+ MODEL

Available online at www.sciencedirect.com

ScienceDirect

Natural Gas Industry B xx (2016) 1−8

www.elsevier.com/locate/ngib

Research Article

Analysis on effective reservoirs and length optimization of horizontal wells in the Sulige Gasfield☆

Luo Chao[a,b,*], Jia Ailin[b], Guo Jianlin[b], He Dongbo[b], Wei Yunsheng[b], Luo Shuiliang[c,d]

[a] *Chongqing University of Science & Technology, Chongqing 401331, China*
[b] *PetroChina Research Institute of Petroleum Exploration and Development, Beijing 100083, China*
[c] *MOE Key Laboratory of Exploration Technologies for Oil and Gas Resources, Yangtze University, Wuhan, Hubei 430100, China*
[d] *School of Geosciences, Yangtze University, Wuhan, Hubei 430100, China*

Received 2 December 2015; accepted 9 May 2016

Abstract

By virtue of unique technical and economical advantages, horizontal well development has become a key technology in the high-efficiency development of tight gas reservoirs, however, this has worked unsatisfactorily in unstratified gas reservoirs. In this paper, the orientation and coverage of gas-bearing sand bodies (in isolated distribution) of Member 8 of Permian Lower Shihezi Fm in the Sulige Gasfield were analyzed by means of outcrop analogy, geostatistical analysis and pilot tests of dense well patterns. Then, four gas-bearing sand distribution patterns suitable for the deployment of horizontal wells in Member 8 were proposed according to the precise geological anatomy results of dense well patterns. These patterns include thick massive isolated pattern, vertically superimposed pattern with physical interlayers, vertically superimposed pattern with argillaceous interlayers and lateral sugar-coated haw string pattern. Based on the statistics on gas-bearing sand bodies drilled by horizontal well drilling, the drilled gas-bearing sand bodies are 670−1300 m long. Based on production data correction, numerical simulation and economic evaluation, the length of rational horizontal sections were optimized by performing a case study of the vertically superimposed reservoirs with physical interlayers in the typical well group SuX-18-36 of Su-X Block. It is indicated that the rational horizontal well length within 1200 m in the Sulige Gasfield under current economic and technical conditions. This paper provides a technical support for the high-efficiency development of the Sulige Gasfield in the future.

Keywords: Ordos Basin; Sulige Gasfield; Permian; Tight sandstone gas reservoir; Gas-bearing sand; Effective reservoirs; Horizontal well; Gas reservoir engineering; Length optimization

Horizontal well drilling, as a critical development technology for increasing gas well productivity, is now the key technology for the high-efficiency development of tight gas reservoirs because of its unique technical and economical advantages [1−3]. In North America, the development technologies for tight sandstone gas reservoirs are the most mature and the application of horizontal wells is theoretically and practically abundant. For example, horizontal wells are applicable only in the specific geologic conditions (e.g. stratified gas reservoirs) instead of all tight sandstone gas reservoirs [4]. The domestic tight sandstone gas reservoirs that have been put into development are mostly in the pattern of typical lens. It is indicated from development practices that horizontal well drilling can increase single-well production rate and decrease production and management difficulty. From the aspect of deployment process, however, horizontal wells are selected more strictly than vertical wells. It is required that the

☆ Project supported by the National Major Scientific and Technological Project, “Key Development Technologies for Natural Gas” (Grant No. 2011ZX05015).
* Corresponding author. Chongqing University of Science & Technology, Chongqing 401331, China.
E-mail address: lc_121989@163.com (Luo C.).
Peer review under responsibility of Sichuan Petroleum Administration.

http://dx.doi.org/10.1016/j.ngib.2016.05.009

size and distribution of gas-bearing sandbodies should be characterized more carefully and the gas-bearing intervals should be geologically understood more intensively [5]. Foreign scholars have been puzzled by the difficulty of horizontal well design, especially the length design of horizontal sections in lenticular gas reservoirs with strong heterogeneity. They have done sufficient research on length optimization of horizontal wells by analyzing multiple factors, such as well bore friction and pressure drop. Due to the geological difference of tight sandstone gas reservoirs in China and the United States, however, foreign experiences and achievements cannot be copied completely. Domestic scholars have performed further analysis on length optimization of horizontal wells in oil reservoirs and carbonate gas reservoirs [6−10], but they haven't studied systematically the length optimization of horizontal wells in strong-heterogeneity lenticular tight sandstone gas reservoirs. In this paper, therefore, the Sulige Gasfield was taken as an example for study. The effective reservoir size, extension direction and distribution pattern of the principal pay zones (Member 8 of Permian Lower Shihezi Fm) in the Sulige Gasfield were analyzed on the basis of its reservoir geology. Then, the favorable geologic conditions for the deployment of horizontal wells in the gasfield were confirmed. Based on field application results of horizontal wells, the length of horizontal wells in the Sulige Gasfield was optimized by means of production data correction, numerical simulation and economic evaluation.

