Discussion on the Technical Countermeasures of Hechuan Xujiahe Gas Reservoir Development

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Abstract. The Xu-2 member of the Xujiahe gas reservoir in Hechuan gas field has a typical characteristic which is low porosity and low permeability. It is a condensate reservoir which has low dew point pressure and microcondensate oil. The development plan made in 2009, 2010, and 2011 was the key construction production phase. So far, the gas reservoir did not reach a stable life and production of scheme design. It was in the stage of production decline. The single well in the gas reservoir was affected by low porosity and tight reservoir that has a performance of low productivity. And it has a poor economic benefit by producing oil and water. Its corresponding development countermeasure should be explicit. So, getting geological reinterprets and carrying out gas well productivity analysis and development countermeasure research have great significance in Xu-2 gas reservoir. In this paper, we take Hechuan 1 area in Hechuan gas field as the research object. We use 3D seismic data processing and interpretation to clear the gas reservoir structure, entrapment, and fault. Well seismic combination was applied for sedimentary facies to clear the relationship between favorable sedimentary microfacies and effective reservoir, to realize phased reservoir prediction, and to clear development area of effective reservoir. Then, we established gas layer identification standard of logging and ensure reserves parameters again, calculated proven geological reserves, and confirmed development potential and present corresponding development countermeasures aiming at residual gas reservoir development potential [1–3].

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1 Introduction

The Hechuan gas field which crosses the Hechuan District of Chongqing and Wusheng County of Sichuan is located in the central part of the Sichuan basin. Jialing River passes through the southwest part of the gas reservoir. The regional structural position is located in the eastern part of the gentle uplift of the central part of Sichuan. The main development layer is the Xu-2 member tight sandstone reservoir. The Hechuan1 well area is the major production area. In 2009, a preliminary development program was developed. In 2011, the maximum production (2 million 400 thousand cubic meters per day) which was only 72.3% of the output in plan was reached. At present, 259 wells have been put into operation in the well area, 110 wells have been opened, and the output is only 230 million in 2017. The characteristics of the gas field are low production of single well, high water saturation of reservoir, and no stable production period of gas wells. These problems lead to high proportion of low-efficiency wells, common groundwater in gas wells, and rapid production decline. Moreover, three phases of oil, gas, and water produce simultaneously, resulting in poor economic benefits of gas fields. In summary, it is of great significance to further understand the geological needs of the Xu-2 gas reservoir, analyze the productivity of the gas well, and develop the countermeasures.

2 Geological Characteristics of the Xu-2 Gas Reservoir in Hechuan Gas Field

2.1 Characteristics of Geological Structure

The top surface of this gas field is a slow and latent structure with undeveloped faults, whose main structural trap line is −1840 m, and the closure height is 90 m, based on 2D seismic interpretation. The latest 3D seismic data collected in 2015 and reevaluated recently show that there are many faults in the Xu-2 reservoir, making the structures more complex. Therefore, the structural characteristics need to be further studied. According to drilling indication, core observation, and imaging logging analysis, the fractures are mainly located in the high position of Jieziba structure. According to the preliminary analysis of seismic profiles, it is believed that this may be due to some faults breaking to Xu-1 reservoir which contains source rocks, providing an upward migration channel for gas and forming high-quality gas reservoirs at the high point of Xu-2 reservoir [4–6].

2.2 Characteristics of Stratigraphic Sequence

The Xujiahe formation whose overlying strata is Jurassic terrestrial strata and underlying strata is marine facies strata of Triassic Leikoupo formation has a normal stratigraphic sequence. The Xujiahe formation divided into six segments from bottom to top is a set of inland terrigenous clastic rocks. The thickness of Xu-2 formation is from 76.5 to 139.5 m, and the average middle depth is 2200 m.

2.3 Characteristics of Reservoir

Based on the existing results, Xu-2 formation should be divided from bottom to top into Xu-21, Xu-22, and Xu-23. The reservoir of Xu-2 formation has many layers and thin thickness, the largest thickness is 16 m, the average thickness is 2.71 m, and the accumulated thickness is generally larger than 11.63 m. Vertically, the reservoir is mainly distributed in the middle and upper parts. Horizontally, the main reservoir segments are traceable and relatively distributed.

