Development and Management of Sulige Gas Field with Low Permeability

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Abstract: Sulige gas field is by far the largest gas field in China and takes 35% of the total resources of natural gas of the Ordos basin. With the unique geographical advantages and the hub position of natural gas pipeline network, it is of great significance to develop and construct of Sulige gas field strategically. From these aspects, the development of natural gas resources in Changqing oil and gas field faces unprecedented opportunities.

As we all known, Sulige gas field is characterized by its "three-lows", namely, "low permeability, low pressure and low abundance" and strong heterogeneity. Just with features like these, in the process of development, we should overcome strong heterogeneity, low single well controlled reserves, gas well optimization and improvement of output and recovery of single well; also, Sulige gas field faces of quite a lot challenges caused by much more gas wells, poorer stability and management, etc.

With perfection in gas well optimization technique, cluster well and horizontal well technique, fast drilling technique and separate pressure production technique, we have managed to enhance the outgrowth in development efficiently; furthermore, with continuous innovation in management, we have overcome the problems by employing the digital management in production, refinement in gas well management and procedures in organisation management in gas field so that we can improve the management and achieve the scientific and efficient development successfully.

Key Words: Heterogeneity; Gas Recovery; Perfection in Technology; Innovation Management

1 Introduction

Sulige Gas Field lies in the north-central Ordos Basin and mainly located in the Otog Banner, Otog Front Banner and Uxin Banner of Inner Mongolia Autonomous Region, and Ding Bian and Wu Qi of Shaanxi Province, which belongs to Ordos City, Inner Mongolia AR. Structurally, it crosses the Yishaan slope and Yimeng upwelling area, mostly covered with desert and grassland in part.

Sulige Gas Field is by far the largest gas field in China, with an exploration area $4\times10^4 km^2$. It has rich natural gas reserves about ※※※$\times10^{12}m^3$, which takes 35% of total resources of the Ordos Basin. From 2003 to 2010, the proven reserves were obtained year by year. From 2007-2010 for four consecutive years, the annual new proven reserves can reach more about $5000\times10^8m^3$. With the expansion of the reserves, it has laid a solid resource foundation for Sulige Gas Field development. According to statistics, by the end of 2010, the cumulative gas reserves and the normal reserves come up to ※※※$\times10^{12}m^3$ in totals. This can be considered as the vital factor to be the significance of effective development of the whole field.

2 Significance of Developing and Constructing Sulige Gas Field

With the unique natural conditions and irreplaceable position, it is important to develop and construct Sulige Gas Field. First and foremost, it has the unique geographical advantage. Located in hinterland of mainland, Sulige Gas Field is a bridge links the east and the west of China. With rapid economic development in the East, there is a huge resources demand market; meanwhile, it can provide necessary oil and gas resources for the economic development of Qinghai and Xinjiang and other western areas.

Secondly, Sulige Gas Field is the hub position of gas pipeline network in China. As we all known, Changqing Gas Field is the junction of the main gas pipelines, including West-East Natural Gas Transmission Project I&II, the Shaanxi-Beijing Pipeline I&II, the Jingbian-Xi'an Pipeline, the Changqing-Ningxia Pipeline, the Changqing-Huhhot Pipeline, the Sebei-Xining-Lanzhou-Yinchuan Extension Pipeline and Longgang-Xi'an Extension Pipeline (under planning), and more. Herein, as the main part of Changqing Gas Field, Sulige really plays a leading role for gas development of the whole country.

Thirdly, it is of strategic significance to develop Sulige gas field. As we mentioned before, Changqing is the key part of our Gas Transmission Project, which not only assumes the role of ordinary gas fields, but also carries emergency gas field for security role. From this perspective, Sulige also undertakes the great political and social responsibility.

Last but not least, Sulige Gas Field is the essential component of building our oil and gas energy base. Actually, Changqing Gas Field is still a potential one, with the main role Sulige gas field. To be specific, with the productivity $200\times10^8 m^3$ and two-thirds of the total output of natural gas of Ordos Basin, the development and construction of Sulige gas field is directly related to the energy base building in the Ordos Basin.

3 Challenges in Development and Management in Sulige Gas Field

3.1 Challenges in Development

During 2001 ~ 2005, we had carried out lots of early evaluation work to have a clearer awareness about the fact that Sulige gas field belongs to He-8 sections and Shan1 session the Permian Lower Shihezi Formation, with burial depth 3200-3600m. The gas reservoir is the typical sedimentary facies. Besides, the effective sand body takes just a small proportion and also poor physical property with average penetration rate 0.5md, pressure coefficient 0.87, and gas abundance $1\times10^8 m^3/km^2$. On this account, it is characterized by "three lows—low permeability, low pressure and low abundance" and strong heterogeneity.

