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A New Gas Injection System for Ultra-Thick Metamorphic Rock Buried Hill Reservoirs

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Abstract

This article proposes a new gas injection system that is a kind of tridimensional gas injection mode applied in the middle-lower part of the reservoir during the process of gas injecting on the reservoir top, which is suitable for the tridimensional reservoir development[1-2]. This system can express the gravity-stable drive effect on the crestal gas injection as well as the effective using of waterflooded wells to form continual micro gas/water slug drive naturally, supply the producing energy timely, diminish the water sealing of waterflooded reservoir matrix, enhance the gas dialysis on fine crack and microscopic sweep efficiency and control the water content, thus improve the production rate and enhance the recovery. Tridimensional gas injection system has been verified by physical simulation and numerical simulation. Pilot testing on Xinggu 7 buried hill reservoir has acquired an actual effect to increase the oil production, boost the pressure and decrease the water cut.

Key words: Tridimensional; Gas injection system; Ultra-thick reservoir; Buried hill; Gravity-stable drive; Waterflooded well

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INTRODUCTION

Thus the feasibility of gas injection in the reservoir is confirmed, the following step is to determine a more reasonable mode. In general, there are two ways can be chosen: horizontal gas injection and vertical gas injection. The former is usually supplied in the thin-moderate thick layered reservoir and sometimes combined with the water slug, as WAG. While in the vertical gas injection, the perforating direction is more often coincident with the conventional one instead of vertically up or vertically down. Description of gas driving direction in the vertical gas injection is that: gas injection wells are designed to be deployed on the reservoir top, for the density difference between gas and oil, the gas moved down to displace the oil, and production wells are deployed in some declinate part or lower part of the reservoir, which could display the action of gravity potential energy well. A high oil recovery would be achieved in the thin and inclined reservoir through using this method; for example, the degree of reserve recovery in Hawkins oilfield in USA has been reached to 65%. After a series of close research we recognize that gas injection development is an advisable and unique way to improve the development effect on ultra-thick metamorphic rock buried hill reservoirs developed high angled fractures with bottom water[3-6]. So, is it the best way to design gas injection wells for vertical injecting in the upper reservoir?

1. BASIC GEOLOGIC CHARACTERISTICS OF RESERVOIR

Xinglongtai buried hill is located in the middle part of the western sag in Liaohe depression, its structural area is 91 km^2 and strata belongs to the Archean Erathem, the shallowest buried depth approaches to 2,335 m, overburden and its surroundings are Mesozoic strata.

It mainly developed a NE fault and a nearly EW fault, it is distributed from NE to SW. The gross structure of Xinglongtai buried hill is an anticline with Xinggu 7 buried hill at the top, which plunges toward south and north with a banding distribution along NE direction.

Xinggu 7 buried hill is mainly composed of metamorphic rock and magmatic rock divided into 7 subgenera with 25 rocks, of which magmatic rock accounts for about 25%. The main reservoir rocks are biotite plagioclase gneiss, migmatitic granite, granite porphyry (granodiorite porphyry) and diorite porphyrite, high dark mineral -contained lamprophyre and diabase are non-reservoir rocks, distributed in banded sporadically. The reservoir space is mainly fractures and intergranular pore in cataclastic grains. According to the core statistics, fractures are mainly medium-high angled ones with dip angles more than 45° account for 99.7%; Average fracture density shows 40.1 cracks/m, and fracture interval of them less than 2 cm account for 75%, with the direction of NE-NEE is most developed. Transecting depth of macrofractures is generally more than 10 cm, most of them are between 10-30 cm, while transecting depth of microfractures is generally less than 10 cm, most are between 5-8 cm. Through calculating the extended length of fractures is between 0.4-4.2 m, of which the longer ones can be reached to 10-20 m even much longer. Structural fractures are mainly partial filled; while the fractures which have not been filled are most contained oil.

