Reserves Estimation of Two-Layer Commingled Gas Well by Material Balance Method

Sun Hedong[1(✉)], Cui Yongping[2], Cao Wen[1], and Li Yanchun[3]

[1] Research Institute of Exploration and Development,
PetroChina, Beijing, China
{sunhed, caow69}@petrochina.com.cn
[2] PetroChina Exploration & Production Company, Beijing, China
cuiyp@petrochina.com.cn
[3] Changqing Downhole Technology Company, CNPC Chuanqing Drilling
Engineering Company Limited, Beijing, China
liyanch@cnpc.com.cn

Abstract. Traditional material balance method takes the gas reservoir as a container and completely ignores the heterogeneity between the layers, which results in great uncertainty of the single-well reserves calculation as well as the evaluation of the producing reserves of each zone for commingling gas wells. Thus, a new approach is developed to measure stratified average formation pressure with one run-in-hole and to calculate the single-well dynamic reserves. The principle of the new method is that: (1) assume that the producing pay consists of two layers, where no fluid exchange exists between the layers, and each layer meets the conditions of the traditional material balance method; (2) measure the stratified average formation pressure (at least twice); (3) On that basis, draw the relationship diagram of the single-layer average formation pressure changes (func1(p_1, p_2)) ~ cumulative production & pressure(func2(p_1, G_p)); (4) the stratified dynamic reserves are calculated by the slope and intercept of func1 and func2 and further stratified production degree can be analyzed. Two-layer situation simulated case study shows that the method is with high accuracy and can improve the effective development of similar gas reservoirs.

This paper was prepared for presentation at the 2018 International Field Exploration and Development Conference in Xi'an, China, 18–20 September, 2018.

J. Lin (ed.), *Proceedings of the International Field Exploration and Development Conference 2018*, Springer Series in Geomechanics and Geoengineering, https://doi.org/10.1007/978-981-13-7127-1_76

Keywords: Two-layer gas reservoir · Commingled well · Material balance · Dynamic reserve

1 Introduction

Commingled production method has been widely used in the Sebei gas field [1], Southwest oil & gas fields [2] and Daniudi gas field [3]. Multilayer reservoirs can be divided into two types according to the cross-flow between layers: cross-flow reservoir and no cross-flow (commingled) reservoir. Dynamic characteristics of commingling wells are different due to the average pressure difference, the permeability differences, and each layer dynamic reserves differences between the layers [4–8]. The material balance method is the main method to calculate the dynamic reserves with degree of reserve recovery greater than 5% [9]. However, the traditional material balance equation cannot accurately predict the performance of commingled well [10]. This paper presents a new method for the single-well dynamic reserves calculation and layered degree of reserve recovery analysis for two-layer commingled gas reservoirs, which provide a foundation for the reasonable and efficient development of multi-layered gas reservoirs.

2 Material Balance Equation of Two-Layer Commingled Reservoir

2.1 Physical Model

Gas reservoir consists of two layers, there is no interlayer fluid exchange, and each layer is in line with the traditional material balance conditions, as shown in Fig. 1. Assumptions: ① the reserves of the layers are G_1, G_2, respectively, and the reserve in barrier is ignored; ② the single-well production is q (the layer productions are q_1, q_2, respectively); ③ the single-well cumulative production is G_P (the layer cumulative productions are G_{P1}, G_{P2}, respectively); ④ the water effect is negligible. ⑤ the initial formation pressure is the same.

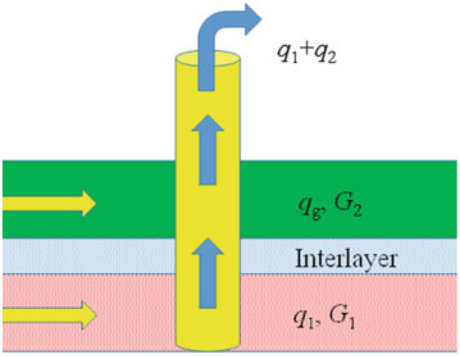

Fig. 1. Two-layer material balance physical model

2.2 Mathematical Model

Layered material balance equation is:

$$\left(\frac{P}{Z}\right)_1 = \left(\frac{P}{Z}\right)_i \left(1 - \frac{G_{P1}}{G_1}\right) \tag{1}$$

$$\left(\frac{P}{Z}\right)_2 = \left(\frac{P}{Z}\right)_i \left(1 - \frac{G_{P2}}{G_2}\right) \tag{2}$$

$$G_p = G_{P1} + G_{P2} \tag{3}$$

According to Eqs. (1), (2) and (3) can be derived as,

$$G_1 \frac{\left(\frac{P}{Z}\right)_i - \left(\frac{P}{Z}\right)_1}{\left(\frac{P}{Z}\right)_i - \left(\frac{P}{Z}\right)_2} + G_2 = G_p \frac{\left(\frac{P}{Z}\right)_i}{\left(\frac{P}{Z}\right)_i - \left(\frac{P}{Z}\right)_2} \tag{4}$$

