Analysis of development performance characteristics of strong heterogeneous carbonate gas reservoirs——the Deng 4 gas reservoir in the GM block

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Abstract. The Deng 4 gas reservoir in the GM block of Anyue gas field is an important area of natural gas production during the "13th Five-Year Plan" period. A correct understanding of its production dynamics is the key to scientific development of gas reservoirs and long-term stable production. Using gas reservoir engineering, production statistics, well test analysis, etc.， combined with gas reservoir geological characteristics, produced fluid properties, oil pressure production decline, gas well productivity, and single well controlled reserves, analyzed and summarized the Dengying Group gas in the block. The dynamic characteristics of production provide a reference for later efficient development.

Keywords: Dynamic analysis; production characteristics; production capacity; dynamic reserves.

1. Introduction

The gas reservoir of Deng 4th Member in the GM block in the middle of the Sichuan Basin is a strong heterogeneous carbonate gas reservoir with low porosity and low permeability. It has great exploration and development potential and is an important area for gas production in the Sichuan Basin [1-2]. The block has strong vertical and horizontal heterogeneity. Affected by the development degree of natural fractures and the development scale of the fracture-cavity system, the gas well exhibits complex seepage characteristics [3]. In recent years, although there has been more in-depth research on the geological characteristics of the block and the engineering characteristics of gas reservoirs, it is still difficult to meet the needs of gas reservoir development. By carrying out dynamic tracking analysis in the Gaoshiti-Moxi block, research the current gas reservoir production dynamics, and provide references for the scientific development of gas reservoirs and long-term stable production [4-6].

2. Overview of gas reservoirs

2.1. Geological Features

The gas field is located in the Weiyuan-Longnüsi tectonic group in the paleo-uplift and gentle tectonic area of the Sichuan Basin, with the Guang'an structure in the east, the Weiyuan structure in the west, and the middle-high and steep structure area in the southeast of Sichuan connected to the south. The structural pattern of the Cambrian base in the GM area is represented by a large northeast-trending nose-shaped uplift on the background of the Leshan-Longnüsi paleo-uplift, which is dipping from west to northeast, showing multiple rows and multiple high points duplex structure features [7]. The most favorable reservoir rocks of the fourth member of the Deng 4 Member are mainly algae clot dolomite, algae stromatolite dolomite, and algae sand clastic dolomite rich in bacteria and algae, with caves, secondary intergranular pores, and intercrystalline pores mainly [8], The average porosity is 3.87%, the average permeability is 0.51mD, the formation temperature is 147.69~159.10°C, the geothermal gradient is 2.65°C/100m, and the pressure coefficient is between 1.09~1.15. It is a high temperature and atmospheric pressure gas reservoir.

2.2. Fluid properties

The analysis of the natural gas composition in the upper and lower sub-members of Deng 4 shows that there is no significant difference in gas composition between the evaluation stage and the production stage of the Deng 4 member in the Gaoshiti-Moxi area. The natural gas is mainly methane, with a content of 90.00% to 97.98%, average 92.68%, ethane content 0.02%~0.60%, average 0.08%, hydrogen sulfide content 8.77g/m^3~45.11g/ m^3, average 16.3 g/ m^3, it contains hydrogen sulfide, carbon dioxide content 73.38g/m^3 ~149.33g/m^3, with an average of 94.8g/m^3. It contains medium carbon dioxide and slightly contains ethane, propane, helium and nitrogen. The hydrogen sulfide content in Moxi area is higher and the carbon dioxide is higher and the carbon dioxide is slightly lower.

From April 2014 to August 2021, more than 2500 produced fluid analysis tests were performed on each production well of the gas reservoir. The results show that the total salinity of gas wells shows an overall downward trend. The gas wells produce condensate and inlet fluids, and the production gas wells of the Deng 4 gas reservoir do not produce formation water.

3. Gas well production characteristics analysis

The oil pressure of gas wells in GM area is generally higher at the initial stage of production, with wells exceeding 30MPa. In the short term, the oil pressure drops rapidly. At this stage, the oil pressure of the wellhead shows a "two-stage" change characteristic [9-10].