Reservoirs are distributed continuously, with a huge thick oil layer in vertical and a large range of oily amplitude, the maximum oily amplitude reaches to -2,335 m. Oil-water interface is near the -4,670 m, reservoirs from the buried hill top to the bottom have been all developed; Ⅰ-Ⅳ four central development sections of the reservoir are recognized in vertical of buried hill on the basis of drilling situation, it is a kind of fractured massive metamorphic rock buried hill reservoir with bottom water. Crude oil in the buried hill reservoir has a good property with a formation crude oil density 0.6442 g/cm^3, viscosity 0.384 mPa·s, which belongs to a same normal temperature and pressure system. Xinggu 7 buried hill reservoir covered by a double caprock composed of Mesozoic dry layer with good sealing and continuous huge thick Mesozoic shale, it has an independent faulting system and suitable for the gas injection development.

2. DEVELOPMENT FEATURE AND SITUATION

Xinggu 7 buried hill reservoir has been started the full development since 2008, the maximum block daily oil production reached to 2,104 t/d, the main development index such as reserves producing rate, well yield and declining rate accomplished the design requirements[1-2]. Until October 2014, 44 wells are opened in total (of which 38 horizontal wells) with daily oil production of 1,046 t, daily water production of 81.5 m^3, and daily gas production of 24.4 × 10^4 m^3; The cumulative oil production is 376.8 × 10^4 t, cumulative gas 9.61 × 10^8 m^3, cumulative water production 18.41 × 10^4 m^3; The oil recovery rate is 1.21%, and the degree of reserve recovery is 10.7%. It was developed by using of natural energy early, which shows the following development characteristics.

2.1 Good Implementation Effect on Horizontal Wells Achieves High/Stable Production and Rapid Productivity Construction

There are 51 horizontal wells in total are putted into production in Xinggu 7 buried hill reservoir, account for 81% of development wells, of which 17 wells achieved a hundred tons of daily oil production in initial. Production of horizontal wells is three times that of the vertical wells; production pressure difference is small, with an average of 1.37-4.21 MPa, it is the 14.7-45.1% of vertical wells'; productivity index shows 19.14-79.45 t/(d·MPa), it is 6.6-27.3 times as high as vertical wells'; probability of penetration increased averagely by 78%.

2.2 Advisable Tridimensional Well Patterns Designed With Overlapping in Vertical and Heaving in Horizontal, Which Released the Gravity Displacement Action Efficiency

On the basis of geologic characteristics of Xinggu 7 buried hill reservoir, tridimensional well patterns with overlapping in vertical and heaving in horizontal in 7 intervals of 4 members are deployed, and the controlled reserves of each single well reaches to 60 × 10^4 -70 × 10^4 t, which effectively improved the reserves producing rate and realized the tridimensional development.

Production performance data and testing data show that design of well pattern and well spacing is reasonable to effectively bring reservoirs into production, and meet the needs of overall development. Interference test results show that changing the switch state of the active well, there is pressure conduction among the adjacent wells in the well group. Counting on 8 groups of adjacent horizontal wells on the same plane are 300 m apart (reasonable well spacing according to the design) and 9 groups of adjacent horizontal wells with vertical distance of about 200 m, production and gas/oil ratio all show no evidence of interference.

2.3 High Return on Investment and Phase of the Economy Benefit

Input and output during the development present three-low and one-high: Low development cost, low production cost, low investment on million tons productivity construction and high input-output ratio, and the latter reaches to 1 : 2.17.

2.4 Low Recovery Efficiency in the Natural Energy Development

Formation pressure of Xinggu 7 buried hill dropped by 35.8% in 2014, and the pressure coefficient reduced from 1.09 to 0.7. However, the formation pressure is continuing to decline, which accelerates the production declining; annual decline rate in Xinggu 7 buried hill was 8.5% before 2013, but it increased sharply to 51.3% in 2014. According to the formula method and yield attenuated method, it is predicted that the primary recovery efficiency would be only 15%.

3. PROPOSE AND STUDY OF TRIDIMENSIONAL GAS INJECTION SYSTEM

After selecting the dry gas as the injected medium through the comprehensive comparison, crestal gas injection mode is designed according to the characteristics of the reservoir and the injected gas[7-10].

