Identification of Interlayer Distribution of Marine Sandstone Based on Four-dimensional Well Test Technology

Ke Li 1,2, Yao Li 3, *, Peng Zhang 4, Kai Wang 2, Chenyang Tang 2, Jing Tang 2

1 State Key Laboratory of Offshore Oil Exploitation. Beijing, China
2 China National Offshore Oil Corporation Research Institute Ltd. Beijing, China
3 College of energy, Chengdu University of science and technology. Chengdu, Sichuan, China
4 China Offshore Oil Co. Ltd. Beijing, China

*Corresponding author e-mail: 2019020203@stu.cdut.edu.cn

Abstract. Reservoir compartment is one of the important influence factors of fluid flow in the reservoir, and it is of great significance to carry out the research on reservoir compartment understanding and characterization for the research and development of residual oil distribution in the middle and late stages of an oil field. However, how the reservoir compartment is distributed, the current method is mainly throughout open heads, rock hearts, logging, and other information to explain, but this method is limited to blocks. Because of this problem, we use the four-dimensional test well method to calculate the distribution of the oil deposit formation coefficient based on the test well pressure data, and then use pressure denoising technology to make the data smoother, and the resulting two-pair curve plate is clearer, the layout can be used to explain the distribution of the compartments in the work area. This method requires only test pressure data and is suitable for multiple workspaces. This is of great guiding significance to the development of sea-phase sandstone inter-layer reservoirs.

1. Introduction

The compartment refers to the basic non-permeable compartment layer, such as mudrock, which is sandwiched in the reservoir, which is different from the collective nature of the reservoir and has a significant effect on the fluid flow in the inner layer in the development and production of oil fields. At present, the research on the straddle is mainly focused on the land phase, especially the river phase, and most scholars believe that the land-phase state is more complex and the distribution of the mezzanine is more uncertain, while the study of the strat phase strat thereof is relatively weak. The existing compartment recognition mainly relies on outcry, rock heart, straight well logging curve, horizontal well logging curve, and production dynamics and other data, its dependence on outcry and rock data and logging data are strong, and the results are not accurate enough, the four-dimensional test well interpretation method proposed in this paper, according to the test well pressure data to calculate the distribution of oil deposit formation coefficients, has a strong theoretical basis. Then use pressure denoise technology to make the two-pair curve plate clearer, so that the results are more accurate. In the process of oil field production, with the deepening of development, the law of oil and water movement in reservoir becomes more and more complex, the flood situation is serious, and the distribution of...
residual oil is scattered. Therefore, it is very important to find out the type and distribution of the internal compartment of the reservoir for oil field development.

2. Four-dimensional well test interpretation theory

The Yeh-Agarwal method was originally used to analyze the pressure drop data of water injection wells to obtain mobility distribution. After the method is modified by Feitosa and Lifu chu et al., the well test pressure data can be used to obtain the reservoir permeability distribution under single-phase flow.

Yeh and Agarwal regard the instantaneous total flow of the injection well as the volume-weighted arithmetic average of the mobility distribution in the detection area. Applying this concept to the single-phase flow of a heterogeneous reservoir, there are:

\[
\frac{k_h}{\mu} = \frac{1}{V} \int_V \frac{k_h}{\mu} (r) dV = \frac{1}{\pi r_i^2 h} \int_{r_i}^{r_f} \frac{k_h}{\mu} (r') r'_dr' \\
= \frac{1}{\pi r_i^2} \int_{r_i}^{r_f} \frac{k_h}{\mu} (r') r'_dr' \\
\]  

(1)

\( \frac{k_h}{\mu} \) represents the instantaneous formation coefficient when the time is \( t \) and the detection radius is \( r_i \), where the detection radius is calculated by the formula (2):

\[
r_i = 1.5 \sqrt{\frac{3.6kt}{\phi \mu C_i}} \\
\]  

(2)

Derivation of (1), after sorting out, formula (3) can get:

\[
\frac{k_h}{\mu} (r_i) = \frac{r_i}{2} \frac{d}{dr_i} \left( \frac{\hat{k}_h}{\mu} (r_i) \right) + \frac{\hat{k}_h}{\mu} (r_i) \\
\]  

(3)

In practical application, especially when the pressure fluctuates greatly with time, the calculation error of the Yeh-Agarwal method is larger than that of the Yeh-Agarwal method. If the Yeh-Agarwal method is used \( \frac{k_h}{\mu} (r_i) \) instead of \( \frac{k_h}{\mu} (r_i) \) in the Yeh-Agarwal method, the calculated permeability is more accurate than that of the Yeh-Agarwal method. (2) and (3) are rewritten as:

\[
\frac{\mu}{k_h} = \frac{1}{r_i} \int_{r_i}^{r_f} \frac{\mu}{k_h} (r') r'_dr' \\
\]  

(4)

\[
\frac{\mu}{k_h} (r_i) = \frac{r_i}{2} \frac{d}{dr_i} \left( \frac{\mu}{k_h} (r_i) \right) + \frac{\mu}{k_h} (r_i) \\
\]  

(5)

This improved method is called the modified Yeh-Agarwal method. The analysis steps of the algorithm are as follows:

1) Choose different instantaneous formation coefficient formulas according to different pressure data, and calculate the instantaneous formation coefficient \( \frac{\hat{k}_h}{\mu} \) (1) at a certain point in time.

