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To cite this article: Xiaoyong Wen *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **384** 012037

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Study on new method for evaluating reservoir formation pressure by wellhead pressure

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Abstract. Formation pressure is an essential parameter for calculating the dynamic geological reserves, evaluating the development effect of oil and gas fields, conducting the daily dynamic analysis of oil and gas Wells and predicting the dynamic of oil and gas fields. Generally, the calculation of reservoir average formation pressure is to use the pressure in the infinite formation to solve the formation pressure. This paper presents a new method for calculating the pressure at any point of one source and one sink by using wellhead pressure. This method has been well applied in the Saertu-Putaoehua industrial area.

Key Words. Wellhead pressure; Reservoir evaluation; Formation pressure.

1. Introduction

Formation pressure has been studied for a long time, but there are still many problems. For a long time, it has been used to solve the average pressure of infinite formation in many cases [1,2]. Obviously, the average pressure of formation obtained by this method is very inaccurate [3-5]. Therefore, many researchers have sought for more accurate methods to solve formation pressure. Li bin et al. (1994) [6] and Zhang Zhifeng et al. (2004) [7] used IPR curve and Vogel equation to deduce the expression of formation pressure. Shen huilin et al. (2006) [8] described several methods and principles for detecting formation pressure with logging data and evaluated them. Caijun (2011) [9] used three-dimensional geological stress simulation method to complete the construction of three-dimensional formation pressure body in Yingqiong basin, and obtained credible pressure prediction results. Wang hui et al. (2016) [10], based on the theory of seepage mechanics, combined with the phase permeability curve and the shunt equation, obtained a new method to calculate the formation pressure using the production dynamic data, which can obtain the formation pressure without testing. Based on the principle of material balance, Tao Yongfu et al. (2019) [11] obtained the formation pressure formula that can track the elastic production stage and waterflood development stage of Yanerxia M reservoir in real time by using the dynamic change relationship between pore volume and oil and water volume of rocks, and the



formula has a very good fitting effect with the actual pressure. Researchers are exploring more accurate methods of formation pressure prediction and evaluation.

2. Conventional formation pressure calculation method

The physical significance of the average formation pressure of the whole reservoir is as follows: in a connective reservoir, the whole reservoir is shut down at a certain time until the formation pressure drop funnel in each well area completely disappears and the pressure distribution reaches a static and stable state. At this time, the pressure measured at the geometric center of gravity of the reservoir represents the average formation pressure of the reservoir at the above time. Conventional formation pressure calculation methods can be divided into arithmetic average method and weighted average method.

2.1. Arithmetic mean method

$$\bar{p} = \frac{1}{n} \sum_{i=1}^n p'_{ri} \quad (1)$$

Where in \bar{p} is average reservoir pressure at the start of shut-in for some Wells in the reservoir, MPa; n is Shut-in well number; p'_{ri} is corresponding well point conversion formation pressure, MPa.

Based on the analysis of the mathematical meaning of the method, the applicable condition of calculating the average formation pressure of the whole reservoir by the arithmetic mean method is: the measured or calculated formation pressure at each well point is an independent event (not subject to interference from other Wells); The well point of formation pressure difference is random error, as the normal distribution, which satisfy:

1. the absolute error between the converted well point formation pressure and the average reservoir formation pressure does not exceed a certain limit;
2. compared with the average formation pressure of the reservoir, the number of Wells with small deviation of the converted formation pressure is more than the number of Wells with large deviation, and the number of Wells with the converted formation pressure close to the average formation pressure of the reservoir is the largest;
3. compared with the average formation pressure of the reservoir, the number of positive error well points with the same absolute value is approximately equal to the number of negative error well points;
4. the more well points, the closer the calculated average reservoir pressure is to the real average reservoir pressure.

2.2. Weighted average method

Different production Wells have different influence on reservoir pressure distribution, and different weights are used to calibrate them to the same level, and then the average value is calculated. How to take the weight coefficient is the key to apply the weighted average method. For the injection-production system, it is necessary to treat the pressure of oil and water Wells differently because of the large difference in the ratio of oil and water Wells and the large difference between the formation pressure of oil Wells and the formation pressure of water layers. If the injection-production ratio is C , the average formation pressure in the block is:

$$\bar{P} = \frac{\sum_{i=1}^M \bar{P}_{oi}}{M} \times \frac{C}{C+1} + \frac{\sum_{i=1}^N \bar{P}_{wi}}{N} \times \frac{1}{C+1} \quad (2)$$

Based on the conventional mathematical statistical calculation of mean formation pressure, the weighted average of volume and flow resistance coefficient can be used:

$$\bar{P} = \frac{\sum_{i=1}^M \bar{P}_{oi} \times V_i}{\sum_{i=1}^M V_i} \times \frac{C}{C+1} + \frac{\sum_{i=1}^N \bar{P}_{wi} \times V_i}{\sum_{i=1}^N V_i} \times \frac{1}{C+1} \quad (3)$$

$$\bar{P} = \frac{\sum_{i=1}^M \bar{P}_{oi} \times \left(\frac{Kh}{\mu}\right)_i}{\sum_{i=1}^M \left(\frac{Kh}{\mu}\right)_i} \times \frac{C}{C+1} + \frac{\sum_{i=1}^N \bar{P}_{wi} \times \left(\frac{Kh}{\mu}\right)_i}{\sum_{i=1}^N \left(\frac{Kh}{\mu}\right)_i} \times \frac{1}{C+1} \quad (4)$$