Gas injection on the reservoir top can maximize the gravity-stable drive effect; Hydrocarbon immiscible drive has a characteristics of large swept volume of gas injection, it's better to improve the physical property of crude oil (volume factor of crude oil increased 1.48 times as much as that of nitrogen injection under the same injection volume), and complement formation energy to keep the production pressure difference for promoting attic oil displacement and gas cap expansion, which can reduce the risk of gas channeling and utilize gas injection energy effectively combined with horizontal well development in order to obtain a higher recovery efficiency.

However, it needs more time to inhibite and displace the bottom water in the reservoir with bottom water coning by the crestal gas injection. In order to meet the gas injection effect quickly and efficiently, and reduce the front end capital investment on gas injection, reasonable design of gas injection wells at the middle-lower part during the phase of crestal gas injection can complement the formation energy timely, inhibite water breakthrough in fractures and water sealing of oil in matrix, and so on. The latter is to use waterflooded wells for gas injection, forming a natural continual micro gas/water slug (WAG) to promote the imbibition between fractures and matrix and gas seeping into the matrix, slowing down the water breakthrough in fractures with bottom water and water sealing of oil in matrix, which is beneficial to produce the crude oil of matrix.

For quantitative measurement of dry gas displacement efficiency on crude oil in micro apertures of matrix, apparatus for soaking testing for high-temperature and high-pressure simulating the reservoir condition has been designed and improved based on the long core model. The test experienced four stages: In the first stage, formation pressure decreased from 38.6 MPa to 25.6 MPa for simulating the situation of depleted recovery and measuring the elastic recovery; the following stage is to inject gas constantly under 25.6 MPa pressure to simulate the continuous gas (water) injection displacement, and measure the recovery efficiency; In the third stage, soaking under the constant pressure to simulate the process of imbibition in matrix, stand for one day after the gas (water) injection and repeat it three times; The last stage, for the further measurement of the degree of imbibition in the deep of matrix, the pressure elevated to 38.6 MPa and repeated the third step. Testing results indicated that gas injection could imbibe in matrix and displace oil better, the displacement efficiency increased by 109% (Table 1).

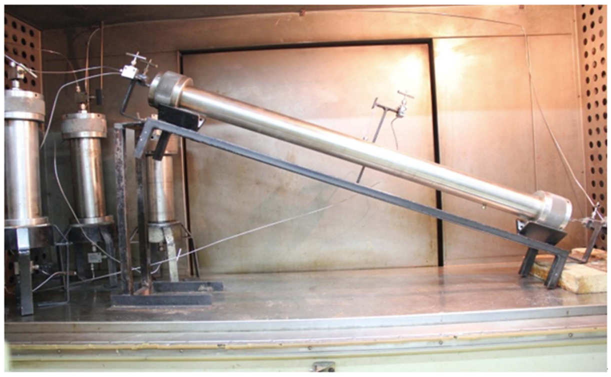

Figure 1
Apparatus for Variable Pressure Soaking Testing Simulating the Reservoir Condition

Table 1
Correlation Table of Measurement Result in Variable Pressure Soaking Testing

Development phase	Displacement efficiency, %	
	Flood development	Gas injection development
Depletion development	5.41	5.41
Continuous displacement	55.37	64.4
Soaking dialysis at constant pressure	8.04	12.24
Deep dialysis at elevated pressure	0.88	6.4
Total	68.14	88.45

The reservoir numerical simulation has been launched at the same time of lab physical simulation, to predict the development index in different development ways and different gas injection modes. The prototype of reservoir numerical simulation is Xinggu 7 buried hill reservoir, it builts a dual medium component model composed of 6 components, 49 vertical simulation layers with 13.8×10^4 grid node, 116 projects are simulated and calculated by Eclipse 300; main parameters of model are shown in Table 2, and the model shown in Figure 2. The model has been corrected through the oil/gas geologic reserves, pressure, water cut, gas/oil ratio and single-well production data and test data fitting with the history data.

