Research and Application of a New Method for Calculating Dynamic Reserves

Xiaoyan Yang*, Jianmin Zhang, Hui Cai and Yuejie Wang

Tianjin Branch of CNOOC Ltd

Abstract: Reserves are the basis of oilfield development, and determination of reserves accurately has great significance for future adjustment of oil fields development. Due to distinct characteristics of offshore oilfield development, it is difficult to obtain dynamic reserves accurately using conventional methods. To overcome the limitations of existing methods, in this paper, a new model for calculating dynamic reserves is established through theoretical derivation with innovative introduction of relative permeability ratio and the quadratic power function of water saturation based on Buckley-Leveret function and frontal movement equation. The result shows that this approach is simple to use and with good applicability, and only needs typical oil field dynamic data. The results of the study facilitates better recalculation of oil field reserves and implementation of oilfield adjustment well. More importantly, it has laid out a new methodology for increasing oil production and exploration in Bohai oil field and provided theoretical foundation for subsequent oilfields' efficient development.

Keywords: Dynamic reserves, Leverett function, efficient development, Adjustment well exploration, offshore oil field.

1. INTRODUCTION

Reserves are the basis of oilfield development, and previous calculation of dynamic reserves has been extensively studied [1-7]. At present, the common methods used including material balance method, pressure drop method, well-testing data analysis method and water flooding curve method. However, these methods are limited in their use. The material balance method requires more parameters in the calculation of water-driven state reserves, and it is difficult to obtain accurate water influx volume. The pressure drop method requires sufficient flow pressure data, which is not applicable for oil wells without down hole pressure monitoring device. Well-testing data analysis method is very costly, especially for offshore oil field, well test data usually very limited, so the applicable scope of this method is limited. The water flooding curve method is only used in the middle and high water cut period [8], which error is very large in the low water-cut stage. Considering the particularity of offshore oilfield development, based on Leverett function and frontal movement equation, in this paper, we creatively introduce relative permeability ratio and the quadratic power function of water saturation and combined with the dynamic data of oilfield, a new model for calculating dynamic reserves is established. This method only needs relative permeability curve, water cut and accumulated oil production data, and it is very simple and with good applicability.

2. NEW MODEL OF DYNAMIC RESERVE

In the dynamic analysis of oil fields, water cut is an important parameter, which can be described with the Buckley–Leverett Function expression [9-10];

$$f_{\mathrm{w}} = \frac{1}{1+\left(\frac{K_{\mathrm{ro}}}{K_{\mathrm{rw}}}\right)\left(\frac{\mu_{\mathrm{w}}}{\mu_{\mathrm{o}}}\right)} \tag{1}$$

where: f_w is the water cut, K_{rw} is relative permeability to water, μ_w is the formation water viscosity, mPa.s; μ_o is the formation oil viscosity, mPa.s.

For the convenience of application, the ratio of relative permeability is often expressed as a function of water saturation. At the same time, to make the fitting more accurate and practical, the original expression is corrected as:

$$\frac{K_{\mathrm{ro}}}{K_{\mathrm{rw}}} = e^{aS_{\mathrm{w}}{}^{2}+bS_{\mathrm{w}}+\mathrm{c}} \tag{2}$$

where: S_w is water saturation, percent; *a, b, c*are regression parameters of the relative permeability curve, dimensionless.

Formula (3) can be achieved by combining formula (2) and formula (1):

$$f_{\mathrm{w}} = \frac{1}{1+\frac{\mu_{\mathrm{w}}}{\mu_{\mathrm{o}}}\cdot e^{aS_{\mathrm{w}}{}^{2}+bS_{\mathrm{w}}+\mathrm{c}}} \tag{3}$$

Further solution can be obtained:

---

*Address correspondence to this author at the Tianjin Branch of CNOOC Ltd; Tel: +86-186-0267-4486; E-mail: yangxy6@cnooc.com.cn

E-ISSN: 2409-787X/18

$$S_w = \frac{-b\pm\sqrt{A+4a\cdot\ln\frac{1-f_w}{f_w}}}{2a} \tag{4}$$

where: $A = b^2 - 4ac + 4a.\ln\frac{\mu_o}{\mu_w}$

Formula (3) derivation can be obtained:

$$f_w'（S_w）=(f_w-1)f_w(2aS_w+b) \tag{5}$$

where $f_w'(S_w)$ is the derivative of water cut to water saturation, dimensionless.

