CURRENT STATUS AND PROSPECT OF EXPLORATION AND DEVELOPMENT OF TIGHT SAND GAS IN CHINA

Wan Yujin, Li Xizhe, Zhang Fudong, Hu Yong

Research Institute of Petroleum Exploration and Development-Langfang, CNPC

Abstract: The tight sand gas in China shows a significant potential, with the estimated resource is about 16Tcm. Sulige gas field is the largest tight gas field in China right now.

After more than ten years of exploration and development, an integrated technology, such as well location optimization, fast drilling, down-hole choking and multi-layer fracturing etc, have been built to exploit Sulige gas field successfully. The geologic characteristics of Sulige gas field have been depicted in detail, and the dynamic performance of both vertical and horizontal wells has been investigated. Generally speaking, a majority of producing gas comes from the "sweet spot" areas at current conditions.

The development of tight sand gas in China is still in the early stage of exploration and development, and the tight gas reserves in different basins need to be further proved. With the support of advanced technologies and favourable policies, it is believed that the tight gas will develop rapidly.

Key words: Tight gas; China; Development

The unconventional gas is developing quickly in the world, especially the tight sand gas. It will play a more and more important role in gas industry in the next 5-10 years. In China, the tight sand gas resource is also very abundant, and has been developed more than 10 years. Now, much more attentions has been taken to it, because the effectively and large scale development of tight sand gas will be the most important supplement for natural gas in China.

1. The resources and distribution of tight sand gas in China

Tight sand gas is extensively distributed in more than ten basins in China, Ordos Basin, Sichuan Basin, Tarim Basin and Songliao Basin are more favourable basins among them(fig 1). The tight gas bearing area is about 123,000 km^2, and the estimate resources are about 16 Tcm (Ma Xinhua etc., 2011).

Ordos basin is about 380,000 km^2, the total gas resources are about 10.7 Tcm and total proved reserves is 2.1 Tcm. The tight sand is mainly located in Permo-Conbonifiers system, the total gas bearing area is about 80,000km^2, the estimated resources of tight sand gas is about 9Tcm, and the proved tight gas reserves are 1.6Tcm. The typical tight gas field is Sulige.

In Sichuan Basin, the tight sand is mainly located in Jurassic and Upper Triassic. The gas bearing area is about 30,000km^2, and the estimated resources are 3.5Tcm, the proved tight gas reserves are 0.5Tcm. The gas reservoir of Xujiahe group is classified as tight sand gas.

In Tarim Basin, the tight sand is mainly located in Lower Jurassic. The gas bearing area is about 30,000km^2, and the estimated resources are 1Tcm.

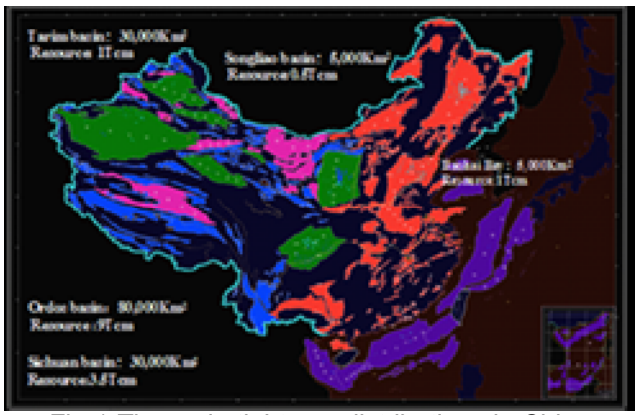


Fig 1 The main tight gas distributions in China

2. The geologic characteristics of tight sand

Located in Ordos Basin, north-west of China, Sulige gas field is the largest and typical tight sand gas field. The gas bearing strata of Sulige is divided into Benxi Formation of Carboniferous; Taiyuan, Shanxi, Shihezi and Shiqianfeng formation of Permian.

The main tight sand layer of Permian includes Shan1 and He8 formation. The proved tight gas reserves are 1.6Tcm at the end of 2011.

2.1 Petrology

He8 and Shan1 are two main gas bearing formations in Sulige, the quartz (75~85%) and lithic (15~25%) are the most part of rock fragment, with very rare of feldspar (table 1). The quartz sandstone, lithic quartz sandstone and lithic sandstone is the main rock type.

Table1 the metrological characteristic of Sulige gas field

Gas Field	Formation	Detrital component (%)			Number of samples
		Quartz	Feldspar	Lithic	
East of Sulige	Upper He8	79.3	0.3	20.4	86
	Lower He8	80.7	0.2	19.2	106
	Shan1	75.9	0.3	23.9	57
	Shan22	80.5	0	19.4	91
	Shan23	86.7	0.1	13.2	114
Sulige	Upper He8	84.4	0.2	15.4	123
	Lower He8	83.8	0.3	15.9	107
	Shan1	84.4	0.2	15.4	59

2.2 Porosity and Permeability

According to the routine core analysis data from more than 1000 samples, the permeability and porosity are very low.

