficulty in product evaluation. It is also difficult to forecast the production capacity and to determine the policy of developing technology. In this paper, by using the actual data of the Moxi area, the reservoir types of Moxi area are defined, and the production performance of different types of reservoirs are revealed. By using the integration of unconventional geological modelling and numerical simulation software Untog, the geological models which can reveal the geological characteristics of different types of reservoirs are established, and the numerical simulation study is carried out. The contribution of different media to the well production is revealed, the larger the pore size, the higher the recovery degree. Higher the proportion of large-scale pore, the higher the gas well production, and higher the well recovery.

1. Introduction
There are multi-media of pores, vuggys, and fractures of different scales in carbonate reservoir, and their macro-heterogeneity is very strong, and multi-scale characteristics are prominent. The corresponding geometric and physical parameters are very different, showing strong micro-heterogeneity and multi-medium characteristics. The fluid properties and occurrence state are different in different scale pore, vuggy, and fracture media, and the flow mechanism and flow state are different greatly. As a result, the production performance of gas wells in the same block is different, and the prediction of production capacity is difficult. In recent years, many researchers devoted to build fracture-vuggy-pore model to describe the complex geological conditions of the carbonate reservoir[1-11], but not so many people focus on the performance of different types of reservoir, and the contribution of different type media.

2. Production performance of different types of reservoirs

2.1. Classification of reservoir types
The reservoir types are divided according to the core and thin section data to identify and classify the fractures of structural fracture and pressure solution fracture, as well as the types of reservoir space dominated by solution pore and solution cave. The fracture density statistics are carried out to
determine the distribution characteristics of fractures, the matching relationship between fractures and vuggy is made clear by using seismic and logging data, and the reservoir types are divided by combining the reservoir physical property data.

There are three types of a reservoir in the Moxi Area: fracture-vuggy-pore type, vuggy-pore type and pore type.

In the fracture-vuggy-pore type of reservoir, fractures are well developed, it can be seen directly by eye from core, and there are a lot of small scale fractures in the slice. The porosity of the fracture-vuggy-pore reservoir is lower (0.6%-14.47%) and the permeability is higher (0.001 MD-37MD).

In the vuggy-pore type of reservoir, there are not so many fractures developed, but big-scale dissolved pore are well developed. The porosity of the vuggy-pore reservoir is higher (0.27%-12.48%) and the permeability is lower (0.001 MD-31.4MD).

In the pore type of reservoir, neither fractures or big scale dissolved pores are developed, only small scale pores can be seen. The porosity of the porous reservoir is lower (<3%) and the permeability is lower (< 0.1MD).

2.2. The production performance of different types of reservoirs

Natural fractures are well developed in fracture-vuggy-pore type reservoirs, and the big dissolved pores are communicated by fractures, so this type of reservoir has good physical properties. It shows high production at the initial stage of gas wells because of the large scale fractures, slow production decline, slow pressure drop, and high cumulative production (As shown in Figure 1).

![Figure 1](image1.png)

**Figure 1.** Production curve of typical wells in the fracture-vuggy-pore reservoir.

![Figure 2](image2.png)

**Figure 2.** Production curve of typical wells in the vuggy-pore reservoir.

![Figure 3](image3.png)

**Figure 3.** Production curve of typical wells in pore reservoir.
Karst is well developed in the vuggy-pore type reservoir, and the reservoir space is dominated by primary solution pores. The main seepage passage is a pore-constricted throat. This type of reservoir has good physical properties. The production performance shows high production at the initial stage of gas wells, with slow production decline and high cumulative production. But there are no large fractures developed, the pressure supply area is small, which result in the pressure dropped more quickly than fracture-vuggy-pore type reservoirs (As shown in Figure 2)

The pore-type reservoir is characterized by low permeability, poor production test, low production, rapid pressure decline, and poor stable production (As shown in Figure 3)

3. Single well models of different reservoir types

In this paper, the geological modelling and numerical simulation are done by using the software Untog, which is specially developed for complex reservoirs.

Firstly, the physical properties of pore and fracture media under different types of reservoirs are analyzed by using core slices, mercury injection and logging data, the parameters such as porosity, permeability, fracture density and the distribution ratio of pores of different scales are defined for different reservoirs.