1. Geological features

The Sulige Gasfield is located at the Yishan slope in the Ordos Basin. It is structurally a broad and gentle west-dipping monocline. Its principal gas-bearing intervals are Member 8 of Lower Shihezi Fm (He 8 Member) and Member 1 of Shanxi Fm (Shan 1 Member) in the Permian, which are buried under 3000−3600 m, and constitute a set of southward-prograding braided river sedimentary reservoir [11,12] with the characteristics of low abundance, low pressure and low permeability [13−17]. It is shown from the drilling ratio of gas-bearing sandbodies that the drilling ratio of gas layers in each sublayer is low, generally in the range of 20−40%. It is proved by sufficient production performance data that the effective reservoirs in the Sulige Gasfield are characterized by small thickness, stronger heterogeneity, small distribution range and obvious directivity. If the dense vertical well development pattern is adopted, the recovery factor can be increased, but multiwell interference tends to occur, leading to difficulties in guaranteeing the economical limit of single-well cumulative production. In addition, strong heterogeneity results in low single-well production rate, fast decline, short stable production and poor development benefit of vertical wells. For the purpose of keeping the current annual production of 250×10^8 m^3 for a long period, 1000 new wells should be drilled annually in the Sulige Gasfield to replace and compensate for the production decline. Horizontal well technology can increase well-controlled reserves, decrease working load of development and management significantly and improve the overall development results [18]. Scale application of horizontal wells in the Sulige Gasfield is, to some extent, restricted, for its effective sandbodies are scattered in multiple layers, presenting strong heterogeneity. Therefore, taking the rational length of horizontal sections into consideration in horizontal well design is significant to the high-efficiency application of horizontal well technology.

2. Approach to determining the rational length of horizontal wells in heterogeneous gas reservoirs

The deployment of horizontal wells with rational length in heterogeneous gas reservoirs is affected by multiple factors. These factors are classified into three categories. (1) Geologic and reservoir characteristics. The He 8 Member reservoir in the Sulige Gasfield is of braided river sedimentation, with gas-bearing sandbodies distributed in an isolated pattern, so the matching degree between horizontal section length and subsurface reservoirs is the key factor affecting the development results of horizontal wells. The horizontal section may run out of sandbodies if it is too long. Therefore, the geologic factors (including the size and extension direction of effective reservoirs) are the top one constraint for the rational length of horizontal sections. (2) Gas reservoir engineering. It is indicated from the production performance simulation that there is no positive linear relationship between the horizontal section length of gas wells and the production results (ultimate production and stable production period), so it is impractical to make too long horizontal sections. (3) Economy. As for the actual production, the construction cost of gas wells increases greatly with the increase of horizontal section length due to the effect of geologic conditions and drilling cost, and there is no simple linear relationship between the development benefit of a horizontal well and its length. Therefore, its development benefit will decrease if the horizontal well is too long or too short [19].

3. Effect of reservoir heterogeneity on the rational length of horizontal wells

3.1. Scale and size of effective sandbodies in reservoirs

The scale of effective sandbodies refers to the distribution range of gas-bearing sandbodies in a three-dimensional space. Its vertical scale can be reflected by the thickness and its lateral scale can be characterized by the length and width. The vertical and lateral scales of effective sandbodies in the Sulige Gasfield can be cognized more accurately by using multiple dynamic and static methods, such as outcrop analogy, geostatistical analysis and pilot test of dense well pattern.

1) Outcrop analogy. At the Liulin outcrops in Shanxi province, which have the same principal pay zones with the Sulige Gasfield, the braided channel sandbodies which are composed of coarse sandstones are mostly in the form of top convex and bottom flat or top flat and bottom convex and the channel migrates fast [20]. So,

Please cite this article in press as: Luo C, et al., Analysis on effective reservoirs and length optimization of horizontal wells in the Sulige Gasfield, Natural Gas Industry B (2016), http://dx.doi.org/10.1016/j.ngib.2016.05.009

there are erosion surfaces caused by channel erosive action and lithological interfaces formed by facies change in reservoir space. As a result, single storage-seepage unit is smaller in size, but the overall connection scale is larger since multiple sandbodies are alternatively superimposed areally and vertically in some areas. It is demonstrated by the statistical width and thickness of channel sandbodies in multiple sections that the thickness of single channel sandbody in He 8 Member is 1.6–7 m, mostly 2–5 m. Its width varies in a large range, but generally less than 1000 m, mostly 200–800 m. Its length is generally less than 1500 m, mostly 400–1200 m.

2) Geostatistical analysis. The thickness distribution of gas-bearing sandbodies is discriminated by using the core data and logging interpretation results of the Sulige Gasfield. The scale of gas-bearing sandbodies is estimated on the basis of width–thickness ratio and length–width ratio of synsedimentary sandbodies that are set in quantitative geology. It is indicated from the quantitative core description and electrofacies analysis that the mid-channel bars at the lower part of He 8 Member are mostly 2–6 m thick in the NS section through Wells Su 6-7-12 and Su 6-8-7 (Fig. 1). It is shown from the Yulin outcrop observation and its laboratory sedimentary physical simulation experiments that the width–thickness ratio and length–width ratio of mid-channel bars are generally 80–120 and 1.5–2.0 respectively. It is accordingly estimated that the width and length of effective sandbodies in the Sulige Gasfield are mostly in the range of 160–720 m and 300–1200 m respectively.
3) Pilot test of dense well pattern. After dense well pattern dissection zones are selected, the vertical and lateral connection relationships of sandbodies in a smaller well spacing range are analyzed and their extension range is estimated [21]. In the Well Su 6 area, the measured formation pressure of two wells (Su 6-J3 and Su 6-J4) with reduced spacing didn't restore to the original formation pressure and earlier pressure relief was obvious with larger pressure relief amplitude. However, the measured formation pressure of four wells (600 m) with reduced spacing is equal to the original formation pressure. Therefore, it is inferred that the width of effective sandbodies in the Well Su 6 area is larger than 400 m and the length is less than 1200 m. It is shown from the situations of other infilling well areas (e.g. Su 6, Su 14 and Su 10) that the effective sandbodies are generally 2–6 m thick, 300–800 m wide and 400–1200 m long. Some of them are cut and connected with large superimposition scale, so the deployment of horizontal wells is geologically satisfied.