The porosity ranges from 5 to12% for He8 sand and averages 8. 95%. The permeability ranges from 0.06 to 2md, with the arithmetic mean of 0.73 md.

The porosity range from 5 to 11% for Shan1 sand and averages 8. 5%. The permeability ranges from 0.06 to 1mD and averages 0.589md.

There are more than 85% samples with in-situ(NOP=50MPa) permeability less than 0.1md.

2.3 Pore type and structure

The pore types have been investigated by thin section, the result shows that there are verities of pore types, such as intergranular pore, arcosic dissolved pore, lithic dissolved pore, and intercrystal pore (table 2).

Table2 Pore type and pore structure

Gas field	Formation	Intergranular Pore	Arcosic Dissolved Pore	Lithic Dissolved Pore	Intercrystal Pore	Number of samples
East of Sulige	Upper He8	0.6	0.1	1.0	0.4	62
	Lower He8	0.1	0.0	0.3	0.6	23
	Shan1	0.1	0.0	1.5	0.5	46
	Shan22	0.7	0.0	0.8	0.3	94
	Shan23	0.4	0.0	0.3	1.0	8
Sulige	Upper He8	0.6	0.3	2.0	0.7	64
	Lower He8	0.3	0.1	1.2	0.7	45

The pore structure can be classified into four types (Fig 2), as detail as the following.

Type Curve Ⅰ：the average pore radius is 107.07μm, median pressure is about 1.0MPa, porosity is great than 12%, permeability is great than 1mD.

Type Curve Ⅱ：the average pore radius is 83.11μm, median pressure is about 7.5MPa, porosity is in range of 9~12%, and permeability of 0.5~1mD.

Type Curve Ⅲ：the average pore radius is 56.91μm, median pressure is about 15MPa, with porosity is in range of 5~9%, and permeability of 0.1~0.5mD.

Type Curve IV：the average pore radius is 11.98μm, median pressure is about 35MPa, porosity is less than 5%, permeability is less than 0.1mD.

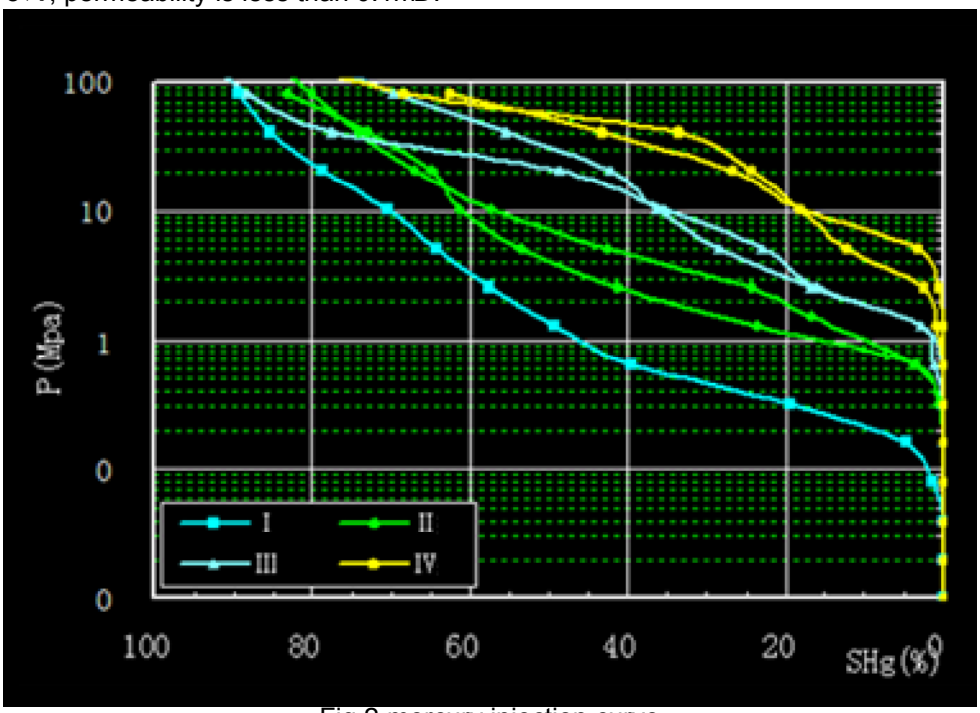


Fig.2 mercury injection curve

2.4 Sand body distribution

The gas reservoirs have a burial depth of 3,200-3,500m，with average depth is about 3295m.

