ENVIRONMENTAL AND EARTH SCIENCES RESEARCH JOURNAL
Vol.2, No.1, 2015, pp.1-6
http://dx.doi.org/10.18280/eesrj.020101

A NEW METHOD FOR DELIVERABILITY EVALUATION OF OFFSHORE GAS RESERVOIR WITH HIGH TEMPERATURE AND PRESSURE

Peng Xiaodong, Wang Xinguang, Tong Luyi, Li Hua, Li Hao, Lv Xindong and Chen Yuxi

CNOOC Ltd._ Zhanjiang, Zhanjiang Guangdong 524057, China.

Email: pengxd@cnooc.com.cn

ABSTRACT

In the early evaluation stage of offshore gas reservoirs, the DST test is mainly utilized to evaluate gas well deliverability. However, due to the specificity of offshore operations, the quality of DST test is generally poor, resulting in the anomaly in deliverability calculation, particularly in the high temperature and high pressure gas reservoirs. Since conventional binomial or exponential deliverability equation cannot be applied; and the open flow capacity can only be calculated by one-point method experience formula of other blocks. Therefore, the accuracy is hard to be guaranteed. On the basis of the binomial deliverability equation, this study proposed an advanced deliverability equation named stable point pseudo pressure deliverability equation, which means that as long as there is stable well testing data and pressure build up data gathering from one choke, the absolute open flow can be accurately calculated, and that it can achieve the same effect with the normal deliverability test. Practices have shown that this method can successfully solve the abnormality in deliverability calculation of offshore gas reservoirs with high temperature and high pressure.

Keywords: Deliverability evaluation, High temperature and high pressure, Pseudo-pressure, Stable point, Equivalent formation coefficient, New method, Yinggehai Basin.

1. INTRODUCTION

Deliverability evaluation is the fundamental basis for reservoir evaluation and development plan compilation. Presently, binomial deliverability equation, exponential deliverability equation and "one-point method" are mainly applied to evaluate deliverability at home and abroad [1-6]. Binomial deliverability equation is based on the theory of layer flow-inertia turbulent flow, and it is derived rigorously from permeation fluid mechanics [1-6]; whereas, exponential deliverability equation and "one-point method" are empirical equations [1-6, 8-10]. In practical application, binomial deliverability equation fits the straight line by using 3-5 testing data's, in order to get the coefficient and calculate open-flow capacity [1-6].

In the early evaluation stage of offshore gas reservoirs, the DST test is mainly utilized to evaluate gas well deliverability. Offshore DST testing procedure is normally "trinal flow and trinal shut-in": The first flow is oil drainage, the first shut-in is formation static pressure measurement; the second flow is deliverability calculation, the second shut-in is transient well test to get physical parameters of reservoir.; the third flow is to get samples. In theory, offshore DST can precisely evaluate deliverability. However, due to the high-expenditures and high risks of offshore operations, factors like numbers of testing wells and layers, times of well open-up and shut-down, timing, and maximum productivity are seriously restricted, thus, the quality of testing results are rather poor, furthermore, this will lead to the anomaly in deliverability calculation, particularly in the high temperature and high pressure gas reservoirs. As for new blocks, the open flow capacity can only be calculated by borrowing empirical one-point method formula of other blocks, and its accuracy is generally poor.

On the basis of the binomial deliverability equation, this study put forward an advanced deliverability equation named stable point (pseudo pressure) deliverability equation, which can achieve the same effect with conventional the binomial deliverability equation. Practices have shown that this method can successfully solve the abnormality in deliverability calculation of offshore gas reservoirs. Therefore, this new method is suggested to apply in future deliverability analysis.

2. THE PROPOSAL OF STABLE POINT (PSEUDO PRESSURE) METHOD

2.1 Binomial deliverability equation

When describing underground flow in conventional gas reservoir, pseudo pressure is the most appropriate pressure expression [1-6]. Pseudo pressure applies to gas of different components, pressure, and temperature [1-6], where the definition is [1-6]:

$$\psi = 2\int_{p_0}^{p} \frac{p}{\mu_g z} dp \tag{1}$$

Based on the layer flow-inertia flow-turbulent flow (LIT) analysis of natural gas, and through rigorous theoretical derivation, deliverability equation of gas wells can be deduced, namely binomial deliverability equation (Forchheimer Equation) [1-7].