During the stage of constant production and depressurization of gas wells, in the early stage of production, the oil pressure at the wellhead drops rapidly, with an average monthly decline rate of 10% to 37%, and an average monthly decline rate of 16%. The duration of this stage is relatively short, usually 1 to 6 months. After the rapid decline phase is over, the oil pressure production enters a relatively stable phase. At this stage, the pressure and production decline rate tends to be slow, and the decline is not obvious. The pressure and production decline rate are both less than 5% per year.

The gas well in this block is produced by means of constant output and pressure reduction. The output is stable at the initial stage of production, and the oil pressure continues to drop. When the oil pressure decline rate exceeds a certain threshold, the gas well is shut in, and the well is opened again when the formation pressure is restored to near the original formation pressure. And maintain a certain output production. At present, gas reservoirs are in the early stage of exploitation. Except for wells that are blocked by the formation or wellbore and restricted by surface equipment, most of the wells are currently in the stage of stable production.

The vast majority of gas wells (over 70%) have good stable production capacity, oil pressure and production are stable; some wells have oil pressure and production declines rapidly within a certain period of time; and a few wells have abnormally low oil pressure And the decline is faster. At present, the gas reservoirs are generally stable and have not yet shown obvious decline characteristics.

Table 1. Overview of Gas Well Classification.

type	Classification standard	Number of wells	Proportion of Wells (%)	Daily gas production per well ($10^4m^3/d$)	Average oil pressure (MPa)
High-pressure stable production well	Oil pressure >20MPa、Deceleration rate <5MPa/a, No obvious decline in daily output	33	65	21.04	33.63

Low pressure stable production well	Oil pressure≤20MPa、Deceleration rate <5MPa/a, No obvious decline in daily output	4	8	15.30	19.37
Decreasing Well	Production after shutting in wells for many times, Deceleration rate >5MPa/a, Big changes in daily output, unstable	12	23	12.62	21.30
Low oil pressure, decreasing well	Oil pressure≤20MPa、Deceleration rate >5MPa/a, Big changes in daily output, unstable	2	4	17.82	14.71

4. Analysis of productivity characteristics

Affected by reservoir type, well type and later transformation [11], The open flow of gas wells in the Deng 4 gas reservoir in the Gaoshiti-Moxi block is 29.95~202×104m^3/d, and the average open flow is 66.95×104m^3/d. Most of them belong to medium and low production gas wells. The productivity of gas wells with different reservoir types and well types have big different.

From the perspective of gas well productivity and structural altitude, there is no regularity at all. There is no obvious direct relationship between the structural position of gas wells. Therefore, the structure of Moxi area is the main factor that controls the gas-bearing capacity of Deng 4, but Structure is not the main factor that affects the productivity of gas wells; as the thickness of the drilled reservoir increases, the productivity of gas wells shows an increasing trend, mainly when the thickness of the reservoir is greater than 200m; at the same time, the porosity and productivity are generally positively correlated , Due to the low overall permeability of the gas reservoir, there is no obvious regularity in the distribution of permeability and productivity.

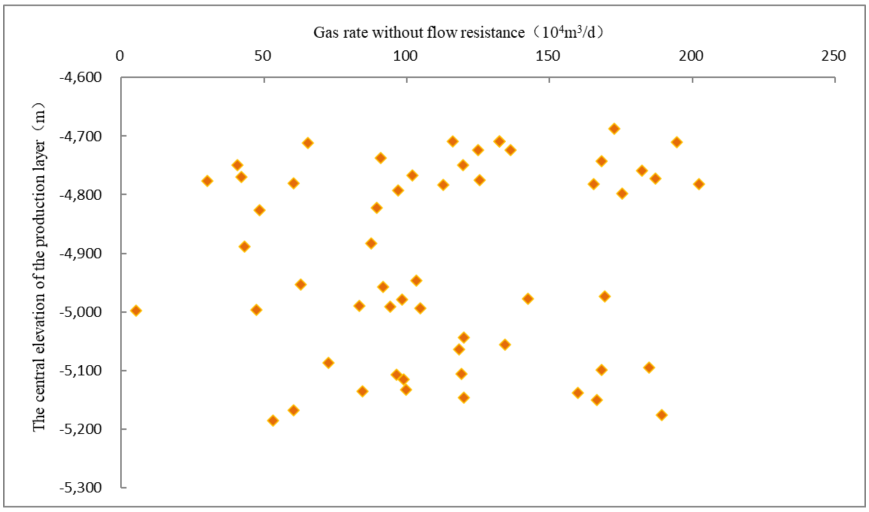

Figure 1. Relationship between open flow of gas well and elevation in the middle of the reservoir.