For Sulige Gas Field, the development is not also facing unprecedented opportunities, but also is facing enormous challenges. It falls in the main followings:

First, reservoir heterogeneity in Sulige gas field is strong which causes the problem of optimizing well sites. Due to the sedimentary facies of target zone, the gas field has strong heterogeneity and thin reservoir. Herein, it is difficult to identify the reservoir distribution and quality by high precision 2-D seismic exploration. So, we have encountered the difficulties in the optimization of well sites.

Second, owing to the low controlled reserves, it is hard to increase the gas output of single well. What the situation we have to face in Sulige gas field is that there are some facts like overlaying when cutting reservoir, the poor connectivity, low reserves and even limited effective sand body and so on. In order to overcome these problems, it is necessary to stabilize production of single well to reduce the pressure drop rate and then to guarantee the

final cumulative gas production of single well in Sulige gas field.

Third, due to the low reservoir porosity and low permeability, it is difficult to enhance gas recovery in Sulige gas field. In effective reservoir, there are faster changes in longitudinal and transversal direction, making reservoir stronger heterogeneous and also more complex distribution, especially in longitudinal direction. Even worse, blocks of reservoir geological features vary markedly. Therefore, to balance the relation between the inter-well infillings and economic benefits, it is difficult to enhance gas recovery in the early stage of economic development.

3.2 Challenges in Management

Since the scale development in Sulige gas field in 2006, the Su-6 block and other parts of regions go gradually into the constructing and developing phase. With fast development of Sulige gas field, the number of gas wells has increased year by year. Currently, the total number is about more than 4,000. Unluckily, the conflicts emerges gradually between heavier management workload and less management personnel, between faster decline in pressure and production capability and poor stability of gas well, between lower output in later production stage and harder management difficulties. Hence, the management of gas field faces with severe challenges as follows:

First, heavier management workload and less management personnel have posed challenges for scientific and effective management in Sulige gas fields. Gas wells in Sulige gas field are more than 4,000 and some low yield ratio and low effectiveness wells are near 20% of the total. Worsely, there are less than 2000 people to do the managerial work. All these factors make Sulige gas field the first place in the nation with overnumbered gas wells, heaviest workload and the worst situation in management. So, that how to make the scientific and effective management in our business is a real challenge for Sulige gas field.

Second, faster decline in pressure and production capability, and poor stability of gas well also presents a challenge for gas field production. In Sulige gas, the single well field has small control range, poor physical property and limited controlled reserves. On the other hand, gas pressure and production capability declines more quickly, coupled with a reservoir of low reservoir porosity, low permeability and low gas field recovery. Hereafter, all challenge the stable production capability of gas field.

Third, in later period, we enter the “low pressure and low output” stage. Because of the low pressure, the condensate liquid becomes more and more. Meanwhile, the low gas can not increase the critical liquid-carrying flow rate and then accumulate the liquid loading in the bottom so that it requires higher foaming drainage or other new techniques. Unfortunately, the fact is that we own too many wells like that. So, this is the key problem we should face.

4 Innovation and Development in Technology

Aiming at solving the existed problems, quickening the developing pace, our company seize the opportunities and meet the challenges positively to create and renovate the gas well optimization technique, cluster well and horizontal well technique, fast drilling technique and separate pressure production technique and other techniques.

4.1 Gas Well Optimization Technique

To deal with strong heterogeneity, we innovate in the technique of gas well optimization. Our experts HAS applied the seismic and geologic exploration, and then combined with rich

region filtering in order to drill wells successfully,

4.1.1 Using Sedimentary Micro-facies and Interval Transit time to Predict the River

By fully using information of rock core in exploratory well and evaluation well, and plotting out sedimentary micro-facies in detail, we can do a research of studying the features of plane distribution of sedimentary facies in target zone. Meanwhile, we can use the causal relation between interval transit time of high precision 2-D seismic exploration and depths of riverbed entrenchment. Specifically, utilizing the time difference is analyzing the depths of riverbed entrenchment to present the main direct and the main stem of river.