Table 2
Statistical List of Main Fluid Physical Property and Reservoir Physical Parameters

Parameter	Numeric value	Parameter	Numeric value
Reference depth (m)	3,500	Reference pressure (MPa)	37.1
Initial formation pressure (MPa)	41.24	Porosity (%)	Matrix: 0.049; Fracture: 0.03;
Oil saturation pressure (MPa)	22	Permeability ($\times 10^{-3}$ um^2)	Matrix: 0.47; Fracture: 140;
Reservoir temperature (℃)	108.5	Initial gas/oil ratio (m^3/ m^3)	148
Geothermal gradient (℃/100 m)	3.4	Oil volume factor	1.474
Pressure gradient (MPa/100 m)	0.88	Water volume factor	1
Surface oil density (g/cm^3)	0.822	Subsurface oil viscosity (mPa·s)	0.384
Oil compressibility ($\times 10^{-4}$ 1/MPa)	19.3	Water viscosity (mPa·s)	0.15
Formation water compacting factor ($\times 10^{-4}$ 1/MPa)	4.6	Rock compacting factor ($\times 10^{-4}$ 1/MPa)	9.08

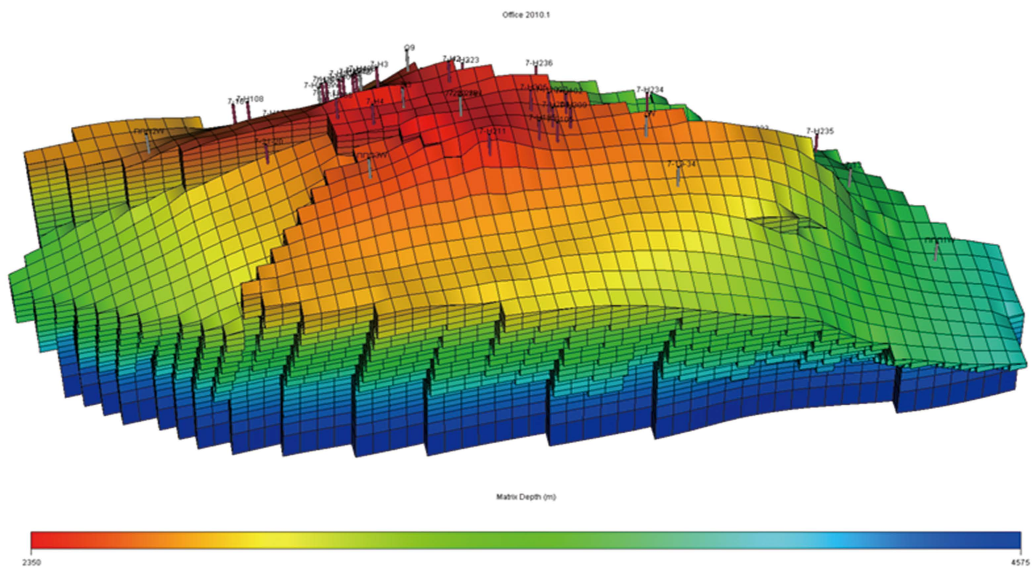

Figure 2
Numerical Model of Xinggu 7 Buried Hill Reservoir

Curve correlation of daily oil production and cumulative oil production by natural energy development and two kinds of gas injection development as shown in Figure 3. The development index of natural energy development, crestal gas injection development and tridimensional gas injection separately indicated with purple, green, and red curve. After gas injection, daily oil production stopped fast dropping down and began rising again and entering a stable production phase and a low-amplitude decline phase. Most notably is that the daily oil production in tridimensional gas injection (upper gas injection combined with middle-lower gas injection) is obviously higher than that of simple upper gas injection in quite a long time (about 16 years), it reflects from the macroscopic view that gas injection in the waterflooded layers formed a natural gas-water slug drive can inhibite water breakthrough in fractures and water sealing of oil in matrix.