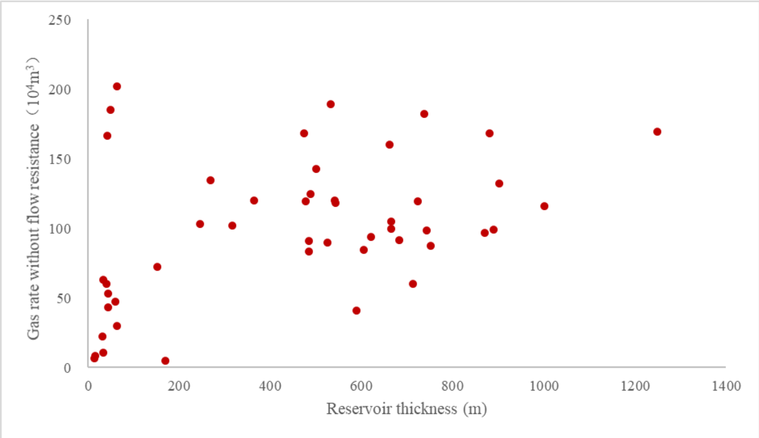

Figure 2. Relationship between reservoir thickness and productivity.

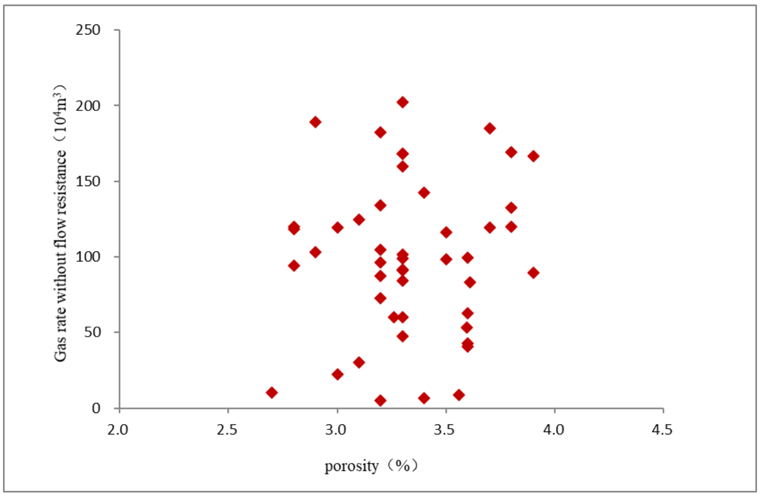

Figure 3. Relationship between porosity and productivity.

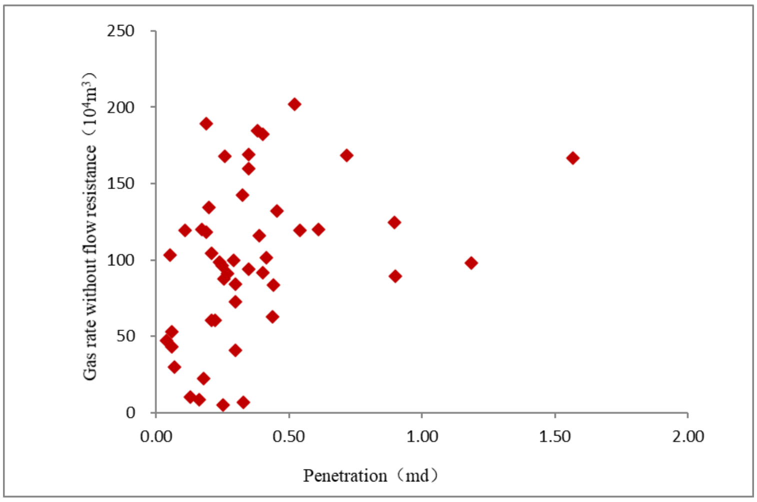

Figure 4. Relationship between penetration rate and production capacity.