Assume

$$Y = \frac{G_p \left(\frac{P}{Z}\right)_{\mathrm{i}}}{\left(\frac{P}{Z}\right)_{\mathrm{i}} - \left(\frac{P}{Z}\right)_2}; \quad X = \frac{\left(\frac{P}{Z}\right)_{\mathrm{i}} - \left(\frac{P}{Z}\right)_1}{\left(\frac{P}{Z}\right)_{\mathrm{i}} - \left(\frac{P}{Z}\right)_2}$$

Then

$$Y = G_1 \mathrm{X} + G_2 \tag{5}$$

It can be seen that $X \sim Y$ is a linear relationship. Thus, the layer reserves parameters can be obtained by the measured points data regression, and the layer degree of reserve recovery can be established. This calculation requires at least two shut-in pressure data with one run-in-hole (Fig. 2).

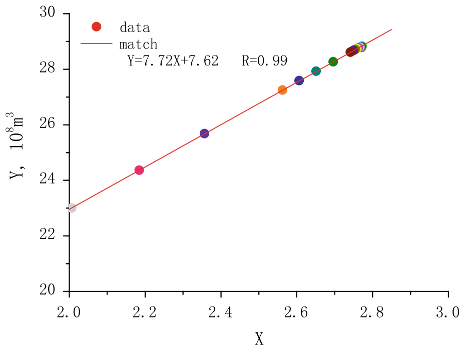

Fig. 2. Match curve (all point data)

2.3 Examples

Well parameters are as follows: two layers are drilled, supply radius is about 1000 m, wellbore radius is 0.1 m, the total thickness of formation is 20 m, the porosity of each layer is equal to 0.1, the formation temperature is 80 °C, the initial formation pressure is 30 MPa, the natural gas relative density is 0.6, the pseudo-critical pressure is 4.67 MPa, and the pseudo-critical temperature is 195.7 K. Original gas in place (OGIP) is 7.65×10^8 m^3, respectively; formation conductivity of the first layer, $(Kh)_1$, is about 30mD.m, formation conductivity of the second layer, $(Kh)_2$, is about 10mD.m. The well produces for 2500d at a 10 MPa constant bottomhole flowing pressure. Cumulative gas production of the first layer is 3.80×10^8 m^3 and the cumulative gas production of the second layer is 1.9×10^8 m^3.

Figure 1 is a data match curve in Table 1. The layer dynamic reserves are 7.72×10^8 m^3 and 7.62×10^8 m^3, respectively, for which the errors compared with the original reserves are, respectively, 0.9 and 0.4%, and the error compared with the commingled layer reserves is 0.26%.

It can be seen from Table 2, the layered reserve is calculated with two adjacent points, G_1 is smaller than the theoretical values, and G_2 is larger than the theoretical values. In order to ensure the error of two layers reserves is less than 5.0%, the degree

Table 1. Two-layer gas reservoir stimulation results at the constant pressure

Production time	Total production	First layer		Second layer	
		P/Z	G_{P1}	P/Z	G_{P2}
D	10^4 m^3	MPa	10^4 m^3	MPa	10^4 m^3
0	0	30.83	0	30.83	0
10	509	30.68	374	30.78	135
20	912	30.56	671	30.73	241
30	1340	30.43	985	30.69	355
40	1765	30.31	1297	30.64	468
50	2188	30.18	1607	30.60	581
60	2609	30.06	1915	30.55	694
70	3027	29.93	2221	30.50	806
80	3442	29.81	2524	30.46	918
90	3855	29.69	2826	30.42	1029
100	4265	29.57	3125	30.37	1140
200	8232	28.41	6005	29.93	2227
300	11,960	27.33	8684	29.51	3276
400	15,461	26.33	11,174	29.10	4287
500	18,746	25.40	13,484	28.71	5262
1000	32,344	21.68	22,709	26.95	9635
1500	42,282	19.14	29,006	25.48	13,276
2000	50,000	17.26	33,671	24.25	16,329
2500	56,939	15.52	38,000	23.20	18,939

Table 2. Two-layer gas reservoir dynamic reserve calculation (adjacent point)