By virtue of outcrop analogy, geostatistical analysis and pilot test of dense well pattern, it is concluded that the gas-bearing sandbodies in He 8 Member and Shan 1 Member are mostly distributed in the pattern of isolated lens along north and south, generally with thickness of 2–5 m, width of 300–800 m and length of 300–1200 m.

3.2. Extension direction of effective sandbodies in reservoirs

The orientation of horizontal sections is mainly controlled by the strike of gas-bearing sandbodies and the maximum principal stress direction. The drilling ratio of gas layers can be increased through horizontal well arrangement along the extension direction of gas-bearing sandbodies, and the production of horizontal wells can be improved by fracturing perpendicular to the maximum stress direction [22,23]. It is shown from the comprehensive geologic studies that long banded sandbodies are extensively distributed in compound forms in He 8 Member and Shan 1 Member due to the frequent diversion of braided channels. And, 86% of gas-bearing sandbodies are distributed at mid-channel bars and they are mostly distributed along NS in the shape of pods, with quick facies change along EW. For example, three braided channels are developed from the north to the south in the sublayer 1 of upper He 8 Member, Well J11 area (Fig. 2). Mid-channel bars are developed at the low positions of channel filling and their strike is accordant to that of channel filling, so it is

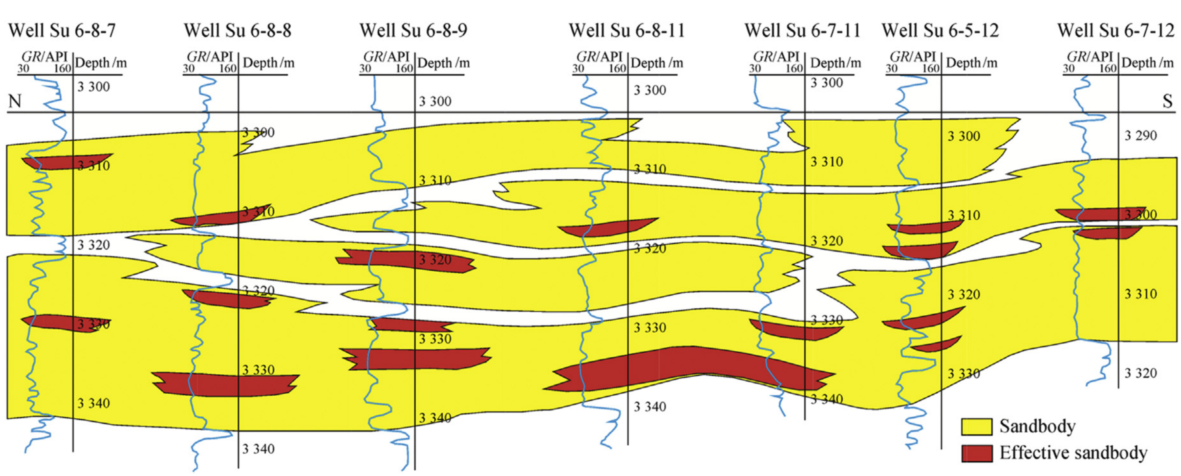


Fig. 1. Distribution of NS effective sandbodies at the lower part of He 8 Member in center Sulige Gasfield.

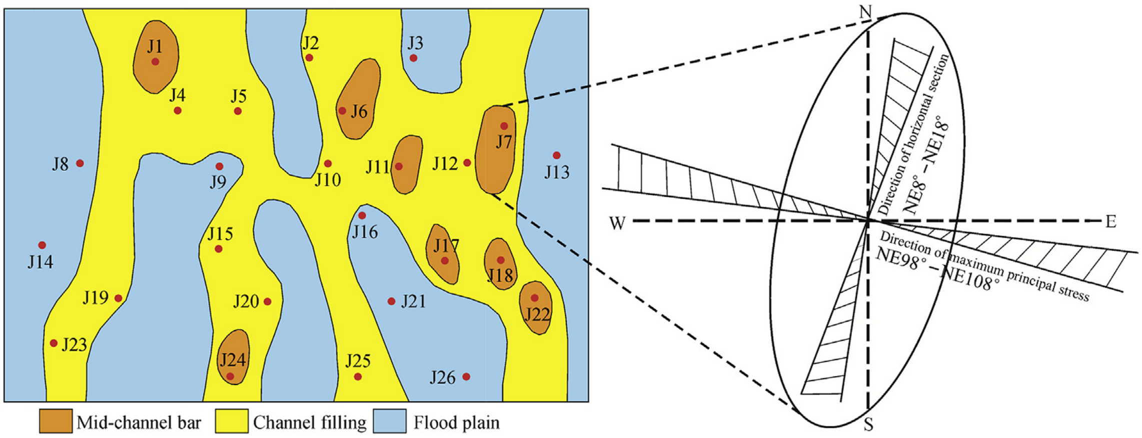


Fig. 2. Sketch of horizontal wells and fracture directions in the Sulige Gasfield.

discriminated that the mid-channel bars in the area of Wells J1, J6 and J7 are mostly extended along NS. Therefore, horizontal wells should be arranged mainly in NS orientation to increase the drilling ratio of gas-bearing sandbodies. Besides, it is necessary to adjust appropriately the horizontal well orientation design when the mid-channel bar sandbodies are locally off the NS direction because of channel migration and diversion.