The underwater distributary channel and estuary dam microfacies of Xu-2 formation are the most favorable sedimentary microfacies for reservoir development, and their distribution area is reservoir development area.

According to the description of exploratory wells and 2D seismic results, it is considered that the thickness of Xu-2 sandstone is thickened from southeast to northwest and the thickness of single well sandstone is 60–135 m. On the plane, the sand body is gradually thinning toward the northwest (Figs. 1 and 2).

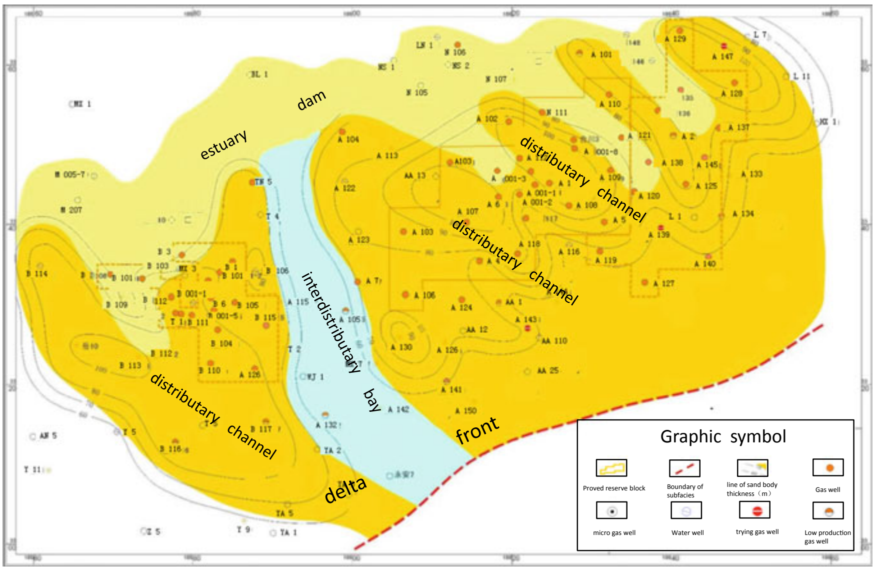

Fig. 1. Sedimentary facies map of Xu-2 reservoir

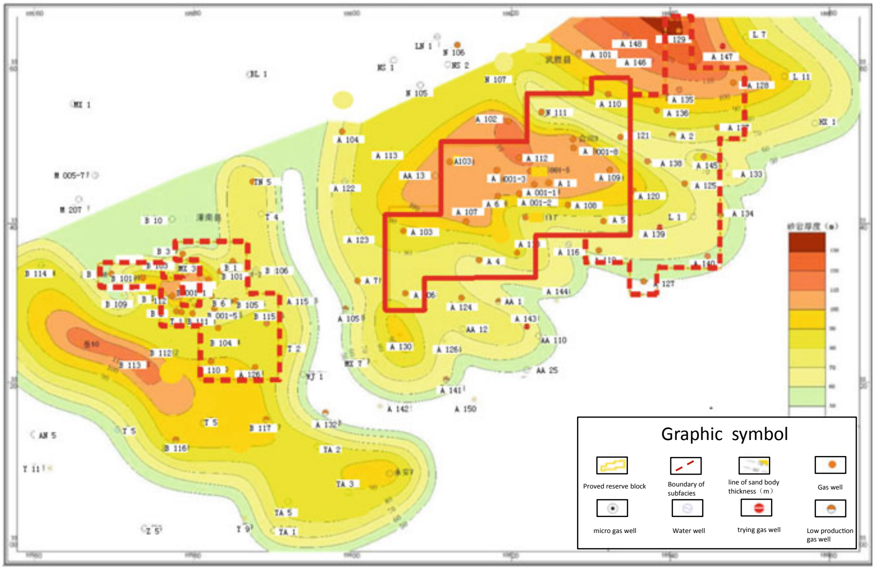

Fig. 2. Sandstone thickness map of Xu-2 reservoir

The Xu-2 reservoir rocks are mainly feldspar lithic sandstone and lithic feldspar sandstone. The grain size of the rock is mainly medium grain, followed by medium–fine grains and fine grains, and the separation is medium to good. The grinding circle is sub-rounded to sub-circle, and most of them are pore type cementation. The main pore types are residual intergranular pores, intergranular dissolved pores, and intragranular dissolved pores. The main types of reservoir throat are lamellar throat and tubular larynx, with large displacement pressure, large middle pressure, and small median radius of pore throat. These are characteristics of low porosity and low permeability sandstone reservoirs. The porosity of the reservoir is mainly distributed between 6 and 12%, with an average of 8.36%, and the permeability of the reservoir is mainly distributed between 0.02– and 0.64 mD, with an average of 0.31 mD. From the relation of core porosity and permeability, there is a positive correlation distribution, but the permeability of some samples at the same porosity is very large, which indicates the effect of pore structure and crack. The lower limit of porosity is 6% (Fig. 3).