Time	Y	X	G_{P1}	G_{P2}	G_{P1} error	G_{P2} error	G error
d	10^8 m^3		10^8 m^3	10^8 m^3	%	%	%
0	0	0					
10	28.7810	2.7713					
20	28.8220	2.7726	30.388	55.434			
30	28.8165	2.7703	2.341	22.330	69.4	−191.9	−61.2
40	28.7964	2.7668	5.802	12.742	24.2	−66.6	−21.2
50	28.7703	2.7629	6.657	10.379	13.0	−35.7	−11.3
60	28.7412	2.7588	7.019	9.378	8.3	−22.6	−7.2
70	28.7103	2.7545	7.210	8.850	5.7	−15.7	−5.0
80	28.6783	2.7501	7.325	8.534	4.3	−11.6	−3.7
90	28.6456	2.7457	7.399	8.330	3.3	−8.9	−2.8
100	28.6124	2.7412	7.450	8.189	2.6	−7.0	−2.2
200	28.2708	2.6960	7.561	7.886	1.2	−3.1	−1.0
300	27.9270	2.6509	7.620	7.727	0.4	−1.0	−0.3
400	27.5865	2.6063	7.635	7.688	0.2	−0.5	−0.1
500	27.2510	2.5624	7.641	7.672	0.1	−0.3	−0.1
1000	25.6792	2.3569	7.646	7.658	0.1	−0.1	0.0
1500	24.3630	2.1848	7.649	7.653	0.0	0.0	0.0
2000	23.4236	2.0620	7.649	7.652	0.0	0.0	0.0
2500	22.9990	2.0064	7.649	7.652	0.0	0.0	0.0

of reserve recovery must be greater than 2.5%; in order to ensure the error of the stratified reserves is less than 5.0%, degree of reserve recovery must be greater than 5.0%.

3 Conclusions

(1) The new calculation method is simple and practical; the stratified reserves error is less than 5% when the degree of the reserve recovery is greater than 5.0%.

(2) The degree of the reserve recovery can be analyzed by the layered material balance equation. The low permeable layer degree of the reserve recovery can be improved through methods such as the low-permeability layer stimulation, the suitable output optimization, and each layer production time optimization.

(3) For multi-well of the same producing position, the total gas reservoir shut-in approach should be applied to acquire the layer average formation pressure, and then the above method can be applied to calculate the dynamic reserves and evaluate stratified degree of reserves recovery.

(4) For the case of more than two layers, firstly all layers should be divided into two sets of layer group according to geological knowledge, and then the above method can be applied to calculate the dynamic reserves.

References

1. Yujin W, Hedong S, Weigang H, Huayin Z, Shimin Z. Reserves producing level analysis of multilayer gas reservoir in the Sebei gas filed [J]. Nat Gas Ind. 2009;29(7):58–60.
2. Xiong Y, Liehui Z, Fangyong Y, Youchang L, Shuqing H. Study on technical policy and threshold value of multiple-zone production with one well for multilayered gas reservoir. Nat Gas Ind. 2005;25(7):81–3.
3. Guo, P, Wang J, Liu Q, Zhang M. Study on development mechanism of commingling production in low-permeability gas reservoirs [C]. In: International oil and gas conference and exhibition in China, Beijing, China; June 2010. pp. 8–10. SPE 130892.
4. Lefkovits HC, Hazebroek P, Allen EE. A study of the behavior of bounded reservoirs composed of stratified layers [J]. Soc Petrol Eng J. 1961;2(3):43–58.
5. Tariq SM, Ramey Jr. HJ. Drawdown behavior of a well with storage and skin effect communicating with layers of different radii and other characteristics [C]. In: SPE Annual Fall Technical Conference and Exhibition, Houston, Texas; 1–3 October 1978. SPE 7453.
6. Ehlig-Economides CA, Joseph JA. A new test for determination of individual layer properties in a multilayered reservoir [J]. SPE Formation Evaluation. 1987;2(3):261–82.
7. Xiangyan Kong. Aadvanced Fluid mechanics in Porous [M]. Hefei: China University of Science and Technology Press; 1999. p. 374–6.
8. Qiguo L, Hui W, Ruicheng W, Xiaochang L. A computing method for layered production contribution and affecting factors analyzing in commingled gas reservoirs. J Southwest Pet Univ (Sci & Technol Edition). 2010;32(1):80–4.
9. People’s Republic of China oil and gas industry standard. SY/ T 6098-2000, Natural Gas Recoverable Reserves Calculation Method, the National Petroleum and Chemical Industry Bureau issued.
10. Smith CR, Tracy GW, Farrar RL. Applied reservoir engineering [M]. Petroleum Industry Press; 1995. pp. 237–48.