Binomial deliverability equation of pseudo pressure expression is:

$$\psi_R - \psi_{wf} = AQ_g + BQ_g{}^2 \tag{2}$$

$$A = \frac{29.22\overline{T}_f}{Kh}(\lg\frac{0.472r_e}{r_w} + \frac{S}{2.302}) \tag{3}$$

$$B = \frac{12.69\overline{T}_f}{Kh} \cdot D \tag{4}$$

$$D = \frac{1.35\times10^{-7}\gamma_g}{K^{0.47}\phi^{0.53}hr_w\mu_g} \tag{5}$$

Coefficient A and B is to describe Darcy Flow (layer flow) and Non-Darcy Flow (turbulent flow) respectively, and they are relative to the property of natural gas, the characters of formation and wells, as well as engineering factors[1-7]. Particularly, the values must be greater than zero, otherwise, they do not comply with the physical significance[1-6].

The expression of absolute open flow is[1-6]:

$$Q_{AOF} = \frac{-A + \sqrt{A^2 + 4B(\psi_R - \psi_{sc})}}{2B} \tag{6}$$

Since coefficients A and B are hard to secured precisely, Expression (2) is converted to liner expression:

$$\frac{\psi_R - \psi_{wf}}{Q_g} = A + BQ_g \tag{7}$$

During the DST testing procedure, conventional backpressure well testing can be followed: changing the chokes from small size to larger size to get 3~5 stable testing data (Pwfi,Qgi) [1-6]. When processing the data, firstly, converting the pressure to pseudo pressure, then regressing the $\frac{\psi_R - \psi_{wf}}{Q_g}$ ～Qg relationship curve, and the corresponding intercept and slope are the values of coefficients A and B, consequently, the absolute open flow Q_{AOF} can be secured [1-6].This method avoid the error of calculating A and B directly from parameters, besides, curve regression can avoid testing errors to some extent.

This method demands that during the deliverability test, drawdown pressure is in the safe and reasonable range, and that it should present the typical coverage[11]. However, due to the high risks and expenditure of offshore test, the duration and production of testing are strictly limited, leading to the fact that accurate stable state is hard to be secured and that the coverage of drawdown test tends to be small, especially for high temperature and high pressure gas wells, the phenomenon is noticeable. Combined with other factors such as liquid accumulation[2], Slope B tends to be less than zero, which doesn't comply with its physical meaning [1-6], and the method above cannot be applied to calculate open –flow capacity.

2.2 Stable point (pseudo pressure) deliverability equation

To solve the problem of abnormality in deliverability calculation, and the study put forward the idea of stable point (pseudo pressure) deliverability equation. This equation is modified on the basis of binomial deliverability equation, with stable point data, equivalent formation coefficient Kh' is calculated, and then coefficient A and B will be secured. This method can achieve the same effect with conventional method (liner fitting to get A and B, furthermore, it is concisely and widely applicable.

The derivation processes are as follows:

$$A = \frac{29.22\overline{T}_f}{Kh}(\lg\frac{0.472r_e}{r_w} + \frac{S}{2.302}) = \frac{A'}{Kh} \tag{8}$$

$$B = \frac{12.69\overline{T}_f}{Kh} \cdot D = \frac{B'}{Kh} \tag{9}$$

Kh' is defined as equivalent formation coefficient[2], adopting one stable testing point (Pwfo, Qgo) , and formation pressure point (PR, 0) , where,

$$Kh' = \frac{A'Q_{go} + B'Q_{go}^2}{\psi_R - \psi_{wfo}} \tag{10}$$

There is difference between Kh' and the real Kh which reflects the combination effect of various formation factor, and the errors of parameters such as rw,re,S can be hedged by the difference[2].