According to the Buckley-Leverett equation and frontal movement equation, after water breakthrough, the tangent of fractional flow function of the wetting phase [11-12] can be obtained as follows:

$$f_w'(S_w) = \frac{1-f_w}{\overline{S_w}-S_w} \tag{6}$$

where $\overline{S}_w$ is mean water saturation, f.

Formula (7) can be achieved by combining formula (5) and formula (6)

$$\overline{S_w} = S_w - \frac{1}{f_w(2aS_w+b)} \tag{7}$$

After combining formula (4) and formula (7), and with the help of big data analysis, the positive solution is obtained.

$$\overline{S_w} = \frac{-b+\sqrt{A+4a\cdot\ln\frac{1-f_w}{f_w}}}{2a} - \frac{1}{f_w\left(\sqrt{A+4a\cdot\ln\frac{1-f_w}{f_w}}\right)} \tag{8}$$

According to the requirements for the calculation of oil and natural gas reserves, the calculation of reserves by volume method is as follows:

$$N_o = 100A_o h\emptyset S_{oi}/B_{oi} = 100A_o h\emptyset(1-S_{wi})/B_{oi} \tag{9}$$

Where N_o is geological reserves of crude oil , 10^4m^3; A_o is oil-bearing area , km^2; his effective thickness, m; ϕ is effective porosity, f; S_{oi} is initial oil saturation, f; B_{oi} is initial oil formation volume factor.

The expression of residual reserves is as follows:

$$N_{or} = 100A_o h\emptyset S_{or}/B_{oi} = 100A_o h\emptyset(1-\overline{S_w})/B_{oi} \tag{10}$$

Where: N_{or} is the remaining geological reserves, 10^4m^3; S_{or} is residual oil saturation.

The accumulation of oil production of an oil field at a certain stage can be expressed as:

$$N_p = N_o - N_{or} = 100A_o h\emptyset S_{oi}(\overline{S_w}-S_{wi})/B_{oi} \tag{11}$$

Where: N_p is accumulative output of oil, 10^4m^3;

The further deformation of the formula (11) can be obtained:

$$N_p = N_o\cdot(\overline{S_w}-S_{wi})/1-S_{wi} \tag{12}$$

Formula (13) can be achieved by combining formula (8) and formula (12);

$$N_p = \frac{N_o}{1-S_{wi}}\cdot\frac{f_w\cdot\left(A+4a\cdot\ln\frac{1-f_w}{f_w}\right)-2a}{2a\cdot f_w\left(\sqrt{A+4a\cdot\ln\frac{1-f_w}{f_w}}\right)} - \frac{N_o}{1-S_{wi}}\cdot\left(\frac{b}{2a}+S_{wi}\right) \tag{13}$$

In the process of oilfield production, the water cut and the accumulated oil production data are abundant, and the formula (13) is represented as a primary equation:

$$Y = \mathrm{KX} + \mathrm{B} \tag{14}$$

Where Y= N_p, X $= \frac{f_w\cdot\left(A+4a\cdot\ln\frac{1-f_w}{f_w}\right)-2a}{2a\cdot f_w\left(\sqrt{A+4a\cdot\ln\frac{1-f_w}{f_w}}\right)}$,

K=$\frac{N_o}{1-S_{wi}}$,B=$\frac{N_o}{1-S_{wi}}\cdot\left(\frac{b}{2a}+S_{wi}\right)$;

The water cut is replaced by the formula, and the correlation curve of the accumulative oil production is drawn. The coefficient is obtained by fitting and regression, and the geological reserves are further obtained.