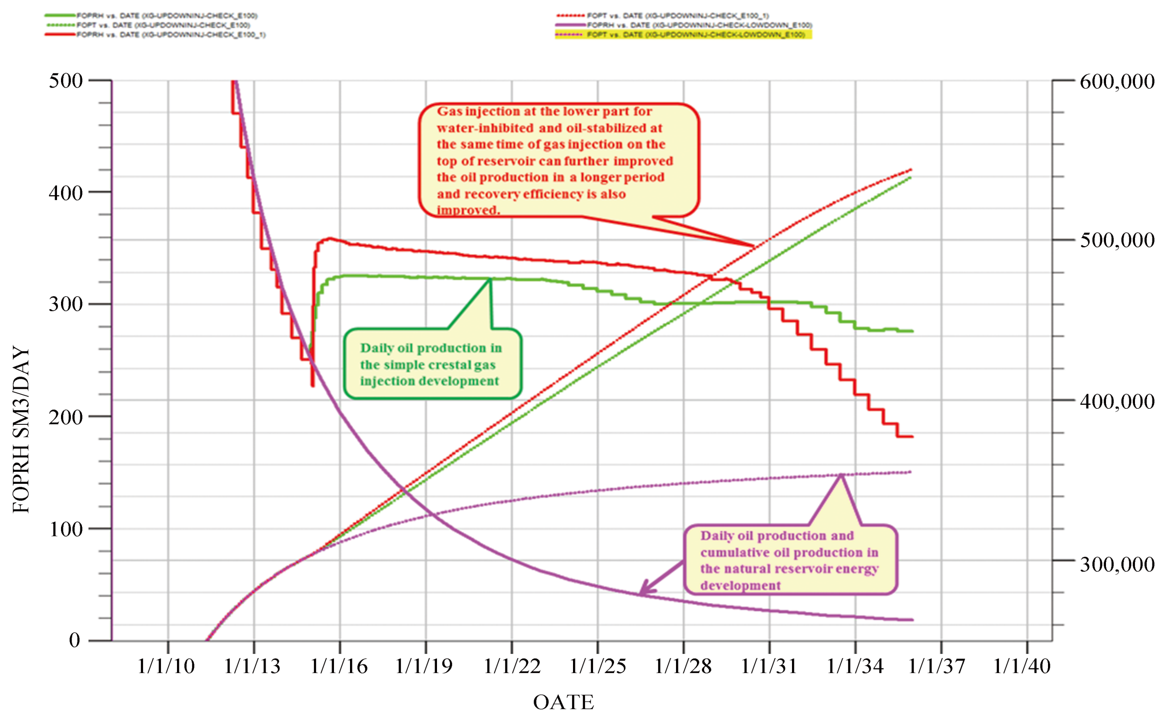

Figure 3
Correlation of Curve Changing of Daily Oil Production and Cumulative Oil Production in Two Development Ways and Two Gas Injection Systems

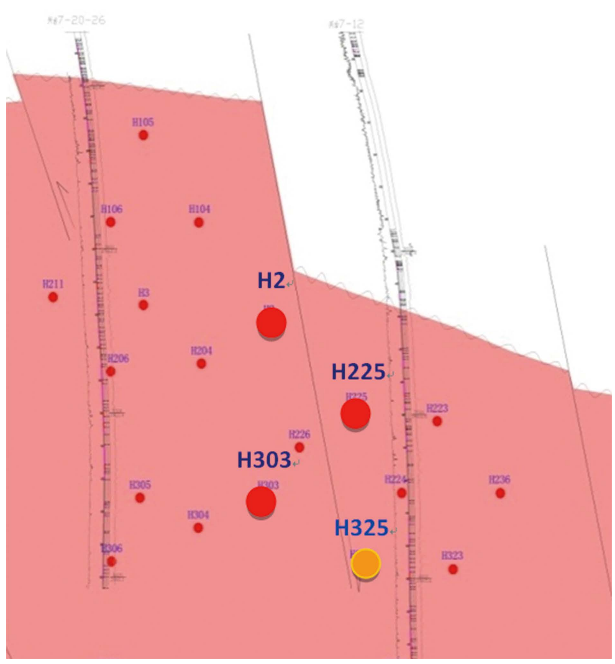

Figure 4
Profile Map of Xinggu 7 Buried Hill Reservoir
Note. Gas Injection Wells and Oil Wells are Separately Indicated by Yellow Dot and Red Dot.