The reservoirs are tight, so it is necessary to carry out multistage fracturing to increase the production rate of horizontal wells. The optimum fracturing stimulation results can be realized when the direction of hydraulic fractures is parallel to that of the maximum principal stress and the orientation of horizontal sections is perpendicular to fractures. After the viscous magnetic remanence of cores from He 8 Member and Shan 1 Member is measured in several wells (e.g. Su X53-74-62H), it is indicated that the maximum principal stress of major gas layers is in the direction of NE98°−NE108°. The strike of gas-bearing sandbodies is better accordant to the direction of maximum ground stress, regional structures are undeveloped, and horizontal wells are less influenced by the anisotropy of reservoirs. Therefore, horizontal sections should be dominantly NS-oriented.

3.3. Distribution pattern of effective sandbodies suitable for horizontal wells

It is shown from the analysis on sedimentation, origins of effective sandbodies and quantitative scale in the Sulige Gasfield that He 8 Member, the principal gas layer, experienced frequent channel migration in areal and sandbody superimposition and cutting in vertical, so the effective reservoirs are distributed in multiple isolated intervals on a small scale. Nevertheless, thicker reservoir intervals with better lateral connectivity are developed locally [24]. After the geologic characteristics (e.g. scale and extension direction) are figured out, it is indicated that horizontal wells can be arranged in this area. Four gas-bearing sandbody distribution patterns suitable for the deployment of horizontal wells are proposed according to the geologic analysis on the sections of drilled horizontal wells.

3.3.1. Thick massive isolated pattern

Mid-channel bar facies sedimentation is dominant with slight channel filling sedimentation. It is characterized by strong sedimentary hydrodynamic force, thick sandbody, coarse grain and stable lateral distribution. Effective sandbodies are distributed in a thick massive pattern with vertical thickness generally larger than 6 m, and they can be traced and correlated between wells owing to their better lateral continuity. Their well-controlled reserves are large. Horizontal wells in this pattern are high in the drilling ratio of gas-bearing sandbodies and in high-yield horizontal wells. In the lower He 8 Member, the target horizon of Well Suping 36-6-23, for example, shows a good production condition with a daily average gas production of 9.8×10^4 m^3 and a cumulative gas production of 5476×10^4 m^3.

3.3.2. Vertically-superimposed pattern with physical interlayers

It is composed of multiphase braided channels and mid-channel bar coarse sandstones by means of vertical superimposition. Sandbodies are laterally combined and communicated with large superimposition thickness. Physical interlayers are developed due to the change of the hydrodynamic conditions between the upper and the lower gas bearing sandstones, and their thickness is generally less than 3 m. Gas-bearing sandbodies are generally 2−5 m thick in each layer and cumulatively in the range of 6−8 m, partially over 10 m. When horizontal wells are deployed in this pattern, the drilling ratio of gas-bearing sandbodies is high. Interlayers are thin, so the upper and the lower gas layers can be communicated by means of fracturing stimulation. Based on current fracturing technologies, gas production can be kept at a higher rate. In the sublayer 4 of He 8 Member, the target layer of Well Su 10-32-50H (Fig. 3), for example, the NS-oriented horizontal section is 720 m long and effective reservoirs of 335.1 m thick are drilled with a drilling ratio of 46.5%. This well is stimulated by four-stage fracturing with open-hole packers. Within

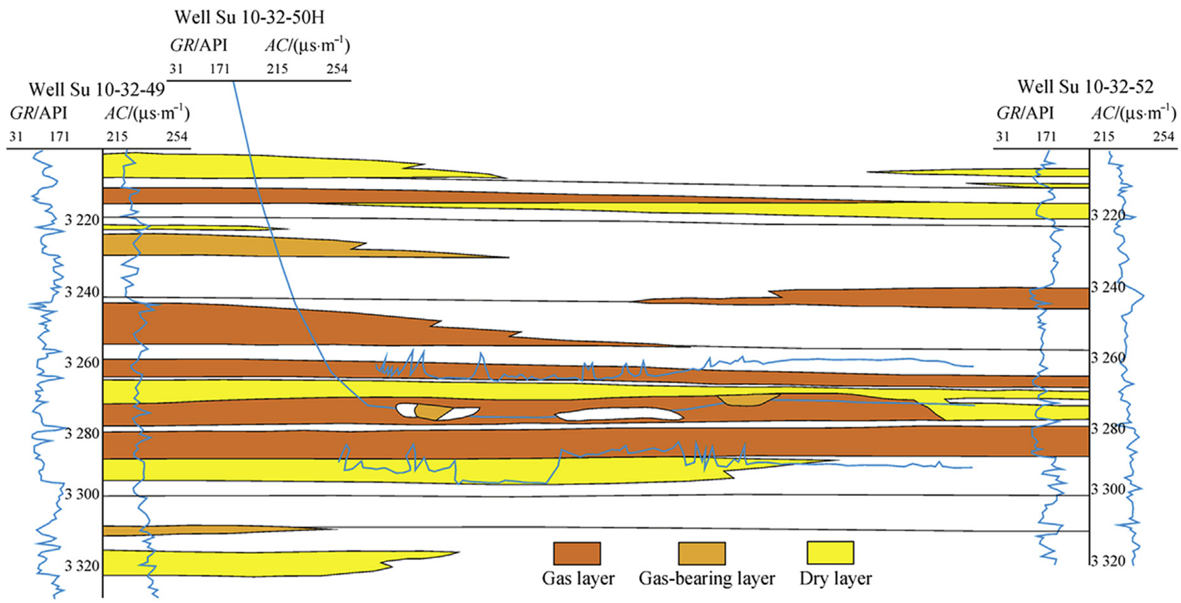


Fig. 3. Trajectory of Well Su 10-32-50H.