By correcting the relative permeability curve, this method is more suitable for all stages of oilfield development, and the oil reserve N$_O$ obtained is more water driving reserve concept. In the case of insufficient pressure data, this method is a good method for obtaining dynamic reserves.

3. CALCULATION EXAMPLE

Bozhong a oilfield is mainly controlled by tectonics and faults and is a layered structural reservoir. It is mainly divided into five well zones at the plane, and different well zones have different fluid interfaces and reservoir depths. Block 4 is a main well area in the oil

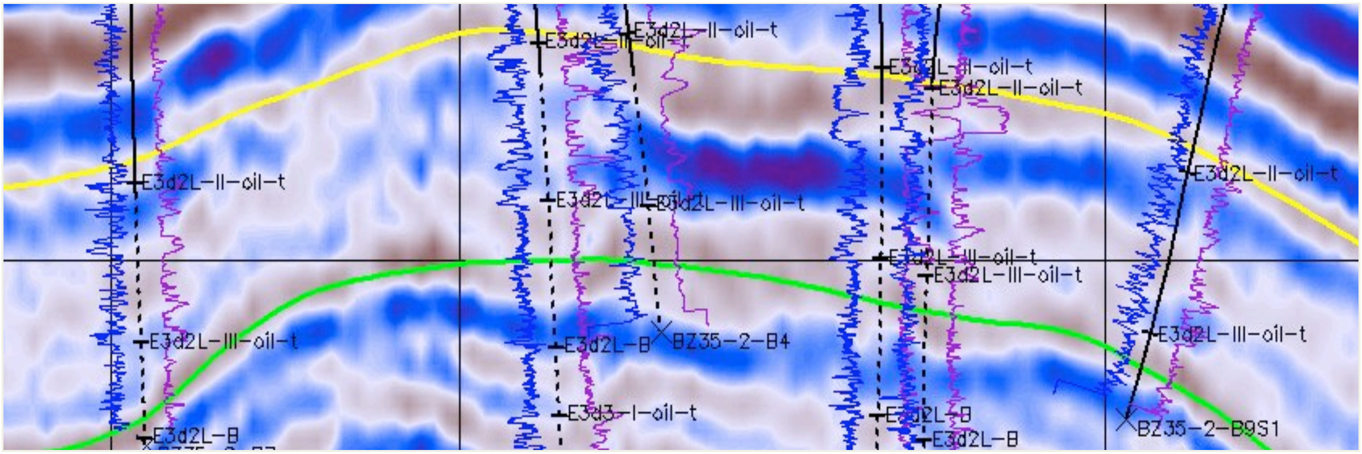

Figure 1: Seismic facies distribution diagram of theII oil group of Lower Dongying Formation.

field. The oil layers are mainly concentrated in theIIoil group of Lower Dongying Formation and IIIoil group of Dongying Formation in the longitudinal direction. The average porosity is 24.2% and the average permeability is 1806.7mD, which belongs to high porosity and permeability reservoir. The well area is developed by using irregular well pattern. Currently, there are 2 injection wells and 3 production wells with composite water cut of 38.5% and oil recovery of 28.8%. According to dynamic data analysis, there is a conflict between the static and dynamic feature. Due to the deep buried depth, formation distribution is unclear, especially for II oil group of Lower Dongying Formation; the seismic faciesin plane varies greatly. Although the distribution of formation is relatively stable, it is difficult to identify through seismic data (Figure **1**). Therefore, it is very important to recalculate the dynamic reserve through dynamic analysis, however, due to the lack of pressure data conventional dynamic reserve calculation method cannot be used, so the new method was used to recalculate the dynamic reserve.