The lenticular sand is controlled by braided river. The sand thickness is 15 ~ 48m and normally thicker than 20m. The net pay ranges from 5 to 15m, with single sand body is 2-5m in thickness and 300-500m wide and 400-700m long (fig 3).

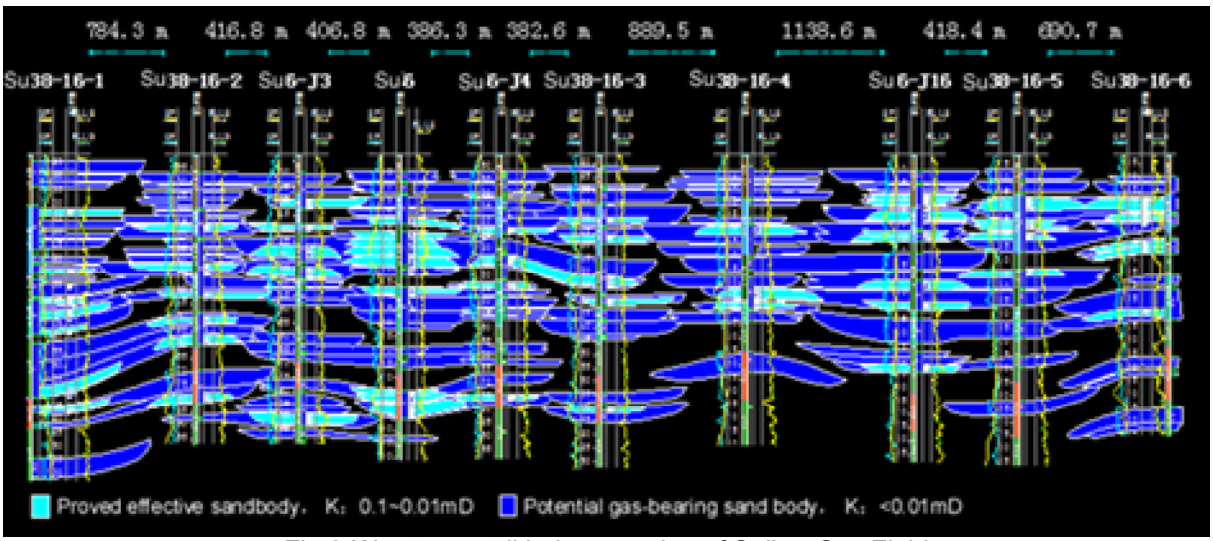
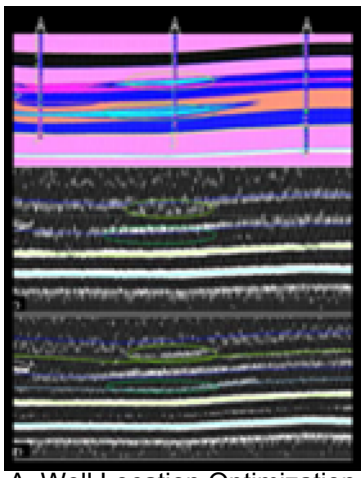


Fig 3 West to east lithology section of Sulige Gas Field

3. The development status of tight sand gas

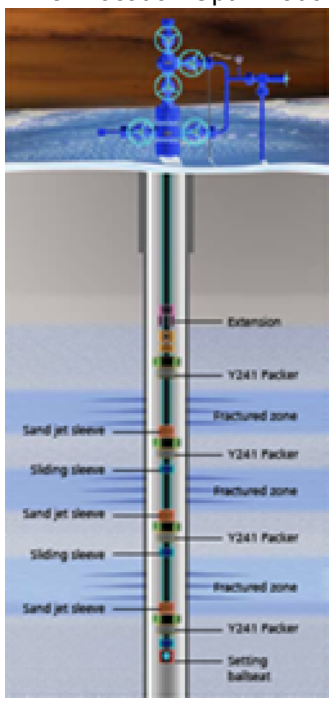
Since 2000, CNPC makes great efforts to seek technical innovation and low-cost solutions for economical and effective development of tight sand gas. By technological innovation, the scale and economic development has been preliminarily realized in Sulige gas field. The core technologies include well location optimization, fast drilling, inter-well concatenation, multi-layer fracturing, down-hole choking and remote control etc. (Fig 4).

Up to 2010, the annual tight gas production is about 16Bcm, accounting for 17% of the total gas production nationwide, in which Sulige gas field in Ordos basin takes 84%.