700 d production, an average daily gas production of 12.2×10^4 m^3 and a cumulative gas production of 8280×10^4 m^3 were obtained, plus a pressure drop rate of 80.024 MPa/d.

3.3.3. Vertically-superimposed pattern with argillaceous interlayers

In this pattern, vertical superimposition of two-phase or multiphase braided channels and mid-channel bar sandbodies is dominant, and the superimposition thickness of sandbodies is large. It, to some extent, is similar to the vertically-superimposed pattern with physical interlayers, but a set of flood-argillaceous barrier (generally less than 3 m thick) is deposited between the upper and the lower gas-bearing sandbodies. The thickness of effective sandbodies in each layer is different. Their lateral distribution range is not quite the same and their continuity is poor. When horizontal wells are adopted in this pattern, the drilling ratio of gas-bearing sandbodies is generally lower. Furthermore, the horizontal wells are mostly low-yield gas producers and the effective controlled reserves are insufficient. In Well Suping 14-13-36 (Fig. 4) which is 1200 m long from the south to the north, for example, the thickness of drilled gas layers and gas-bearing layers is 470.5 m and 106.3 m respectively, and the drilling ratio of gas-bearing sandbodies is 48.1%. This well is stimulated by two-stage fracturing of hydraulic jetting, the natural gas AOF

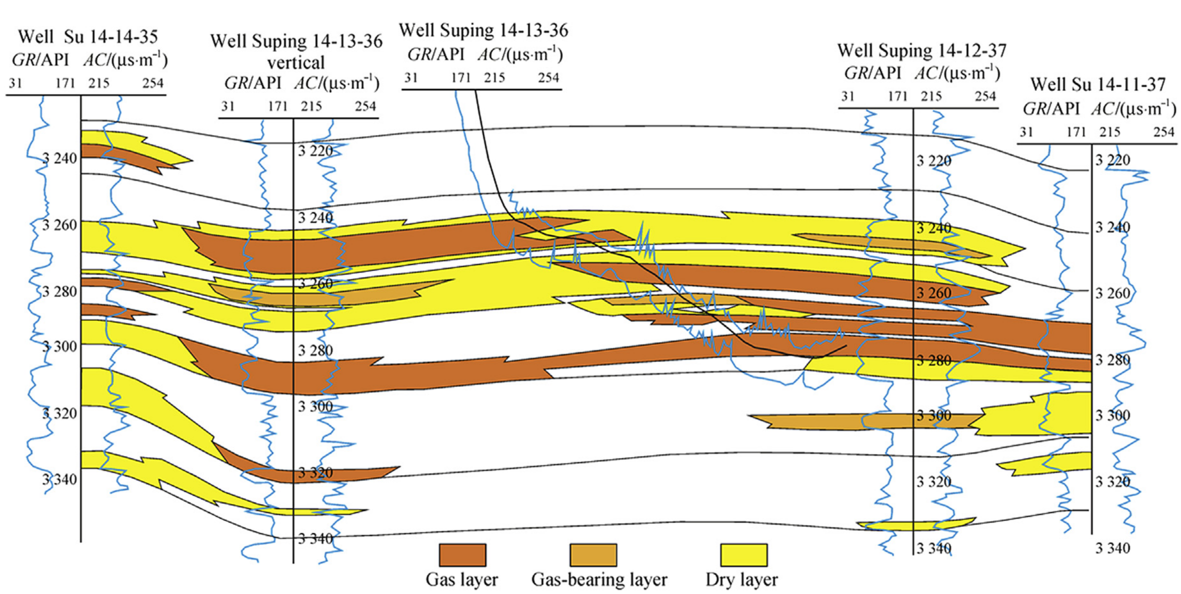
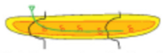
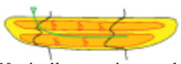
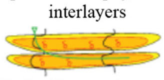
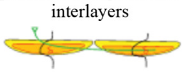


Fig. 4. Trajectory of Well Suping 14-13-36.

Please cite this article in press as: Luo C, et al., Analysis on effective reservoirs and length optimization of horizontal wells in the Sulige Gasfield, Natural Gas Industry B (2016), http://dx.doi.org/10.1016/j.ngib.2016.05.009

Table 1
Relevant parameters of effective sandbodies drilled by horizontal wells in the Sulige Gasfield.

Type	Gas layer thickness/m	Sample numbers	Percentage in total samples	Effective sandbody length/m		
				Min.	Max.	Average
 Thick massive isolated pattern	>6	27	24%	350	1300	670
 Vertically-superimposed pattern with physical interlayers	6–15	38	34%	350	1800	980
 Vertically-superimposed pattern with argillaceous interlayers	6–15 (the thickness of argillaceous barrier less than 3 m)	23	21%	600	1500	870
 Lateral sugar-coated-haw-string pattern	>3	5	5%	1000	3500	1300

(absolute open flow) is 12.4 × 10^4 m^3/d. Within 980 d production, an average daily gas production rate of 3 × 10^4 m^3 and an average pressure drop rate of 0.014 MPa/d were obtained.

3.3.4. Lateral sugar-coated-haw-string pattern

In this pattern, two gas-bearing sandbodies are laterally separated by mudstones, and in sections, it is presented in the shape of sugar-coated haw string. When horizontal wells are arranged in this pattern, the drilling ratio of gas-bearing sandbodies is lower and effective controlled reserves are insufficient with more risks. In Well Su 36-8-18H, for example, the horizontal section is 671.8 m long, effective reservoirs are 269.2 m thick and drilling ratio of effective reservoirs is 40.1%. Its average daily gas production rate is 1.9 × 10^4 m^3 and pressure drop rate is 0.036 MPa/d.