4.1.2 Applying Logging Integrated Interpretation and Pre-stack Inversion Technology to Paint Sand Body Distribution

Through studying on the drilled well, logging integrated interpretation, features of logging curves, we analyze the thickness of sand body in target zone of single well and study sand distribution of drilled well within area. At the same time, on the basis of qualitative forecast in the main stem, we can employ the elastic impedance inversion and use P wave and S wave impedance to calculate thickness of sand body and then to paint sand body distribution.

4.1.3 Combination of Physical Property and AVO (Amplitude Versus Offset) Hydrocarbon Detection to Predict the Distinction and Quality in Effective Reservoir

By analyzing the study of distribution of sand body and physical property, one important work is launched to make an effective prediction on reservoir distribution of drilled well. Meanwhile, we make use of far and near offset trace stacked profile of AVO, normal profiling method and amplitude intensity to prospect the gas to predict the distribution of effective sand body.

Through a combination of geological and seismic methods, we can locate the favorable target are accurately and choose the proper well site. Then, in the context of strong heterogeneity of reservoir, we manage to increase drilling success rate furthest.

4.2 Cluster Well and Horizontal Well Technique

To create a proper way for Sulige gas field's economic development, after experiencing the traditional vertical well, we constantly innovate the new mode of cluster well and horizontal well development technique. Based on the continuous process of drilling technique, the pattern of Sulige has been changed into the "cluster well and horizontal well ——oriented" mode from the previous " vertical well——oriented" mode. With this new pattern, it reduces the cost of develop and increase the benefits in all direction.

4.2.1 Perfection in Well Deployment Technique and Well Profile Technique of Cluster Wells

By enhancing detailed descriptions of gas reservoir and law of distribution of gas reservoir, and optimizing well deployment, the cluster wells are from 2-3 to 5-7; the number of well increases more and more within the same well area.

In the process of drilling cluster wells, our experts continue to perfect the well profile technique. Under the comparative analysis between "straight-buildup-stable profile design" and "sustained ramp- sustained drop- oblique-hold angle-sustained drop", moving up the kick-off points and improving ROP, the cycle of directional well drilling is reduced from the previous 36 days to less than 20 days.

Matureness in Accuracy of Target-entering Technique and Guiding Drilling Technique in Horizontal Section of Horizontal Well

In the development of horizontal well, after continuous explorations and tests, a series of techniques are set up, including gas well optimization, entering target point without slanting pilot well, perfecting well trajectory technique and geosteering method and so on.

The accurate target-entering of horizontal wells mainly predicts the target zone by sticking the capturing marked bed; applying altitude correction to more accurately predict the altitude of the target zone; by contrasting the drilling time, cuttings and gas logging, we can check whether the drill touch the target zone or not and then to ensure the angle and vertical depth of inserting point. After that, to making a comprehensive analysis judgment and precise positioning is to achieve the exact target-entering.

Geo-steering in horizontal section is mainly based on the way of "if the sand body distributes equally, then the drill parallels along the ups and downs from the middle of sand body; if not, track effective sand body according to the lithologic association characteristics ". On the basis of analyzing the lithology of profile of logging, drilling-time, gas logging, engineering parameters and combination gamma ray neutron laterolog, the operators can correct and adjust timely to ensure the horizontal section in gas reservoir (sand), hitting.

4.3 Fast Drilling Technique

By using conventional drilling technique in Sulige gas field, a set of techniques are formed which takes PDC bit and combined technology as the core. Then, through optimizing drilling parameters and PDC bit's adaptability, the structure of gas well and cementing method are simplified gradually. Furthermore, as the improvement of ROP, the cycle of well drilling is reduced from the previous more than 40 days to less than 20 days.

4.3.1 Optimum Matching of drilling parameters

Adhere to the principles of "increasing the drilling pressure when dealing with the homogeneity; reducing the speed and pressure when conducting the heterogeneity", the torque should be increased and the parameters should be decreased accordingly. On the condition of meeting the requirement of "the drilling fluid carrying sand", we should decrease the equivalent density properly of the drilling fluid flow to lessen chip hold-down effect in the bottom.

4.3.2 BHA Optimization

In Sulige gas field the development model has been focused on cluster wells and horizontal wells. In order to overcome the difficulties of the directional cluster wells in inclined shaft of drilling, controlling trajectory and poor stability, etc, after continuous explorations and experimentations, it has formed well in selecting different BHA with different specific technical measures. To be specific, by using φ 222.2PDC+ PHI 172LZx1.25 screw +421*460+SDC (3-3.5 m), +stab (φ 208-210) + streets of directional BHA, it would effectively reduce the directional slide section, but increase the proportion of combined drilling well to shorten the drilling cycle, to some extent.