The water saturation of reservoir cores is mainly in the range of 60–90%, accounting for 91.05% of the total samples. The average water saturation of logging reservoir is 38.3%, which is quite different from that of core. The upper limit of water saturation is determined to be 54% by semipermeable baffle air–water capillary pressure method and productivity simulation and relative permeability curve method. Because there is no oil-based closed coring data in the area, preliminary analysis shows that water-based mud affects the measurement of water saturation and makes it higher. We plan to collect oil-based coring data during drilling in the future, combined with conventional logging and NMR logging data, to comprehensively evaluate the water saturation of reservoirs in this area.

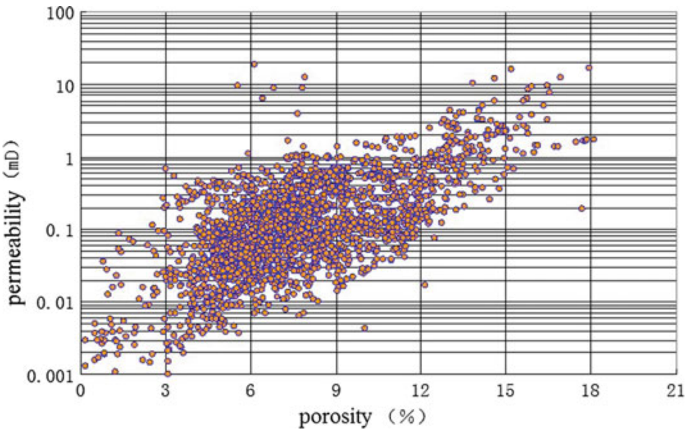

Fig. 3. Relationship diagram of core porosity and permeability

2.4 Stratigraphic Pressure and Temperature Characteristics

The formation pressure of Xu-2 formation is between 29.16 and 32.02 MPa, and the pressure coefficient is between 1.3 and 1.4, which is a gas reservoir with high-pressure coefficient. The gas reservoir temperature is between 75 and 77 °C, and the geothermal increasing temperature is 41.5 m/°C, which is the normal temperature gradient.

2.5 Fluid Properties

The gas of Xu-2 formation mainly composed of methane which is between 88.03 and 93.29% with very low acidic component, and no H_2S is the high-quality gas. The Hechuan gas field is a condensate gas system. The critical condensate pressure is 15.296 MPa, and the critical condensate temperature is 110 °C, which indicates that the fluid is a single gas phase under the formation condition. The average condensate content of Xu-2 gas reservoir in Hechuan which belongs to microcondensate reservoir is 28.78 cm^3/m^3. The water type of Xu-2 gas reservoir in Hechuan is $CaCl_2$, and the salinity is between 167.1 and 218.55 g/l.