Secondly, the geological model of a single well is established, including the fracture model, big scale dissolved pore model, and matrix pore model. The big-scale fracture model is deterministic modeling. The small scale fracture model and dissolved pore model is generated randomly according to the matching relation of fracture and cavity and core observation data. The matrix pore model is generated randomly according to the distribution ratio of pores in different scales.

Table 1 shows the fracture models of different reservoir types. In the fracture-vuggy-pore reservoir, big scale and small scale fractures are both well developed, while the pore reservoir has only a few small scale fractures. Vuggy-pore reservoir has few big-scale fractures and some small scale fractures.

| Reservoir type       | Fracture-vuggy-pore reservoir | Vuggy-pore reservoir | Pore reservoir |
|----------------------|-------------------------------|----------------------|---------------|
| Different scales     | Fractures distribution model  |                      |               |
|                      |                               |                      |               |

Table 2. Big-scale dissolved pore distribution models of different reservoir types.

| Reservoir type       | Fracture-vuggy-pore reservoir | Vuggy-pore reservoir | Pore Reservoir |
|----------------------|-------------------------------|----------------------|---------------|
| Model of big-scale   |                               |                      |               |
| dissolved pore       |                               |                      |               |
| distribution         |                               |                      |               |
| (pink present        |                               |                      |               |
| dissolved Pore)      |                               |                      |               |

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Table 2 shows the big-scale dissolved pore distribution models of different reservoir types. In the vuggy-pore reservoir, there are a lot of big scales dissolved pore (the pink one), while there are only a few big scales dissolved pore in pore reservoir. In the fracture-vuggy-pore reservoir, there is more big scale dissolved pore than pore reservoirs, but less than the vuggy-pore reservoir.

Table 3 shows the proportion of different scale pores in different reservoir types and the different scales pore distribution models of different reservoir types. In the vuggy-pore reservoir, the big pore, medium pore, and small pore are dominant, the proportion is 75%. In the fracture-vuggy-pore reservoir, medium pore and small pore are dominant, the proportion is 60%. In the pore reservoir, nanopore and micropore and small pore are dominant, the proportion is 85%.

Finally, according to the data of single well layering, the single well model is established. Figure 4 shows the geological model of Fracture-vuggy-pore reservoir, Figure 5 shows the geological model of Vuggy-pore reservoir, Figure 6 shows the geological model of Pore Reservoir.

**Table 3. Different scales pore distribution models of different reservoir types.**

| Reservoir type       | Fracture-vuggy-pore reservoir | Vuggy-pore reservoir | Pore Reservoir |
|----------------------|--------------------------------|----------------------|----------------|
| The proportion of different scale pores | ![Fracture-vuggy-pore](image1) | ![Vuggy-pore](image2) | ![Pore Reservoir](image3) |
| Different scales pore distribution models | ![Fracture-vuggy-pore](image4) | ![Vuggy-pore](image5) | ![Pore Reservoir](image6) |

**Figure 4.** Geological model of XX22 (Fracture-vuggy-pore reservoir).

**Figure 5.** Geological model of XX105 (Vuggy-pore reservoir).

**Figure 6.** Geological model of XX1 (Pore Reservoir).
4. Numerical simulation

The difference between physical property and oil-bearing property of different scale pore media results in the difference of availability and recovery degree of different pore media. At the same time, the quantity composition, spatial distribution, physical properties, and size of matrix rock have a great influence on production performance too. Through the history matching and prediction of the established single well model, the contribution of different scale pores to productivity is analyzed.

Table 4 shows the proportion of different scale pores and the porosity and permeability of each scale pore. These data are used in numerical simulation.

Figure 7-9 shows the history matching and the predicted production curve of each type reservoir. And the data of table 5 are based on predicted data.

Table 4. The proportion of pores in different scales and their physical properties.

| Reservoir type           | Proportion of pores of different scales (nano-pores: micro-pores: Small Pores: medium pore: Large pores) | Porosity/% (nano-pores: micro-pores: Small Pores: medium pore: Large pores) | Permeability/mD (nano-pores: micro-pores: Small Pores: medium pore: Large pores) |
|--------------------------|---------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------|---------------------------------------------------------------------------------|
| Fracture-vuggy-pore reservoir | 0.1: 0.2: 0.3: 0.3: 0.1                                                                          | 1.23: 2.7: 4.5: 9.2: 14.5                                                      | 1.25: 1.9: 2.67: 3.89: 4.5                                                      |
| Vuggy-pore reservoir     | 0.1: 0.15: 0.2: 0.3: 0.25                                                                        | 1.45: 2.3: 4.6: 7.8: 11                                                        | 0.34: 1.2: 2.6: 3.5: 4.27                                                      |
| Porous Reservoir         | 0.25: 0.35: 0.25: 0.10: 0.5                                                                       | 0.9: 1.1: 2.6: 4.2: 6.9: 8                                                     | 0.13: 0.69: 1.26: 1.8: 2.7                                                     |

Figure 7. Predicted production curve of typical wells in the fractured-vuggy-pore reservoir.