Based on the statistical data of existing horizontal wells, the effective sandbodies in four types of geological targets that are suitable for the deployment of horizontal wells are dominantly 670–1300 m long (Table 1). The drilling ratio of gas-bearing sandbodies in each sublayer is mostly in the range of 20–40%, so the second gas-bearing sandbody may be drilled after a long interval of mudstones when the first one is drilled by the horizontal section. Single-layer thickness is small, so it is hard to predict accurately the distribution of the second effective sandbody. Even though two gas-bearing sandbodies are drilled successfully, the economic benefit of horizontal wells will be decreased because of the drilling of a long mudstone interval. The Sulige Gasfield is not a gasfield with laterally stable reservoirs. So, considering the current technologies, single gas-bearing sandbody should be taken as the major target in the process of well selection so that smooth fracturing stimulation can be carried out. That is to say, the thick massive isolated pattern and the vertically superimposed pattern with physical interlayers are most favorable for the deployment of horizontal wells. Further length optimization of horizontal sections plays a vital role in improving the development results of horizontal wells.

4. Gas reservoir engineering analysis on the rational length of horizontal sections

4.1. Analysis on the relationship between horizontal section length and gas well productivity using gas reservoir engineering method

In the center of Sulige Gasfield, there are 16 horizontal wells that are deployed in superimposed sandbodies with physical interlayers and they have been put into production over a longer period. The relationship between the horizontal section length and the gas well AOF is calculated by using the formula of Joshi horizontal well productivity of heterogeneous gas reservoir which is corrected according to the data of these horizontal wells. It is shown that the horizontal wells that are matched with this type of effective sandbodies slow down in terms of AOF growth rate with the increase of the horizontal section length and the inflection point occurs at about 1200 m (Fig. 5). Therefore, this inflection corresponds to the rational length of horizontal sections.

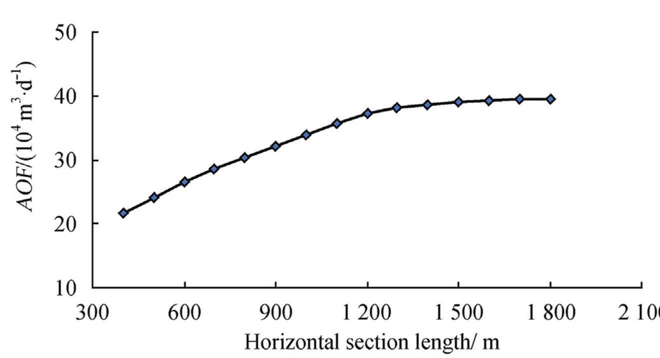


Fig. 5. Horizontal section length vs. natural gas AOF.

4.2. Simulation analysis on the relationship between the length of horizontal sections and the stable production period of gas wells

In well group SuX-18-36 where the typical size and distribution characteristics of gas-bearing sandbodies of the Sulige Gasfield are presented, for example, two horizontal wells (J1 and J2) are deployed in two sublayers of He 8 Member (two-stage sandbodies with physical interlayers), and the length of horizontal sections are set at 500 m, 800 m, 1200 m, 1500 m and 1800 m. The proration of Wells J1 and J2 is 6×10^4 m^3/d and 2×10^4 m^3/d respectively. Their stable production periods are simulated and compared by varying the length of horizontal sections. In Well J1 (Fig. 6), for example, its stable production lasts for 1000 d when its horizontal section is 500 m long, and rises to 1445 days when its horizontal section is 800 m long. When the length of horizontal section is over 1200 m, however, the growth rate of stable production period declines and the stable production basically lasts for 1684 days.

4.3. Simulation analysis on the relationship between the horizontal section length and the cumulative gas production

The relationship between the horizontal section length and the cumulative gas production is similar to that between the length of horizontal sections and the stable production period of gas wells. When the length of horizontal sections in Wells J1 and J2 is set at 500 m, 800 m and 1200 m, their cumulative gas production increases quickly with the increase of horizontal section length. When the horizontal section is more than 1500 m, obvious inflection occurs at the cumulative gas production curve (Fig. 7). It is indicated from the relationships of horizontal section length vs. stable production period and cumulative gas production that when a horizontal well is deployed in the pattern of superimposed sandbodies with physical interlayers, its horizontal section length should be shorter than 1500 m.

5. Economic evaluation on the rational length of horizontal sections

Drilling costs increase with the extending of horizontal sections. Therefore, it is necessary to optimize economically

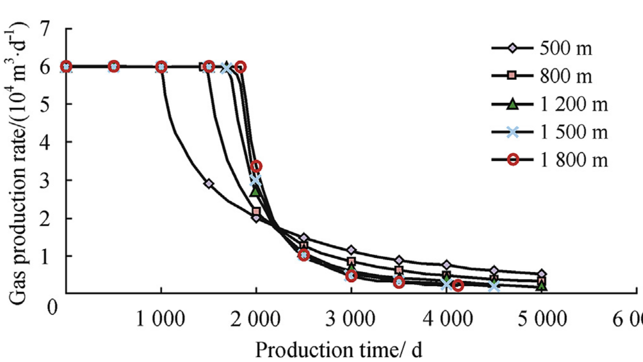


Fig. 6. Stable production period of Well J1 with different horizontal section lengths.