2.6 Distribution of Gas and Water

It was believed that the distribution of gas and water was not completely controlled by the structure. In general, the gas was in the upper part, and the water was in the lower part. The high part of the structure and the upper end of the sand body were enriched with natural gas. The aquifers were mainly located in the subsection of the Xu-21 reservoir. The gas reservoir is mainly the lithologic gas reservoir on the basis of the structure. However, according to our preliminary analysis, it is believed that the area of gas well below the tectonic trap line may be an independent fault block with gas cutting, and the height of the actual gas column is greater than the tectonic range, that means the structural trap still needs to be further implemented [7, 8] (Fig. 4).

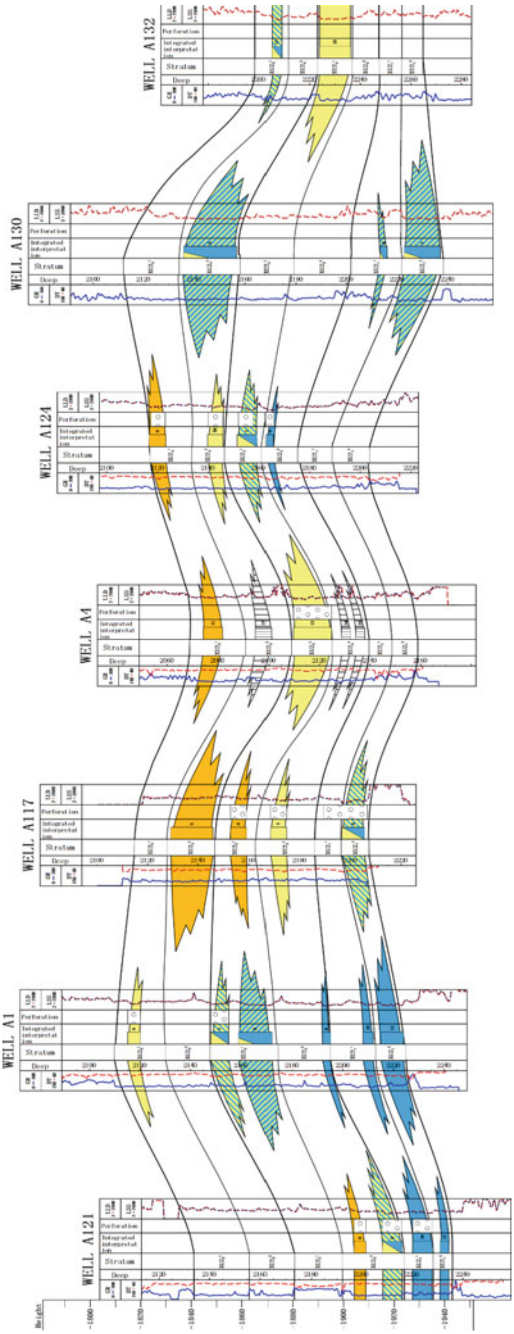

Fig. 4. Section of connected wells in reservoir

3 The Dynamic Characteristics of the Xu-2 Member of Xujiahe Gas Reservoir

3.1 Main Controlling Factor of High Production Is Fracture

The gas field own 37 wells which have a cumulative production above 30 million cubic meters, and the number of wells is 16.3% of the total number of production wells. Their total cumulative production is 2.517 billion cubic meters, which is 55.8% of whole cumulative production. Four wells of them had drilled xu_2^3 layer of the Xujiahe gas reservoir founded large-scale fractures when open hole testing. Three wells of them have a cumulative production above 100 million cubic meters. Main production layer of 19 wells is xu_2^3 layer among high production wells, and the number of wells is 51.3%. The reservoir also developed 27 wells which are rich for fractures, and the number of wells is 90%. Main production layer of 4 wells is xu_2^2 layer of Xujiahe gas reservoir, and the number of wells is 10.8%. According to analysis of the dynamic characteristics of single well, we preliminary think that the fractures are the main control factor. About 90% high effective wells developed fractures in xu_2^3 layer of Xujiahe gas reservoir.

3.2 Gas Wells Usually Produce Water

Gas wells usually produce water during testing. There are 182 wells produced water, 51% of the total number of wells, and the water production of well was different widely. There are 294 testing wells, of which the average production of water is 11.5 m^3/d, and the highest production of water is 108 m^3/d. Producing water causes significant influence on gas well producing.