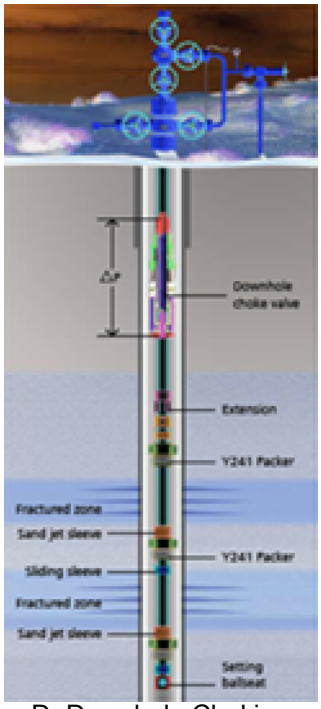


A. Well Location Optimization

B. Inter-well Concatenation



C. Multi-Layer Fracturing



D. Downhole Choking

Fig.4 Development technologies used in Sulige Gas Field (reference 2)

3.1 Development status of Sulige Gas field

There are about 3700 vertical gas wells and 137 Horizontal wells in Sulige gas field, and the average gas rate is about $10\times10^3m^3/d$ for vertical wells and $60\times10^3m^3/d$ for Horizontal wells. The annual gas production is about 13.5Bcm in 201 1, whose productivity scale becomes the largest in China. The annual gas production will be to 23 Bcm in 2013.

3.2 Fracturing vertical well

The production performance shows a great difference because of the strong heterogeneity. So the wells have been classified into three types (Fig 5) according to the geology conditions and the well performance (table 3).

Well type I:

The single net pay is bigger than 5m, and the total effective thickness is usually bigger than 8m. The absolute open-hole flow potential is higher than $100\times10^3m^3/d$, the initial gas production rate is about $20\text{-}50\times10^3m^3/d$, period of stabilized production is about 3years.

Well type II:

The single net pay ranges from 2 to 5m, and the cumulative thickness of I+II formations is usually bigger than 8m. The absolute open-hole flow potential ranges from 50 to $100\times10^3m^3/d$, early gas production rate is about $10\text{-}20\times10^4m^3/d$.

Well type III:

The cumulative thickness of I+II formations usually smaller than 8m, without type I formation. The absolute open-hole flow potential is smaller than $5\times10^4m^3/d$, gas production is less than $10\times10^3m^3/d$, with averages $6\times10^3m^3/d$.

Table 3 the types of vertical gas well

Well type	Net Pay (m)		AOF	EUR per well 10^6m^3	Initial gas rate $10^3m^3/d$	period of stabilized production years	Typical well
	I	I+II	$10^3m^3/d$				
I	>5	>8	120～250	40	20～50	3	Su4
II	5～2	>8	50～100	25	10～20		Su39-17
III	<2	<8	20～40	12	<10		Su35-15

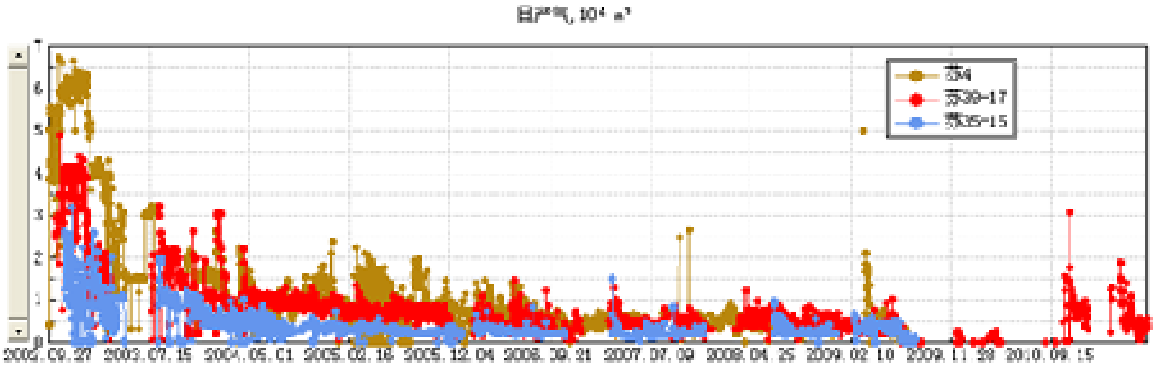


Fig 5 production performance of Fracturing vertical well

3.3 Horizontal wells

Horizontal wells have been used in Sulige for tow years, with 137 wells in producing at September 2011. Comparing with the fracturing vertical well, the horizontal wells drilled in the formations with 25m thickness and 0.2mD permeability is very good.