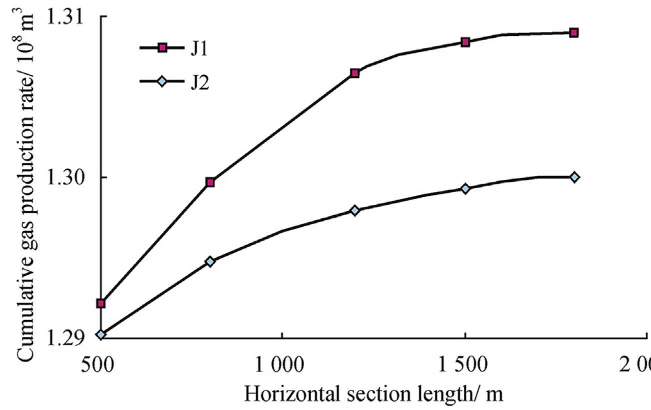


Fig. 7. Horizontal section length vs. cumulative gas production.

the rational length of horizontal sections under current economic and technical conditions by comparing the difference between the drilling cost per unit length and the income derived from gas incremental. That is to say, the rational length of horizontal sections is determined by balancing the relationship between the incremental benefit increase from the gas production due to the length increase of horizontal sections and the increase of drilling costs.

Based on the economic parameters and index related to the development of Sulige Gasfield, the drilling cost of horizontal wells per unit footage is RMB1613–2009 yuan/m and natural gas price is RMB1000 yuan/10^3 m^3. It is shown from the calculation results that the income per unit length of horizontal section derived from gas incremental declines gradually. When the horizontal sections in Wells J1 and J2 are 800 m long, the income per unit length of horizontal section derived from gas incremental is much higher than the cost per unit footage. With the extension of horizontal sections, the income per unit length derived from gas incremental decreases quickly. When the length of horizontal sections in Wells J1 and J2 is close to 1200 m, the income per unit length derived from gas incremental is basically equal to the cost per unit footage. When the length is more than 1200 m, horizontal wells are basically incapable of making profits (Fig. 8).

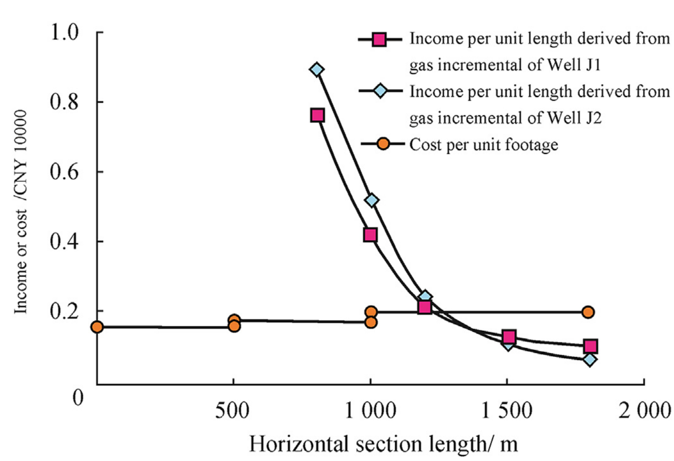


Fig. 8. Relationship between the income per unit length derived from gas incremental and the drilling cost at different length of horizontal sections.

Please cite this article in press as: Luo C, et al., Analysis on effective reservoirs and length optimization of horizontal wells in the Sulige Gasfield, Natural Gas Industry B (2016), http://dx.doi.org/10.1016/j.ngib.2016.05.009

To sum up, the length of horizontal sections should be kept less than 1200 m based on current gas price and horizontal-well technical conditions when horizontal wells are deployed in the vertically superimposed sandbodies with physical interlayers in the Sulige Gasfield.

6. Conclusions

1) It is indicated by multiple methods (e.g. outcrop analogy, geostatistical analysis and pilot tests of dense well patterns) that the gas-bearing sandbodies of He 8 Member and Shan 1 Member are mostly distributed in the pattern of NS isolated lens along north and south and they are mostly 2–5 m thick, 300–800 m wide and 300–1200 m long. Four distribution patterns of effective sandbodies suitable for the deployment of horizontal wells are proposed, including thick massive isolated pattern, vertically-superimposed pattern with physical interlayers, vertically-superimposed pattern with argillaceous interlayers and lateral sugar-coated-haw-string pattern. Based on the statistics of their drilling ratios of the four effective sandbodies, it is recommended to take the single gas-bearing sandbody as the principal target in the process of well selection.
2) By means of production data correction, numerical simulation and economic evaluation, the optimum length of horizontal wells deployed in vertically-superimposed sandbodies with physical interlayers of tight sandstone gas reservoirs in the Sulige Gasfield is comprehensively analyzed by performing a case study on the same sandbody distribution pattern in the typical well group SuX-18-36 of Su-X Block. Based on current economic and technical conditions, the rational length of horizontal sections should be set shorter than 1200 m. And it is recommended to carry out horizontal section length optimization specific for the effective sandbodies with different superimposition patterns that are suitable for the deployment of horizontal wells.