3.3 Low Permeability and Strong Heterogeneity

Finite diversion interpretation model and half-length of fracture reflect that fracturing has an obvious effect on improving seepage capacity of reservoir; explaining average permeability is $(0.03–0.3) \times 10^{-3}$ μm^2, reflecting that the reservoir has strong heterogeneity. The permeability of reservoir is low. It reflects that the reservoir has strong heterogeneity according to the log–log curve of A3 well become warped on continued and log–log curve of A103 well concave upward (Figs. 5 and 6).

3.4 Large Difference of Dynamic and Static Reserves

The well control dynamic reserves of Hechuan gas field are 7.12 billion cubic meters calculated by well group, compared with the proven reserves of 100 billion cubic meter and the use of geological reserves of 60 billion cubic meters, the differences are so obvious, and single well control reserves is usually small. This is closely related to the high water saturation and density of reservoir. The dynamic reserve of the average single well is 0.29 billion cubic meters [9–12].

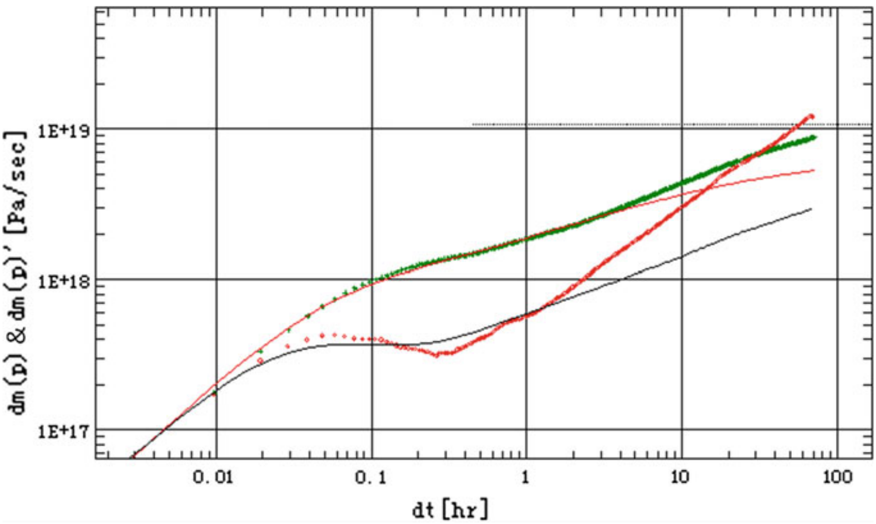

Fig. 5. Log–log curve of pressure recovery analysis figure of A3 well

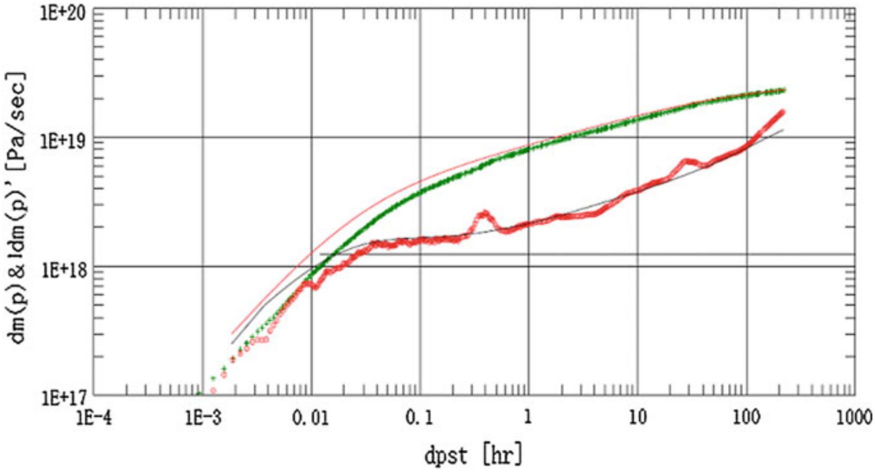

Fig. 6. Log–log curve of pressure recovery analysis figure of A103 well

4 Technical Countermeasures for Development

(1) Due to the precision of existing structure based on 2D seismic data cannot meet the requirements of fine development deployment and the 3D seismic data (2015) collected in the east of Gaoshi 16 well is aimed at the deep layer, in view of the problems of low interpretation accuracy of Xujiahe formation, the lack of fault interpretation and the poor reliability of the structure, the unified 3D seismic data

processing, fine interpretation, structural distribution features, and reservoir fine prediction are put forward for Xujiahe formation.