The horizontal length range from 800 to 1200m, averaging 916m. The average net/gross ratio of the horizontal literal is about 56%. The fractured stages generally range from 3 to 7, averaging 5.

By type-curve match, the estimate reserves for single well range from 50 to 150 million cubic meters with averaging 65 million cubic meters, which is about 4-5 times of the vertical well. The average AOF in first month is about $360\times10^3m^3/d$, which is 3-6 times of the vertical well. The gas production rate (with 3 years of stable production period) is $40\sim100\times10^3m^3/d$ (fig 6). From this view point, the application of horizontal Gas well is successful in Sulige gas field.

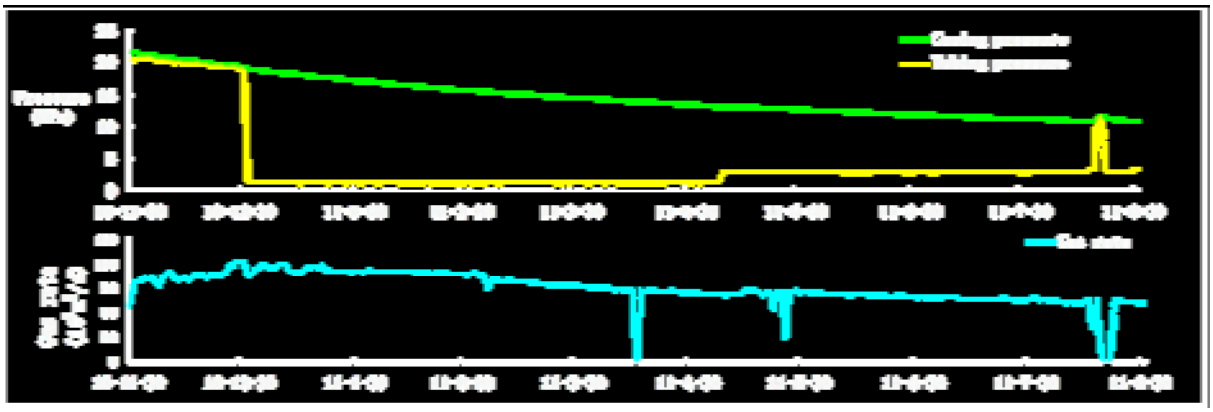


Fig.6 the production performance of Horizontal gas wells in Sulige

4. The prospect of tight gas development

Tight sand gas in China is still in the early stage of exploration and development. In the long view, the tight sand gas will play a more and more important role in development of natural gas. Currently, tight gas has sufficient reserves and could be strengthened. With progress in exploration, the gas

reserves of Sulige Gas Field well be in the trend of increasing. It is predicted that Sulige will have proven gas reserves of 2.5 Tcm in the near future.

By 2015, the predicted gas production in China could reach 150 Bcm, in which tight sand gas production will be 30Bcm, accounting for 20% of the total production. By 2030, the predicted gas production in China could reach 250-300 Bcm, tight sand gas production could reach 40-60 Bcm.

The tight gas reserves in other basins need to be further proved. So, currently, the highest priority is to establish suitable methods to exploit the tight gas, which includes:

(1) Establishment of an evaluation standard to assess tight sand gas resources potential in China;

(2) Further improvement of the stimulation technologies for tight gas reservoirs, including multi-layer fracturing for vertical wells, and multi-stage fracturing for horizontal wells with low formation damage and low cost;

(3) Intensified research of technical policy and strategies for tight sands gas.

With the support of advanced technologies and favourable policies, it is believed that some positive results will be achieved quickly.

5. Conclusions

(1) The tight sand gas in China shows a significant potential, but the reserves need to be further proved at different basins.

(2) In Sulige gas field, the porosity is usually less than 12%, the permeability is usually less than 0.1mD, the pore structure is very complex and the formation shows strong heterogeneity.

(3) The vertical well has no natural capacity. Daily gas production is usually not exceeding $30\times10^3m^3$ even after stimulation treatment.

(4) Horizontal wells have been successfully used in Sulige gas field with high dynamic reserves and Gas rate.

(5) There are still a great efforts should be done to improve the technology for more complex tight sand gas.

References:

1. Xinhua Ma, Ning Ning, Hongyan Wang, Resource Base and Development Technologies of Unconventional Gas in China. 20th world petroleum congress, 4-8 December 2011, Doha, Qatar.
2. Tight Gas Reservoirs -Economical Solutions for Sulige Gas Field, http://www.cnpc.com.cn/Resource/english/images1/pdf/Brochure/Tight%20Gas%20Reservoirs.pdf