4.3.3 Optimizing the Mode of Drill Bits

Aiming at dealing with the lots of sands and stones in the bottom, and strong abrasivity, less footage of single bit and lower speed of ROP, after a number of demonstrations and tests, M, EM, FX, P series drills bits are selected perfectly. Besides, the average ROP and single bit mean footage has significantly improved.

4.3.4 Perfection in System of Drilling Fluid

Through continuous proof and tests, it forms a system of drilling fluid in Sulige gas field.

First, we use clay mud to deal with sand bed and then add the anti-caving agent to keep the well eye. When drill into target zone, the operator will change drilling fluid into a sulfonated polymer drilling fluid to avoid these phenomena, such as, the touching resistance, pump sticking, etc.

4.4 Separate Pressure Production Technique,

In 2006, since the scale development in Sulige gas field, in order to improve the degree of storage utilization and cooperating with the multi-storey development of Sulige gas field, the separate pressure production technique is carried out actively. A number of new techniques and technologies, especially the fracturing technique and the system of reservoir reconstruction technology have been improved step by step.

4.4.1 Breakthrough of the Separate Pressure Production Technique

By continuous explorations and tests, a new way "mechanical plugging sealing + nylon ball" is put into practice, with 5 layers once at most. Besides, we also focus on the full reconstruction of each layer which is much better than multi-layer pressure.

4.4.2 Continuous Improvement in Fracturing Technology

It is formed a mature system in fracturing fluid technology with liquid nitrogen injection, carboxymethyl liquid and so on. For the technique of fracturing, we put to use the mixed fracturing fluid and fiber proppant backflow technique to boost the effect of reservoir reconstruction.

5 Innovation in Management of Sulige Gas Field

Sulige gas filed is progressing in the management practice to form their own new management model of “six-unifieds, three-sharings, one-centralized”, namely, “unified planning deployment, unified organisation for the harmonization of first-aid, unified technology policy, unified external coordination, unified production scheduling and unified logistics support; resource sharing, technology sharing and information sharing; centralized management.” Thus, there forms an operation mechanism, unified, competitive, demonstrative and positive.

5.1 Digitalization in Production Management

Facing the situation of more gas wells, heavier workload, and fewer manage personnel, we make a new “electric well-patrolling system, man-made patrolling station system, remote monitoring, the Centre on-duty" way to lay down our burden. By applying the new ways of organizing production can effectively reduce the difficulties of management and improve the accuracy of and effectiveness of management.

5.1.1 Digital Management of Single Well

Based on single well data remote transmission technology of Sulige gas field, we have constantly followed single well production management requirements to explore and perfect about 8 wellhead digital technologies, things like wellhead data monitoring, timer camera inspection, wellhead remote control, remote voice alarm, wellhead production anomaly diagnosis, wind and solar power generation, data consolidation monitoring and so on.

5.1.2 Digitalizing in Gas Gathering Station Management

To further improve the management, reduce security risks and labor intensity, and to follow the constructing line for digital gas station of the Changqing oilfield company, by 2010 the company have advanced and have completed digitalization of gas gathering station in Su

6, 36-11 experimental area blocks, achieving "electric well-patrolling system, man-made patrolling station system, remote control, emergency shutdown, man-made restoration", and equipped with around-the-clock unattended operation of gas gathering station.

5.1.3 Building Digital Management Platform

In order to meet the demand of digital construction, perfect the terminal management platform and build digital production management platform, our company has formed a digital production management framework which is supported by a 6 systematic functions and a two-tier platform. This makes centralized control, dispatching, and overall planning come true in Sulige gas field.

5.1.4 Gas Production Plant in Digital Mode

By building digital gas production plant, perfecting the matching techniques and carding digital operation management process, we initially formed the gas production plant in digital mode--- "technical system as the support, two-level monitoring system for management as the core and application management as the target".

5.1.5 Digital Management of Gas Fields

More than 4,000 wells and nearly 100 gas gathering stations in Sulige gas field are connected via using digital means to operate the command from production information platform. Thus, it achieves the unified control, unified management, and initially forms a digital management model in Sulige gas field.

5.2 Refinements in Gas Well Management

By following the developing guideline of “controlling gas pressure drop rate, prolonging the period of stabilized production of gas well”, our company formed a fine systematic management model in the process, namely, “producing by stages and in groups for normal production well and belching well; one group and one way; one well one way towards key well and liquid loading well”. Consequently, we can make sure to achieve fine classification and management, and try our best to maximize deliverability and enhance final gas well recovery.