Figure 8. Predicted production curve of typical wells in the vuggy-pore reservoir.

Figure 9. Predicted production curve of typical wells in pore reservoir.

Table 5 shows the result of numerical simulation, it contains the original reserves, remaining reserves, cumulative production and recovery of each scale pores.
5. Result and discussion
From the results of numerical simulation, we can see: (1) Bigger the pore, higher the recovery degree. The recovery of big pore can reach 40% while the recovery of the nanopore is lower than 10%. (2) Under the condition that the quantity and composition of pore medium of different scales have a good influence on the production performance. Higher the proportion of large-scale pore, the higher the gas well production, and the higher the well recovery.

Table 5. Reserves and recovery of porous media in different scales.

| Reservoir type       | Proportion of porous medium | Original reserves (108m3) | Remaining reserves (108m3) | Cumulative production (108m3) | Recovery   |
|----------------------|-----------------------------|--------------------------|---------------------------|-----------------------------|------------|
| Fracture-vuggy-pore reservoir | Nanopore(5%)                | 2.23                     | 1.85                      | 0.18                        | 8.07%      |
|                      | Micron pore(20%)             | 3.29                     | 2.44                      | 0.85                        | 25.84%     |
|                      | Small pore(15%)              | 5.64                     | 4.18                      | 1.46                        | 25.89%     |
|                      | Medium Pore(40%)             | 8.36                     | 5.72                      | 2.84                        | 33.97%     |
|                      | Big pore(20%)                | 4.19                     | 2.46                      | 1.73                        | 41.29%     |
|                      | Total                        | 23.71                    | 16.65                     | 7.06                        | 29.76%     |
|                      | Nanopore(15%)                | 0.89                     | 0.78                      | 0.08                        | 8.99%      |
|                      | Micron pore(20%)             | 1.67                     | 1.49                      | 0.21                        | 12.57%     |
|                      | Small pore(30%)              | 2.73                     | 2.18                      | 0.55                        | 20.15%     |
|                      | Medium Pore(30%)             | 4.26                     | 3.22                      | 1.04                        | 24.41%     |
|                      | Big pore(5%)                 | 3.29                     | 2.36                      | 0.93                        | 28.27%     |
|                      | Total                        | 12.84                    | 10.03                     | 2.81                        | 21.90%     |
|                      | Nanopore(25%)                | 1.08                     | 1.03                      | 0.05                        | 4.63%      |
|                      | Micron pore(35%)             | 2.23                     | 1.92                      | 0.31                        | 13.90%     |
| Vuggy-pore reservoir | Small pore(25%)              | 2.16                     | 1.89                      | 0.27                        | 12.50%     |
|                      | Medium Pore(10%)             | 1.34                     | 1.11                      | 0.23                        | 17.16%     |
|                      | Big pore(5%)                 | 0.89                     | 0.71                      | 0.18                        | 20.22%     |
|                      | Total                        | 7.7                      | 6.66                      | 1.04                        | 13.46%     |

6. Conclusions
There are three types of carbonate reservoirs in the Moxi Area: fracture-vuggy-pore type, vuggy-pore type and pore type.

The production performance of different types of reservoirs are different: fracture-vuggy-pore type reservoirs have high production at the initial stage, the production decreases gradually, and the pressure drops slowly; the vuggy-pore type gas well has high production at the initial stage of gas wells, with slow production decline and high cumulative production, but the pressure dropped rapidly. The pore-type reservoir is characterized by low production, rapid pressure decline, and poor stable production.

The difference of geometry scale and quantity composition of different scale pore medium leads to the difference of availability and recovery degree of different pore medium and also has a great influence on production performance. Larger the porosity, the higher the recovery degree, the higher the proportion of big-scale pores, the higher the gas production and the higher the recovery of a single well.

From the results, it can be seen from the results that in the future well location optimization, the area with more fractures and large scale pores can be obtain higher production.

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