Putting Kh' into A' and B', deliverability equation coefficient A1and B1of stable point (pseudo pressure) are secured:

$$A_1 = \frac{A'}{Kh'} \tag{11}$$

$$B_1 = \frac{B'}{Kh'} \tag{12}$$

Finally, stable point (pseudo pressure) deliverability equation is secured as:

$$\psi_R - \psi_{wf} = A_1Q_g + B_1Q_g{}^2 \tag{13}$$

According to Formula (14), open-flow capacity is derived.

$$Q_{AOF} = \frac{-A_1 + \sqrt{A_1{}^2 + 4B_1(\psi_R - \psi_{sc})}}{2B_1} \tag{14}$$

This method solves the anomaly in deliverability testing, at the same time, it also extends the applicable range of binomial deliverability equation: I t can be used as long as there is one stable testing point. Particularly, PR and Tf are acquired from DST or MDT testing; μg, Z and γg can be either acquired from gas sample testing or calculated from empirical formula; Φand h are acquired from logging; K, Re and S are acquired from well test interpretation, D can either be calculated from empirical formula (5) or interpreted from well test[1-6].

3. THE APPLICATION OF STABLE POINT (PSEUDO PRESSURE) METHOD

Yinggehai Basin is located in the West of South China Sea, and its mid-deep gas reservoir is classified as high temperature and high pressure gas reservoir. Its burial depth is about 3,000 m, its temperature is over 140℃, the pressure is above 50MPa, the pressure coefficient is about 2, and the temperature gradient is 4.2℃/100m[12-14]. So far, 11times of DST test on 6 wells have been performed, however, as to most the wells, either the quality of testing is poor (Well D-X-13) or the working system is unreasonable (Well D-X-1), as a result, both binomial and exponential deliverability equation cannot be applied to calculate deliverability. In addition, since there is no “one-point method” empirical parameters in this region, open-flow capacity can only be calculated by borrowing empirical equations of high temperature and high pressure wells in other regions, and its accuracy tends to be poor. The following content takes Well D-X-13 and Well D-X-1 as examples, and it discusses the application of stable point (pseudo pressure) method.

3.1 Well D-X-13

Dual flow and dual shut-in test curve of Well D-X-13 is as follows (Fig.1), and the quality of the test is poor. Fig.2 shows that pseudo pressure binomial deliverability coefficient B is less than zero, thus, conventional binomial equation is not applicable. However, by using data under the second and third working system, normal binomial deliverability equation can be achieved (Fig.3), and its open flow capacity is 5.70×104m3/d.

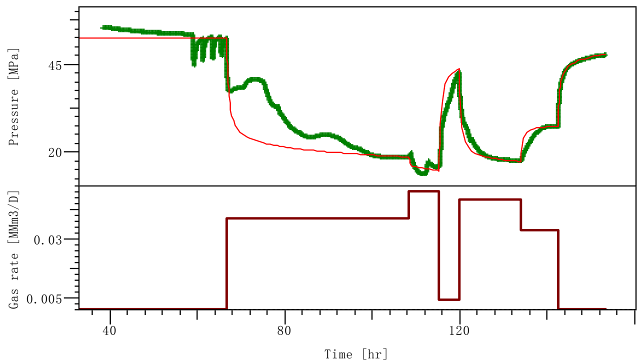

Figure 1. The bottom hole pressure test and interpretation fitting curves of Well D-X-13