3. A new method for predicting formation pressure between oil and water Wells

3.1. Mathematical model

It is assumed that: in the infinite formation, there is equal output, one source and one sink, B and A, the well radius is R_w , the output is expressed by q , the two Wells are separated by $2a$, the bottom hole pressure of the sink is P_w , the bottom hole pressure of the source is P_H , the formation pressure is P_e , the single-phase incompressible liquid, obeys darcy's law and stable seepage law.

The potential at any point M in the formation can be written according to the principle of potential superposition:

$$\Phi_M = \frac{q}{2\pi} \ln \frac{R_1}{R_2} + C \quad (5)$$

Where in R_1 and R_2 are the distance from point M to the production well and the injection well respectively.

3.2. Production calculation

On the wall of well A, $\Phi = \Phi_w$, $\Phi_w = \frac{K}{\mu} P_w$, $R_1 = R_w$, because of $R_w \ll 2a$, so there is $R_2 \approx 2a$, and:

$$\Phi_w = \frac{q}{2\pi} \ln \frac{R_w}{2a} + C \quad (6)$$

On the wall of well B, $\Phi = \Phi_H$, $R_1 \approx 2a, R_2 = R_w$, get:

$$\Phi_H = \frac{q}{2\pi} \ln \frac{2a}{R_w} + C \quad (7)$$

The equation (7) minus the equation (6) is:

$$q = \frac{\pi(\Phi_H - \Phi_w)}{\ln \frac{2a}{R_w}}$$

$$Q = \frac{\pi Kh(P_H - P_w)}{\mu \ln \frac{2a}{R_w}} \quad (8)$$

Formula (8) is the production rate formula of the producing well.

If point M is placed on the supply edge, then $\Phi_M = \Phi_e$, $R_1 = R_2 = R_e$, so:

$$\begin{aligned}\Phi_e &= \frac{q}{2\pi} \ln \frac{R_e}{R_e} + C \\ \Phi_e &= C\end{aligned}\quad (9)$$

Substitute equation (8) into equation (7) to get:

$$q = \frac{2\pi(\Phi_H - \Phi_e)}{\ln \frac{2a}{R_w}} \quad (10)$$

Output can also be calculated using equation (10).

3.3. Pressure distribution

Subtract equation (7) from equation (6) to get:

$$\Phi_M = \Phi_w + \frac{q}{2\pi} \ln \left(\frac{R_1}{R_2} \cdot \frac{2a}{R_w} \right) \quad (11)$$

$$P_M = P_w + \frac{Q\mu}{2\pi Kh} \ln \left(\frac{R_1}{R_2} \cdot \frac{2a}{R_w} \right) \quad (12)$$

Subtract equation (5) from equation (7) to get:

$$\Phi_M = \Phi_H + \frac{q}{2\pi} \ln \left(\frac{R_1}{R_2} \cdot \frac{R_w}{2a} \right) \quad (13)$$

$$P_M = P_H + \frac{Q\mu}{2\pi Kh} \ln \left(\frac{R_1}{R_2} \cdot \frac{R_w}{2a} \right) \quad (14)$$

With each formula of equations (5) to (14), the pressure or potential at any point M at one source and one sink can be calculated.

4. Examples of application

At present, there are two sets of development layers in the work area, which is Gaotaizi and Saertu-putaohua. Fig.1 shows the well location distribution of Saertu formation. According to the situation of production Wells in the work area, the coordinates, medium depth, converted or measured flow pressures of Wells in different layers are calculated and calculated. Combined with the corresponding situation of oil and water Wells in specific layers, the pressure distribution relationship between oil and water Wells in the working area was predicted (as shown in Fig.2), and the formation pressure distribution in gaotaizi, saertu and putaohua layers was obtained (as shown in Fig.3 and Fig.4) by using the kriging inter-well parameter prediction model.