References

[1] Zhang Liehui, Zhang Su, Xiong Yanli, Wang Rui, Zhu Bin. Productivity analysis of horizontal gas wells for low permeability gas reservoirs. Nat Gas Ind 2010;30(1):49–51.
[2] Yang Chengbo, Guo Jianchun, Yang Jian, Xu Shoucheng, Yuan Caixia. Modification of horizontal well binomial deliverability equation of low permeability gas reservoir. J Southwest Pet Univ Sci Technol Ed 2014;36(4):123–30.
[3] Yang Zhilun, Zhao Weilan, Chen Qiwen, Dong Yu, Zhang Chun. High efficiency and productivity technology for horizontal wells in the Sulige Gas Field, Ordos Basin. Nat Gas Ind 2013;33(8):44–8.
[4] Wan Yujin, Han Yongxin, Zhou Zhaohua. Characteristic and development techniques of tight gas pool in USA. Beijing: Pet Industry Press; 2013. p. 112–23.
[5] Li Jianqi, Yang Zhilun, Chen Qiwen, Wang Zan, Zhou Tong. Horizontal well technology for the development of the Sulige Gas Field. Nat Gas Ind 2011;31(8):60–4.
[6] Zhang Jianguo, Liu Jinhua, Xu Yundong, You Liangrong. A study on horizontal well length optimization in low permeability and thin layer carbonate reservoir. Nat Gas Geosci 2015;26(1):180–5.
[7] Cheng Linsong, Li Chunlan, Chen Yueming. An optimum method for determining proper length of horizontal well in a water-drive reservoir. J China Univ Pet Ed Nat Sci 1998;22(5):58–60.
[8] Zhao Jiyong, He Yonghong, Fan Jianming, Li Shuheng, Wang Shitou. Optimization technology for horizontal well pattern in ultra-low permeable tight reservoirs. J Southwest Pet Univ Sci Technol Ed 2014;36(2):91–8.
[9] Zeng Xiaojing, Tong Dengke. An improvement of the design method of optimal horizontal wellbore length. Pet Explor Dev 2011;38(2):216–20.
[10] Yang Yukun, Zhai Jianming. Casing program optimization technology for ultra-deep horizontal wells in the Yuanba Gas Field, Sichuan Basin. Nat Gas Ind 2015;35(5):79–84.
[11] Ye Chenglin, Wang Guoyong, He Kai, Xu Zhongbo. Macro heterogeneity of reservoirs in Sulige Gas Field—a case study of the 8th member of the Shihezi Fm and the 1st member of the Shanxi Fm in the Su 53 Block. Oil Gas Geol 2011;32(2):236–44.
[12] Wen Huaguo, Zheng Rongcai, Gao Hongcan, Dai Chaocheng, Li Guojun. Sedimentary facies of the 8th member of lower Shihezi Fm in Su 6 Area, Sulige Gas Field. Acta Sedimentol Sin 2007;25(1):90–8.
[13] He Zixin, Fu Jinhua, Xi Shengli, Fu Suotang, Bao Hongping. Geological features of reservoir formation of Sulige Gas Field. Acta Pet Sin 2003;24(2):6–12.
[14] Zhou Yanjie, Zhang Guowei, Wang Denghai, Chi Kun, Wei Wei, Guo Xiaojing. Ground engineering construction for the horizontal well development zone in the Sulige Gas Field, Ordos Basin. Nat Gas Ind 2014;34(3):131–6.
[15] Bi Mingwei, Chen Shiyue, Zhou Zhaohua, Liu Jin, Zheng Guoqiang, Zhang Manlang. Genesis of secondary pores of tight sandstone reservoir in He 8th Member in Su 6 area of Sulige Gas Field. J China Univ Pet Ed Nat Sci 2015;39(1):8–16.
[16] Cong Lianzhu, Jiang Bo, Ma Xinhua. Research on the microcosmic damage mechanism of He 8 gas bearing reservoir in the Sulige Gas Field. J China Univ Min Technol 2006;35(6):808–12.
[17] Bai Ye, Xue Linfu, Shi Yujiang, Pan Baozhi, Zhang Haitao, Wang Jianqiang. An automatic identification method of log diagenetic facies and its application in Sulige area, Ordos Basin. J China Univ Pet Ed Nat Sci 2013;37(1):35–41.
[18] He Dongbo, Jia Ailin, Ji Guang, Wei Yunsheng, Tang Haifa. Well type and pattern optimization technology for large scale tight sand gas, Sulige Gas Field. Pet Explor Dev 2013;40(1):79–89.
[19] Fan Zifei, Fang Hongchang, Yu Guofan. A study on design method of optimal horizontal wellbore length. Acta Pet Sin 1997;18(1):55–62.
[20] Jin Zhenkui, Yang Youxing, Shang Jianlin, Wang Linsheng. Sandbody architecture and quantitative parameters of single channel sandbodies of braided river: case from outcrops of braided river in Fukang, Liulin and Yan'an areas. Nat Gas Geosci 2014;25(3):311–7.
[21] He Dongbo, Wang Lijuan, Ji Guang, Wei Yunsheng, Jia Chengye. Well spacing optimization for Sulige tight sand gas field, NW China. Pet Explor Dev 2012;39(4):458–64.
[22] Fei Shixiang, Wang Dongxu, Lin Gang, Pan Xiaoli, Wang Yong, Zhang Baoguo, et al. The key geological technology for horizontal wells overall development in tight sandstone gas reservoir: take the Sudongnan area of Sulige Gas Field for an example. Nat Gas Geosci 2014;25(10):1620–9.
[23] Li Haitao, Wang Junchao, Li Ying, Luo Wei. Deliverability evaluation method based on volume source for horizontal wells by staged fracturing. Nat Gas Ind 2015;35(9):55–63.
[24] Lu Tao, Zhang Ji, Li Yuegang, Wang Jiping, Wan Danfu, Zhu Yajun, et al. Horizontal well development technology for tight sandstone gas reservoirs in the Sulige Gas Field, Ordos Basin. Nat Gas Ind 2013;33(8):38–43.

Please cite this article in press as: Luo C, et al., Analysis on effective reservoirs and length optimization of horizontal wells in the Sulige Gasfield, Natural Gas Industry B (2016), http://dx.doi.org/10.1016/j.ngib.2016.05.009