Fitting was made (Figure **2**) based on relative permeability data (Table **1**), and a = 11.77, b = -32.084, c = 12.567 were obtained, then A = 575.98 is calculated.

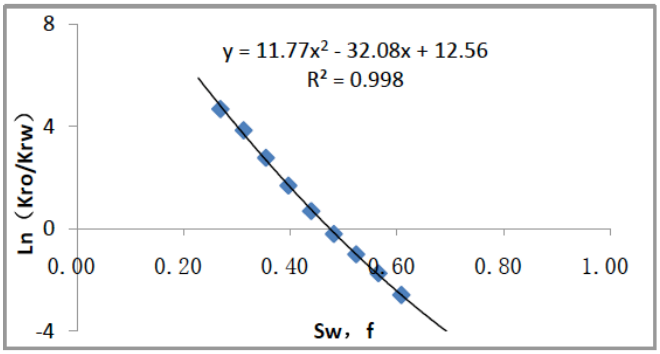

Figure 2: Phase-curve fitting curve.

Table 1: Relative Permeability Data

Sw	krw	kro	kro/krw	LN(kro/krw)
0.23	0.00	1.00	-	-
0.27	0.01	0.85	106.5	4.7
0.31	0.02	0.70	46.5	3.8
0.35	0.03	0.46	16.0	2.8
0.40	0.05	0.27	5.4	1.7
0.44	0.08	0.16	2.0	0.7
0.48	0.12	0.10	0.8	-0.2
0.52	0.17	0.06	0.4	-1.0
0.57	0.23	0.04	0.2	-1.7
0.61	0.31	0.02	0.1	-2.6
0.65	0.41	0.00	-	-
1.00	1.00	0.00	-	-

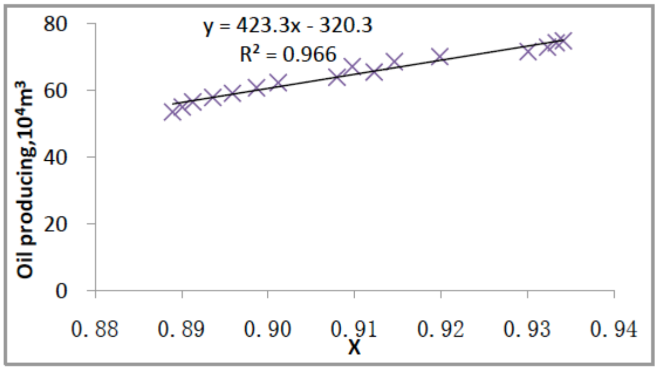

Figure 3: dynamic reserve fitting curve.

Substituting the obtained parameters into Eq. (13) and combining with the dynamic data, a relationship curve between water cut and oil recovery is established (Figure **3**). By linear regression, K = 423.36 is substituted into the irreducible water saturation and the dynamic reserve result is 3.259 million square meters, which increase nearly 1 million square meters compared with the previous understanding.

4. EXAMPLE APPLICATION

Combined with the latest geological reserves, oil-water contact and oil bottom encountered by development wells, the formations are better characterized. It is considered that it is possible to lower oil-water contact for drilled oil-bearing layers. Using numerical simulation technology (Table **2**), the sensitivity of oil-water interface lower depth was analyzed. The result shows that oil-water interface lower 10 m for layer 1, oil-water interface lower 30 m for layer 2, oil-water interface lower 25 m for layer 3 is reasonable. By applying the result in latest geological model, we reached out very good fitting.

According to the latest understanding of geological and reservoirs characteristics, combining with the remaining oil distribution in well area and reserve scale, three adjustment wells were deployed to further improve injection and production well pattern and increase producing reserves. In November 2017, three adjustment wells were completed, one of the injection wells interpreted oil-water interface which completely consistent with the understanding before drilling, so the accuracy of the method was further confirmed by adjustment well's implementation.