5.2.1 New Concept in Gas Well Management

Since the scale development in Sulige gas field in 2006, we have experienced a change of “single-management---systematic management---refined management”. With the further development of managerial work, it forms a fine systematic management model of “producing by stages and in groups for normal production well and belching well; one group and one way; one well one way towards key well and liquid loading well”.

5.2.2 Improvement in Gas Well Management

According to ideas of "big oil field construction, large gas field management", in 2009, we dropped out of participating in the institute of geology and technology of gas production plant in Sulige gas field. Instead, we transferred the previous system to set up a research centre on production management which focuses on centralized analysis and unified management of Sulige gas field.

5.2.3 Scientific Methods in Gas Well Management

By strengthening the dynamic analysis of gas-well production and depending on different production features of each gas well, we employ the mixed classification method in pressure and output, and also develop sound management practices in Sulige gas field accordingly. For continuous production well, we strictly carry out the instructions of controlling gas production and pressure drop rate, and prolonging the period of stabilized production of gas

well; for belching well, we lead a mode of production, namely "long closed short opening", "short closed short opening" and "long opening long closed". By optimizing the intermittent production system, the rate of utilization and productivity contribution of gas well would be increased; for liquid loading well, the method of "foaming drainage agent + intermitting system" and "foaming stick + intermitting system" and new drainage process are put into use to drain away the water efficiently and then to improve the output of gas well.

5.2.4 Remarkable Achievements in Gas Well Management

Nowadays, by employing with refinements in gas well management, the gas production rate of single well remains 10,000m m^2 per day. And according to the development index of gas well, this amount can meet the requirement---"a single well: 10,000m m^2 per day, be stably developed 3 years."

5.3 Sequencing of Organisation and Management

Sulige gas field, under the "output of 20 billion cubic meters, 2000 people management" requirement, through structural adjustment and mechanism design, achieve the sequencing, institutional and standardized management.

5.3.1 Aiming at achieving refined management

Facing the reformation of large-scale development and management of Sulige Gas Field, we must break down the previous traditional management mode of "small oil field and small organisation". Hereafter, through the well-designed management processes and efficient project management, the management can be standardized, simplified and refined, and then go further to achieve the modernization of management in Su gas field.

5.3.2 Matrix Management.

Breaking the previous pattern of line management, we apply the matrix management to do our business, such as improving the management decision-making and execution speed, promoting management efficiency, strengthening horizontal linkages among sectors and making full use of specialized equipment and personnel and other resources, then to enhance gas field management effectiveness.

5.3.3 Process Management

In the practice of innovative management, we have adopted a new process management model instead of using the original functional management. According to the "convenient, simple, efficient" requirements and management responsibilities, we have neatened our business process, amended rules and regulations, establish responsibility system and draw up the standardized process control specifications to build up a unified procedure, a centralized business control, a clear structure, a concise and efficient management. With these, when in all activities, do as the established procedures and standards state. Hereafter, our business can be standardized in management, in business process and in practice from all aspects. Meanwhile, the operational efficiency can be improved consequently.

6 Progress

First, generally speaking, Sulige gas field has those advantages as follows: the unique geographical advantage, the hub location of natural gas pipeline in China, the strategic significance of the development, and the major component of Chinese important oil and gas energy base. Furthermore, from the above, the development of Sulige gas field faces the unprecedented opportunities.

Secondly, Sulige gas field shows its strong reservoir heterogeneity, low reservoir porosity,

low permeability, and low single well controlled reserves. With these features, in the process of development, we also face the difficulties in optimizing gas well sites, increasing output of single well, enhancing recovery, and many other difficulties.

Thirdly, Sulige gas field is in the face of quite enormous challenges in management, which are caused by heavier workload, fewer management personnel, faster decline in pressure and production capability, poor stability of and other difficulties.

Fourthly, with our great efforts, our experts and workers go in for perfecting and innovating the technology system, including gas well the optimization technique, cluster well and horizontal well technique, faster drilling technique and separate pressure production technique. Thus, quite lots problems can be solved efficiently, like enhancing the development, increasing the output and recovery of single well and so on.

Last, with continuous innovation in management, our company has made the digital management in production, refinement in gas well management and sequencing in organisation management to overcome the existed problems of gas field so that we can achieve the scientific development and effective management in the future work.