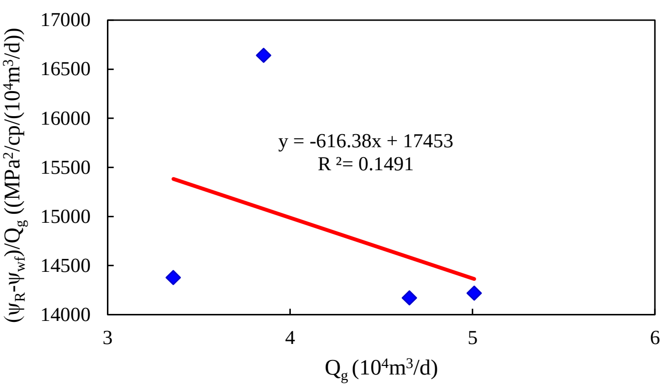

Figure 2. The binomial deliverability index curve of Well D-X-13

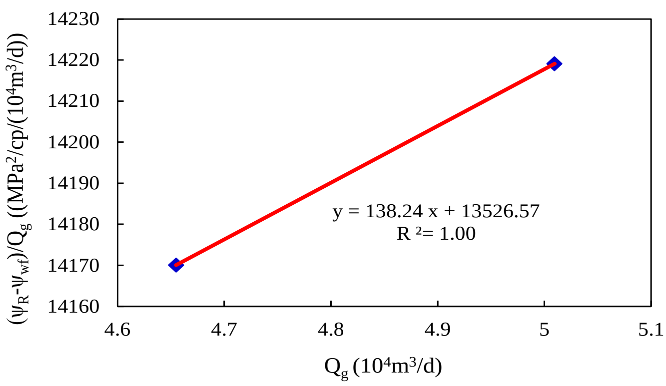

Figure 3. The binomial deliverability index curve of Well D-X-13

Open flow capacity under different working system was calculated by applying stable point (pseudo pressure) method. The calculation parameters are shown in Tab. 1, and the result is shown in Fig. (4). The picture shows that apart from obvious anomaly under the first working system, results of open flow capacity under other working systems are almost the same, and that they check fairly well with actual testing ones, besides, the results are almost the same with results calculated from Fig. (3). It proved that stable point (pseudo pressure) method has a high degree of reliability. Since pressure exerted on the third testing point is relatively stable, and its productivity is high, consequently, open flow capacity calculated from this point is selected as the final result and its value is 5.71×104m3/d.

Table 1. Deliverability calculation parameter table of Well D-X-13

parameters	P_R	R_e	R_w	μ_g	Z	T	S	D	γ_g	φ	K	h
unit	Mpa	m	m	mPa S		K		$\times10^{-4}$			md	m
value	51.963	16.7	0.1	0.101	1.055	406.41	0.76	0.0452	1.19	0.16	0.06	33.5

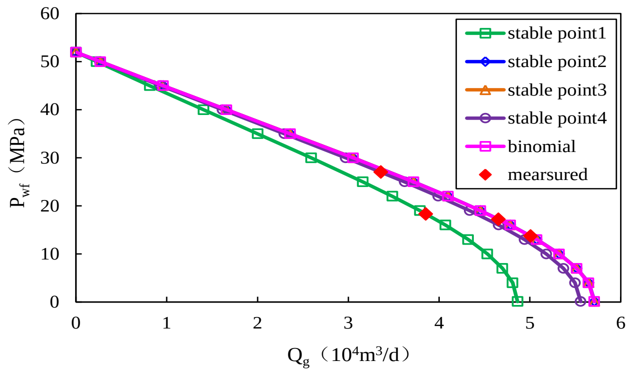

Figure 4. The IPR curves of Well D-X-13

3.2 Well D-X-1

The testing quality of Well D-X-1 is fairly well (Fig. 5), however, in view of the safety of offshore operations, the maximum productivity of testing is limited, leading to the fact that the both pressure differential and pressure coverage are rather low; furthermore, anomaly aroused during the deliverability calculation[11] (Fig. 6), and pseudo pressure binomial deliverability coefficient B is less than zero.

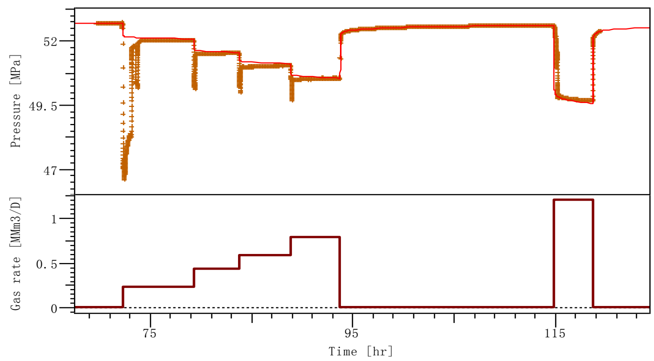

Figure 5. The bottom hole pressure test and interpretation fitting curves of Well D-X-1