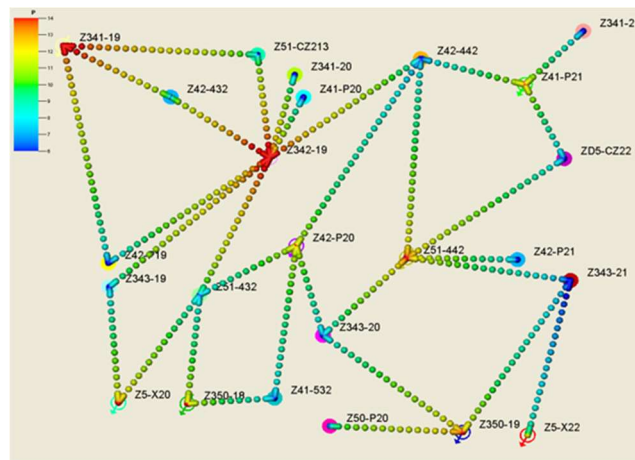


Figure 1. well location distribution map of Saertu formation

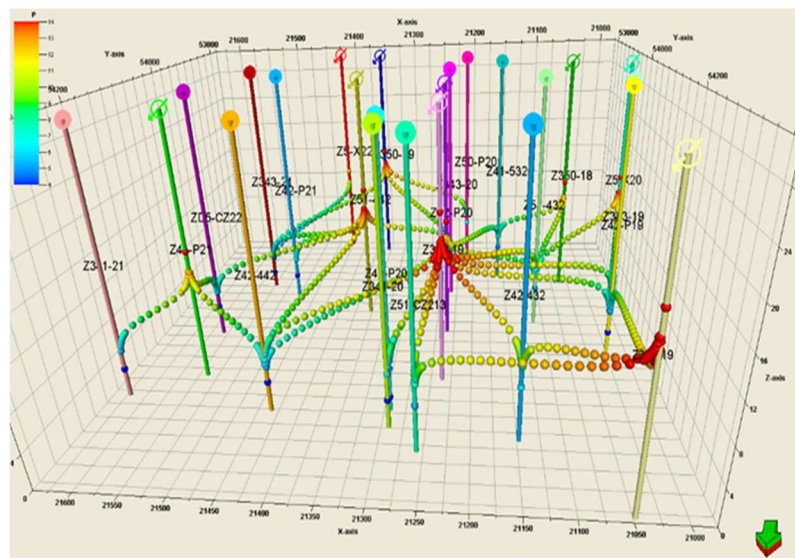


Figure 2. formation pressure distribution between Wells in Saertu formation

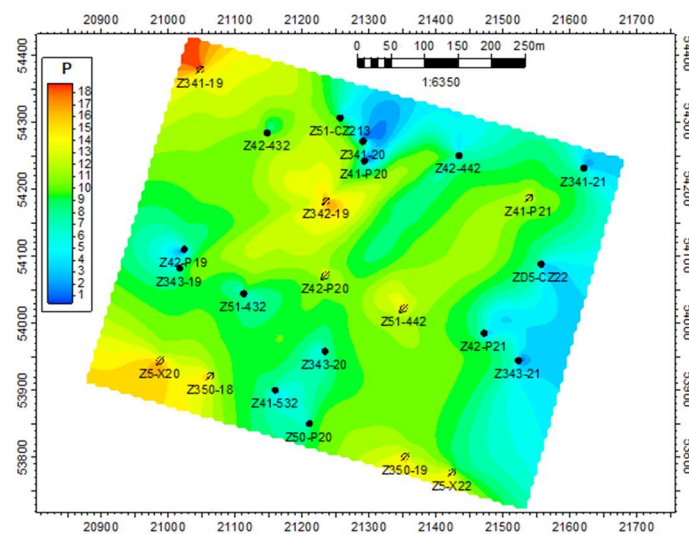


Figure 3. reservoir pressure plane distribution of Saertu formation

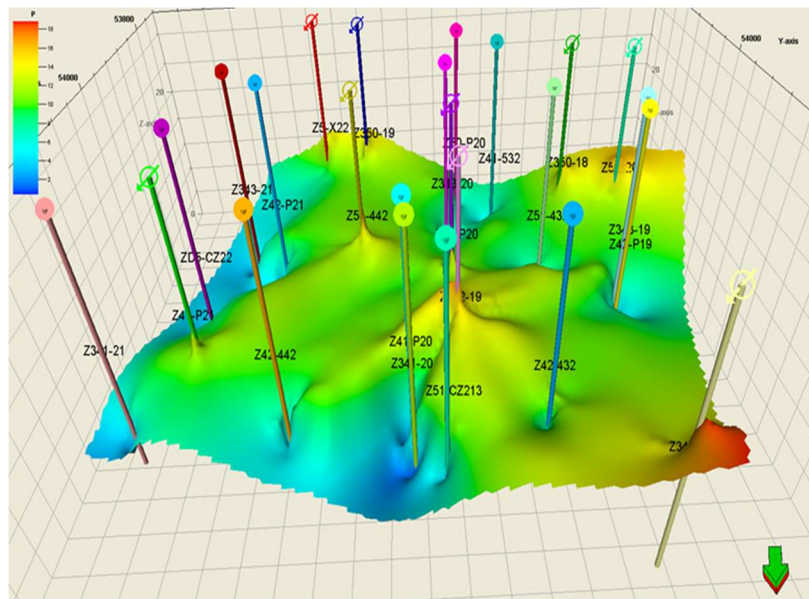


Figure 4. reservoir pressure distribution diagram of Saertu formation

5. Conclusion

The application example shows that this method can be used to solve the pressure or potential at any point in the formation under the condition of Darcy's law.

Acknowledgements

This study was supported by the National Natural Science Foundation of China (Grant No. 51304032, Grant No. 51674044), the Opening fund of State Key Laboratory of Oil and Gas Reservoir Geology and Exploitation (No. PLC201609).

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