For verifying the validity of the tridimensional gas injection system especially the middle-lower gas injection, nonhydrocarbon gas driving pilot testings for 3 well groups has been launched in Xinggu 7 buried hill reservoir since March, 2014. Until November in the same year, the daily nitrogen injection volume is 9.7 × 10^4 m^3, and cumulative nitrogen injection volume is 837.5 × 10^4 m^3, gas injection has gained a good effect in 5 wells around H325 well with the maximum injection volume (cumulative gas injection volume is 580 × 10^4 m^3); Daily increased oil production is 15.8 t, and cumulative increased oil production is 1,600 t. Among which, daily oil production and oil pressures are both increased in H225 well and H2 well upon the gas injection well (Figure 4), production decline of lateral wells slowed down even kept a stable decline while the bottom pressure changed a little. H303 well located in the side top of H325 gas injection well, has been completely flooded, the well was opened after four months of gas injection and found oil with a daily production of 2-6 t, water cut decreased from 100% to 80% nearby.

CONCLUSION

(a) Geological characteristics of reservoirs differ in thousands ways, it is necessary to design gas injection system according to their own characteristics. Simple crestal gas injection could be not satisfied the requirement of complementing formation energy timely and controlling the water channeling in the ultra thick fractured reservoir developed with bottom water.

(b) Tridimensional gas injection is a kind of new tridimensional gas injection system applied in the middle-lower part of the reservoir during the process of gas injecting on the reservoir top. Physical modeling experiment, numerical modeling prediction and field testing results indicated that tridimensional gas injection system could increase the microscopic sweep efficiency, oil production rate and recovery efficiency.

(c) Gas injection well should be deployed on the main body of the reservoir, giving consideration to every area on the plane to guarantee reserves controlling degree and producing degree, optimizing favorable areas of the reservoir in vertical, keeping an advisable distance between the gas injection well and the adjacent production well to reduce the risk of gas channeling.

(d) For obtaining an ideal gas injection effect, in addition to optimizing the injection medium and the gas injection mode, elaborat designing of several parameters of gas injection well in each part is necessary such as gas injection velocity and control gas injection pressure.

REFERENCES

[1] Ren, F. X. (2012). Discussions on tridimensional reservoir development models. *Petroleum Exploration and Development*, *39*(3), 338-345.

[2] Xu, N. (2014). Present situation and research progress of tridimensional reservoir development. *Fault-Block Oil and Gas Field*, *21*(5), 322-325.

[3] Shen, P. P. (2006). Technological developments in enhanced oil recovery. *Petroleum Industry Press*, (9), 235-256.

[4] Yuan, S. Y., Song, X. M., & Ran, Q. Q. (2004). Development technology for fractured reservoirs. *Petroleum Industry Press*, (12), 216-228.

[5] Yue, X. G., Wang, Y. F., & Wang, K. L. (2007). Fundamental study on enhanced oil recovery. *Petroleum Industry Press*, (8), 151-171.

[6] Lv, Y. F., Fu, G., Fu, X. F., & Sun, Y. H. (2013). Conducting and sealing effect of faults on hydrocarbon. *Petroleum Industry Press*, (8), 95-118.

[7] Wang, H. F., & Qu, Z. Y. (1997). The metamorphic rock reservoirs in Wangzhuang. *Petroleum Industry Press*, (12), 60-84.

[8] Jia, A. L., & He, D. B. (2013). Natural gas development theory and practice. *Petroleum Industry Press*, (5), 213-223.

[9] Sun, L. D. (2003). Development of gas condensate field in Tarim basin. *Petroleum Industry Press*, (2), 88-126.

[10] Chen, Y. Q. (2005). The practice of petroleum reservoir engineering. *Petroleum Industry Press*, (11), 357-369.