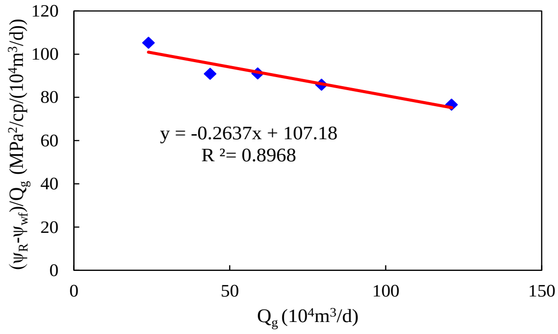

Figure 6. The binomial deliverability index curve of Well D-X-1

Open flow capacity under different working system was calculated by applying stable point (pseudo pressure) method. The calculation parameters are shown in Tab. 2, and the result is shown in Fig. (8). The picture shows as follows, since the duration time of the third flow is short, bottom hole pressure is unstable, the result tends to be larger; as to the second flow under first working system , since the pressure differential is low, its degree of accuracy is rather low; as to the second flow under the second, the third and the fourth working system, the calculated open flow capacity didn't appear to be much different from each other, and results check fairly well with actual testing ones. In view of the fact that bottom hole pressure of the second flow under the fourth working system is more stable than the others, consequently, open flow capacity calculated from this point is selected as the final result and its value is 898.36×104m3/d.

Table 2. Deliverability calculation parameter table of Well D-X-1

parameters	P_i	R_e	R_w	μ_g	Z	T	S	D	γ_g	φ	h	K
unit	Mpa	m	m	mPa S		K		$\times10^{-4}$			m	md
value	52.702	510.4	0.1	0.0304	1.191	422.68	8	0.0044	0.6365	0.1782	27.2	43.9

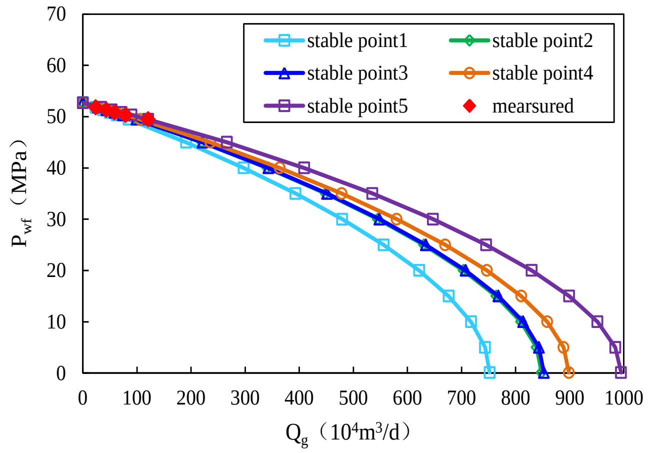

Figure 7. The IPR curves of Well D-X-1

4. CONCLUSIONS AND SUGGESTIONS

(1) With respect to offshore high temperature and high pressure gas reservoirs, due to the expenses and safety issues, the quality of DST testing of appraisal wells is rather poor, thus, conventional binominal equation method is hard to apply in deliverability calculation. The study put forward the stable point (pseudo pressure) method; this method can effectively solve the anomaly in deliverability calculation of offshore high temperature and high pressure gas reservoirs, furthermore, it is concisely and widely applicable.

(2) It is suggested that in the future DST deliverability test, the duration of build-up should be prolonged, so as to obtain high quality well test interpretation curves; it is also suggested that at least one testing point should achieve stable status before the build-up; In addition, careful study of reasonable testing working system should be accomplished beforehead, so as to make sure that drawdown pressure is in safe, reasonable and typical coverage.