With the advancement of drilling technology and geosteering tools, horizontal wells, highly deviated wells, and branch well technologies have been widely used in the development of various gas reservoirs. The reservoirs in the fourth member of the Dengying Formation have a large development span, overlap each other, and have strong heterogeneity. The use of inclined wells can take into account the effective production of the reserves of each layer in the vertical direction. At the same time, the area is mainly dominated by karst caves, intergranular pores, intercrystalline pores and intercrystalline pores. The pores and pores are the main storage space of the fourth member of the Dengying, and the fractures are developed to improve the seepage capacity of the reservoir. The inclined well is adopted. Or the development of horizontal wells is easy to drill into the fracture-cavity system, which is beneficial to improve the productivity of gas wells.

The analysis of the actual drilling of the Deng-4 gas reservoir in the Moxi block shows that the use of highly inclined wells (horizontal wells) can achieve better development results. The test production of horizontal wells/highly deviated wells is mainly distributed in 50~120×104m^3/d, the average test production of wells is 69.58×104m^3/d, the unblocked flow is mainly distributed in 60~150×104m^3/d, and the average unblocked flow of wells is 88.10×104m^3/d; The test production of vertical wells is mainly distributed in 20~80×104m^3/d, the average test production of wells is 46.15×104m^3/d, the open flow is mainly distributed in 30~100×104m^3/d, and the average open flow of wells is 85.39×104m^3/d; Except for individual wells, the unblocked flow rate of horizontal wells/highly deviated wells is higher than that of vertical wells on the whole. The test production of horizontal wells/highly deviated wells is 1.98 times that of vertical wells. The unblocked flow rate of all wells is that of vertical wells. 1.38 times that of horizontal wells/highly inclined wells with good development results.

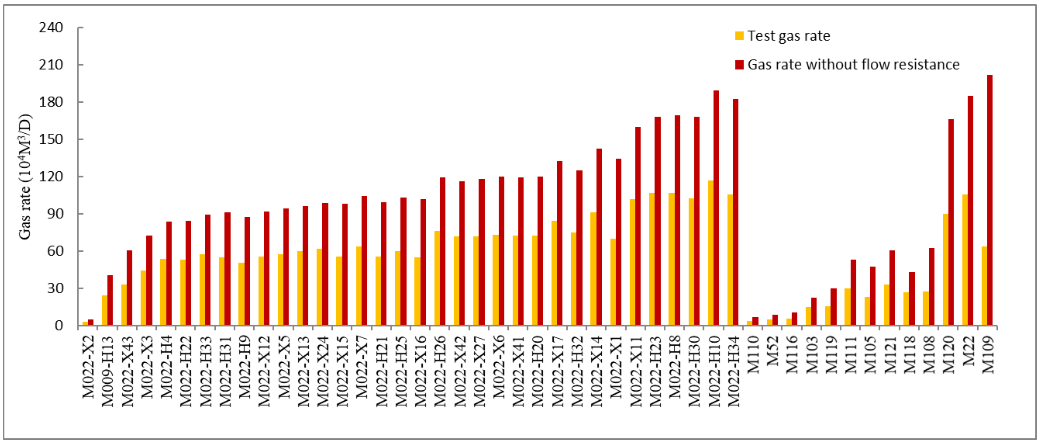

Figure 5. Productivity statistical histograms of different well types of gas wells.

The reservoir lithology of the Dengying Formation is dominated by dolomite, and acidification is an effective means to improve the seepage conditions of the dolomite reservoir. Through comparative analysis of the test conditions before and after the acidification of the gas wells in the Deng 4 gas reservoir, it can be seen that, except for Well Moxi 118, The acidification transformation greatly improved the pollution in the area near the well and in the wellbore, reduced the seepage resistance, and increased the gas well test production and unblocked flow. The increase ratio is generally 2-6, and the acidification transformation has a significant effect.

Table 2. Comparison table of test production and unblocked flow before and after reservoir reconstruction of gas well in Deng 4 gas reservoir of Moxi.