CONCLUSION

(1) In the process of dynamic reserve calculation, the quadratic power function of relative permeability ratio and water saturation is introduced for the first time, and a new model of dynamic reserve calculation is established through correlation derivation.

(2) The new method is especially suitable for fields with inadequate or even missing pressure data. The method is simple and practical.

(3) From the application effect, the reserves calculated by the method are accurate, reliable

Table 2: Sensitivity Analysis

Program	Program Description		Reserves	Average Water Cut of Model	Actual Water Cut	Fitting Error
			$10^4 m^3$	%	%	%
1	$E_3d_2^{I}$Ⅱ-2 push down 30m		302.92	52.5	38.5	36.4
2	$E_3d_2^{I}$Ⅱ-2 push down 30m	$E_3d_2^{I}$Ⅱ-1push down3.3m	306.7	50.3	38.5	30.6
3		$E_3d_2^{I}$Ⅱ-1 push down 6.6m	310.79	47.8	38.5	24.2
4		$E_3d_2^{I}$Ⅱ-1 push down 10m	315.19	44.1	38.5	14.5
5	$E_3d_2^{I}$Ⅱ-2 push down 30m , $E_3d_2^{I}$Ⅱ-1 push down 10m	$E_3d_2^{I}$Ⅱ-3 push down 8.3m	318.5	42.5	38.5	10.4
6		$E_3d_2^{I}$Ⅱ-3 push down 16.6m	322.13	40.6	38.5	5.5
7		$E_3d_2^{I}$Ⅱ-3 push down 25m	325.99	38.8	38.5	0.8

and effectively which can guide the deployment and implementation of the well adjustment wells, and the follow-up has a good promotion effect in the Bohai oil field.

REFERENCE

[1] Liu Zhenyu, Zhang Yingan and LvXiu feng. Using pressure dynamic data to estimate single well controlled reserves. J drilling technology 2004, 27(1): 24-27.

[2] Gao Wenjun and Wang Jin. Basis and application of the theory of discriminant theory of yield decline equation. J Xinjiang oil and geology 1999; 20(6): 518-521.

[3] Wang Nutao, Zhang Fengbo and Luo Zhifeng. Research on new method for determining single well controlled reserves and other wells. J Journal of Southwest Petroleum University 2007; 29(5): 77-78.

[4] Luo Yinfu and Ma Zhongliang. Technology a new method to determine oil reserves of single well. J Xinjiang petroleum geology 2007; 28(6): 736-737.

[5] GuJianwei, Guokun Qin and Zhang Yongjun. From the result of numerical simulation of reservoir water flooding index. J Henan petroleum 2004; 18(4): 35-36.

[6] Dooley, Chen Qinghua and Dai shengqun. Application of oil-water relative permeability curve and dynamic data to determine the water flooding status. J PGRE 2006; 10(4): 45-46.

[7] Penuela G ,IdroboE A ,Ordonez A, et a1. A n ew material balanceequation for naturally fractu red rese rvoirs u sin g a du al—systemapproach. R SP E68831; 2001.

[8] He Shengping, Zhang Minjuan. Using water drive curve to study the dynamic J. off shore oil and gas in the north of dike 1993; 7(5): 40-46.

[9] Yang Shenglai and Wei Junzhi. Oil layer physics [M]. Beijing: Petroleum Industry Press 2004: 261-263.

[10] Zhang Jianguo, Du Dianfa, Hou Jian, *et al*. Percolation mechanics in oil and gas layers, [M], Shandong: China University of Petroleum press 2006: 214-217.

[11] Craft B and Hawkins MF. Applied petroleum reservoirs engineering M. New Jersey:Prentice-Hall Inc 1991: 340-341.

[12] Chen Yuanqian and Li Shui. Modern reservoir engineering [M] Beijing: Oil Industry Press 2001; 73-74.

Received on 10-01-2018 Accepted on 11-01-2018 Published on 17-01-2018

DOI: http://dx.doi.org/10.15377/2409-787X.2018.05.2