NOMENCLATURE

p —Formation pressure, MPa ; p_R —Original formation pressure, MPa ; p_{wf} —Well bottom flow pressure, MPa ; ψ —Pseudo pressure, $MPa^2/(mPa\,s)$; ψ_R —Pseudo Pressure of Formation Pressure, $MPa^2/(mPa\,s)$; ψ_{wf} — Pseudo Pressure of well bottom flow pressure, $MPa^2/(mPa\,s)$; ψ_{sc} —Pseudo pressure of atmospheric pressure, $MPa^2/(mPa\,s)$; $\overline{T}_f$ —Formation temperature, K ; μ —Gas viscosity, $mPa\,s$; Z —Gaseous z-factor; γ_g —Gas relative density; D —Non-Darcy flow factor, $(10^4m^3/d)^{-1}$; β —Turbulent coefficient, m^{-1} ; h —Net pay thickness, m ; S —Skin factor; ϕ —Porosity; K —Permeability, md ; r_w —Well bore radius, m ; r_e —Well controlled radius, m ; Q_g —Gas production, 104 m^3/d ; Q_{AOF} —Open flow capacity, 104 m^3/d ; Kh' —Equivalent formation coefficient, $10^{-3}\mu m^2\cdot m$; A , B , A_1 , B_1 , A' , B' —Coefficient.

REFERENCES

1. HUANG Binguang, Ran Xinquan, Lixiao Ping, Analysis Method of Gas Reservoir Engineering [M], Beijing: Petroleum Industry Press, 2004: 70-84.
2. ZHUANG Huinong, Gas Reservoir Dynamic Description and Well Test [M], Beijing: Petroleum Industry Press, 2009: 56-94.
3. Tarek. Ahmad, write. Ran Xinquan, He Jiangchuang, Translation. Reservoir Engineering Handbook [M], Beijing: Petroleum Industry Press, 2002: 337-355.
4. L. John Robert, A. Voight Berg, write. Wang Yupu, Guo Wankui, Pang Yanming, et al., Translation, Gas Reservoir Engineering [M], Beijing: Petroleum Industry Press, 2007: 331-375.
5. LI Chuanliang. The Principles of Reservoir Engineering [M], Beijing: Petroleum Industry Press, 2005: 256-276.
6. LIU Nengqiang. Applied Modern Well Testing Interpretation Method (Fifth Edition) [M], Beijing: Petroleum Industry Press, 2008：11-28, 269-288.
7. WU Wenming, Yang Yu, Liu Xin, etc. The Productivity Analysis in Tight Gas Reservoir by Using Wire-line Logging and Trial Production Data [J], Procedia Engineering, 2012 (31): 29-37. DOI: 10.1016/j.proeng.2012.01.986.

8. LI Yong, Liu Qiguo, Gao Guoxi, et al. Discussion on Open-Flow Potential Equations of Gas Wells in Tarim Basin[J], Xinjiang Petroleum Geology. 2004. 25 (1): 72-73.
9. LIANG Haiyun, a Xiaoping, Li Xiangfang. Principles for Application of Single-point Test and Errors of Deliverability Evaluation of Gas Exploration Well [J], Natural Gas Industry. 2006. 26 (4): 92-95.
10. HU Jianguo, Zhang Zonglin, Zhang Zhenwen, et al. A New Method on Processing the Data from One-point Deliverability Test in Gas Fields [J], Natural Gas Industry. 2008. 28 (2): 111-113.
11. LI Xiangfang, Sui Xiuxiang, Tang Dezhao, et al. Theory and Method of Rational Working System Design During HTHP Testing of Gas Well[J], China Offshore Oil and Gas (Engineering). 2003, 15(5): 30-32.
12. XIE Yuhong, Zhang Yingzhao, Li Xushen, et al. Main controlling factors and formation models of natural gas reservoirs with high-temperature and overpressure in Yinggehai Basin [J], Acta Petrolei Sinica. 2012, 33 (4): 601-609.
13. WANG Zhenfeng, Pei Jianxiang. A new accumulation model of high pressure gas in Huangliu Formation of the middle-deep interval in Yinggehai basin [J], China Offshore Oil and Gas. 2011, 23 (4): 213-217.
14. PEI Jianxiang, Yu Junfeng, Wang Lifeng, et al. Key challenges and strategies for the success of natural gas exploration in mid-deep strata of the Yinggehai Basin[J], Acta Petrolei Sinica. 2011, 32 (4): 573-579.