(2) The existing seismic data are mainly old 2D, and the existing 3D seismic data cannot completely cover the whole research block in Hechuan, which is not conducive to the overall study of this gas field; therefore, it is urgent to put forward the acquisition work of 3D seismic data which cover all areas of proven reserves submitted.

(3) In view of the characteristics of low porosity and permeability, contradiction between logging and core water saturation, and complex distribution of gas and water in Hechuan gas field, reservoir logging evaluation is redeveloped to make full use of all well data in the area in order to meet the needs of current development. Besides, the interpretation standard of gas–water reservoir logging and the reservoir interpretation model of pore, permeability, and saturation are reestablished, and the reservoir movable water saturation is evaluated with conventional logging and nuclear magnetic resonance logging data. On the basis of gas–water identification of reservoir, pore permeability model, and dynamic data, the evaluation standards of reservoir classification logging are established.

(4) The reservoir in Hechuan gas field is composed of several layers vertically with the thin single layer thickness of 2.71 m on average and Xu-2 member is divided into three subsections, which cannot satisfy the prediction of the distribution scale of thin reservoir. In order to enhance the macroscopic understanding of reservoir distribution, the fine division and reservoir correlation study of three submembers in the Xu-2 member should be carried out with the help of the combination of well and seism. The study on sedimentary facies description and sand distribution characteristics of three submembers in the Xu-2 member is carried out to provide support for reservoir prediction and reservoir classification evaluation. On the basis of fine division of substrata and description of distribution characteristics of sand bodies, the reserves of each submember are recounted.

(5) The gas well productivity difference in Hechuan gas field is great, so it is necessary to study the productivity evaluation technology of low permeability sandstone in gas reservoir and to carry out the research on research on reasonable production allocation of gas wells. After determining the reasonable production rate of gas well, the research on productivity evaluation of gas well should be carried out, influence of water production and condensate production on gas well productivity is clarified, and the main control factors of gas well productivity by dynamic and static combination are determined. Besides, the relationship between single well production and open-flow capacity are analyzed to give the reasonable production range of single well, the classification standard of the gas well in production and the early warning mechanism is established in combination with productivity calibration to determine the reasonable dynamic production rate of gas wells [13–17].

(6) The development effect of Hechuan gas field is poor, and the reserves producing degree is low. It is necessary to strengthen the recognition of gas field geology and determine the development potential by combining dynamic and static data. The

development idea of “the fracture development zone and large-scale fracturing and low pressure differential production” is put forward. Reasonable deployment of horizontal well, vertical well and inclined well reduces the waste of reserves, mixed well pattern of cluster type well group and horizontal well development..

5 Conclusion

(1) In view of the characteristics of low porosity and permeability, contradiction between logging and core water saturation, and complex distribution of gas and water in Hechuan gas field, reservoir logging evaluation is redeveloped. Besides, the interpretation standard of gas–water reservoir logging and the reservoir interpretation model of pore, permeability, saturation are reestablished, and the reservoir movable water saturation is evaluated with conventional logging and nuclear magnetic resonance logging data. On the basis of gas–water identification of reservoir, pore permeability model, and dynamic data, the evaluation standards of reservoir classification logging are established.

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(4) The development effect of Hechuan gas field is poor, and the reserves producing degree is low. It is necessary to strengthen the recognition of gas field geology and determine the development potential by combining dynamic and static data. The development idea of “the fracture control of reservoir permeable sand body and small-scale acidification and low pressure differential production” is put forward.

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