Well number	Before reservoir modification		After reservoir modification		Test yield ratio	Unblocked flow ratio
	Test yield(10^{4}m^3)	Unblocked flow(10^{4}m^3)	Test yield(10^{4}m^3)	Unblocked flow(10^{4}m^3)		
M022-X1	34.25	48.56082	69.78	113.08	2.04	2.33
M022-X3	18.55	20.38529	44.21	58.02	2.38	2.85
M105	6.197	5.223486	24.4614	29.56	3.95	5.66
M108	6.53	8.489072	27.47	42.95	4.21	5.06
M109	43.36	75.96136	63.98	120.98	1.48	1.59
M118	31.48	46.38228	26.63	41.03	0.85	0.88

5. Dynamic reserves analysis

Combined with the dynamic and static detection data of the Deng 4 gas reservoir and the production law of gas wells in the GM block, The pressure drop method, the elastic two-phase method, and the production instability method are used to calculate the single well dynamic control reserve. The main advantage of the pressure drop method is that it has no direct relationship with the single well supply area morphology, boundary type, reservoir seepage characteristics and other factors, and it has a wide range of applications. After reaching a certain degree of recovery of 10%, the pressure drop method is more accurate in calculating reserves. When applying the elastic two-phase method, there are stricter requirements for production data: First, high-quality pressure drop data is required, and pseudo-steady-state characteristics must be present; Second, the production of gas wells must be selected appropriately, which not only reflects a certain pressure drop, but also keeps production stable for a certain period of time. The production instability analysis method uses single well production data (production and flow pressure) for material balance analysis. A method for calculating dynamic reserves using gas well production history data and typical charts for fitting. The characteristic of this method is that it can use abundant daily production data of a single well, it is not necessary to perform shut-in pressure measurement, nor does it need to perform constant production or constant pressure production, and has no special requirements for production and flow pressure data.

Table 3. Single well reserve calculation method adaptability and reserve calculation statistics.

method	Scope of application	Gas reservoir adaptability of Dengying Formation	required materials
Pressure drop method	The extraction degree reaches 10%~15%	The extraction rate is about 10%	Formation pressure, Cumulative gas production
	Gas reservoirs with inactive edge and bottom water	No active side bottom water	
	Suitable for gas reservoirs with good connectivity	Connectivity is unclear	
Elastic two-phase method	Production reaches pseudo-steady state	46 wells accord	Test data of pressure drop under stable production conditions (need to reach a pseudo-steady state)
	High-precision instrument to measure flow pressure	Sufficient oil pressure data can be converted into flow pressure for calculation	
Yield instability method	Requires longer production time	50 wells accord	Single well production dynamics

Through the above three methods, the dynamic reserves of gas wells in the Dengying Formation gas reservoirs in the GM block are calculated. Some wells in this block have been put into production for a short time and have not reached the pseudo-steady seepage stage. Combined with the applicable conditions and production dynamic characteristics of each method, Comprehensive consideration has been given to the dynamic reserves of gas wells in Dengying Formation gas reservoirs. The dynamic reserves of individual gas wells vary greatly, ranging from 0.5 to $65\times10^8m^3$, and the average well is $13.16\times10^8m^3$.

From the analysis of the results, the gas wells with larger well-controlled reserves are mainly distributed in the favorable development zone of Type I. Among them, the average dynamic reserves of the wells in the G1 well area are the largest, reaching 1.552 billion cubic meters, followed by the M109 well area, the M108-111 well area, and the M118 well area is relatively the smallest.

6. Conclusions

(1) The average porosity of the Deng 4 gas reservoir in the GM block is 3.87%, the average permeability is 0.51mD, and the characteristics of low porosity and permeability are obvious; The formation temperature is 147.69~159.10 ℃, the geothermal gradient is 2.65℃/100m, and the pressure coefficient is between 1.09 and 1.15. It is a high temperature and atmospheric pressure gas reservoir.

(2) Gas reservoirs produce mainly natural gas, with methane content exceeding 90%, and no formation water is currently produced.

(3) Affected by factors such as reservoir type, well type, and post-modification, the productivity of gas wells varies greatly. Horizontal wells have better development effects and the production improvement effect is significant after acidification renovation.

(4) Affected by the actual production conditions, the results of calculating the dynamic reserves of a single well of a gas well at different times and different methods are quite different. The pressure and production decline of gas wells should be combined with multiple time periods and multiple methods to reduce calculation errors and provide reliability of calculation results.

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