2) Calculate the oil drain radius at a certain point in time by formula (2).

3) Use different formulas to calculate the formation coefficient value of each point:

4) YA method: using (3) formula to calculate the formation coefficient value of each point;

5) MYA method: using (5) formula to calculate the formation coefficient value of each point.

Through the above steps, the reservoir formation coefficient distribution can be calculated from the well test pressure data.
3. Pressure denoising technology

However, due to the high output of a single well in the study area, it is susceptible to multiple effects of water hammer effect, production fluctuation effect, wellbore flow pattern mutation effect, and temperature effect during the production process. The pressure data of the downhole electric pump partner has obvious low-frequency oscillations, so the pressure data must be denoised by filtering and denoising methods of low-frequency oscillation signals.

Smoothing filtering is one of the commonly used preprocessing methods in fluctuating pressure analysis. Using the Savitzky-Golay method for smoothing filtering can improve the smoothness of the pressure curve and reduce noise interference. The smooth filtering effect of Savitzky-Golay can meet the needs of many different occasions. The Savitzky-Golay convolution smoothing algorithm is an improvement of the moving smoothing algorithm. The Savitzky-Golay algorithm is widely used in data stream smoothing and denoising. It is a method of best-fitting based on polynomials in the time domain and using the least-squares method. In this way, it is possible to ensure that the original data is not distorted as much as possible. This method is relatively simpler and faster.

The purpose of multiplying each measurement value by the smoothing coefficient $hi$ is to minimize the impact of smoothing on useful information, thereby improving the disadvantages of the smoothing denoising algorithm. $hi/H$ can be calculated based on the principle of least squares for polynomial fitting. The key to Savitzky-Golay convolution smoothing lies in the solution of matrix operators. Suppose the width of the filter window is $n=2m+1$, and each measurement point is $x=(-m,-m+1,...,0,1,...,m-1,m)$ using $k-1$ degree polynomial to the window data points are fitted.

Figure 2 shows the implementation process of the Savitzky-Golay smooth filtering part of the program.
Figure 2 shows the pressure change curve of Well B12H and the pressure curve filtered by wavelet transform. It can be seen from the figure that the pressure transition of well B12H is rather chaotic because the pressure fluctuations caused by the water hammer phenomenon are particularly obvious. There are particularly obvious pressure fluctuations in the pressure rising section, the pressure rapidly decreasing section, and the previous section before the pressure is stable. The pressure curve smoothed and filtered by Savitzky-Golay can fit the measured data well in the pressure rising section, the pressure rapidly falling section, the pressure fluctuation section, and the pressure stable section. This further shows that the Savitzky-Golay smoothing filter has a good effect in reducing the noise of the water hammer oscillation pressure when the pump is stopped.

![Figure 3. Comparison of three filtering methods and measured data](image)

It can be seen from the above discussion that the Savitzky-Golay smoothing filter method proposed in this paper is feasible and effective to reduce the noise of the water hammer oscillation pressure when the pump is stopped.

4. Field application

After noise reduction by wavelet transform, the smoothed data is imported into the Saphir well testing software, and then the interpreted double logarithmic curve is inverted through four-dimensional well testing to obtain a four-dimensional well testing inverted thickness map. Compare the results reflected by the two.

Well B12H is located in the Panyu 5-1 oilfield in the South China Sea. Well 12 started the first well drilling operation in 2012. The BO16.80 layer of this well has a porosity of 0.277, a permeability of 5770.8, and a water saturation of 16.6%. It can be seen from the logarithmic curve and the interlayer detection curve near the B12H well that the interlayer was found when the well was detected at 100m.

![Figure 4. Double logarithmic curve of B12H well bottom hole pressure](image)

![Figure 5. Interlayer detection curve near B12H well](image)

5. Conclusion

The four-dimensional test well interpretation theory introduced in this paper, by using different calculation formulas in different work areas, obtains the distribution of the oil deposit formation
coefficient, and in practice, the smooth data after noise reduction is applied to Saphir test well software, and then the interpreted two-pair curve is introverted through the four-dimensional test well, and the four-dimensional test well intrinsic thickness map is obtained. The two are then compared to get the distribution of the compartment. This method does not need to use the field outing and the rock heart data, only the test well pressure data can be, adaptable.

References
[1] Zhang Changmin, Yin Taiju, Zhang Shangfeng. Hierarchical analysis of mud compartments Acta Petrolei Sinica, 2004, 25(3): 48-52.
[2] Ma Shizhong, Sun Yu, Fan Guangjuan. The research method of thin mezzanine structure inside the single sand body of the underground curved river channel Acta Sedimentologica Sinica, 2008, 26(4): 632-638.
[3] Wang Yanzhang, Lin Chengyan, Wen Changyun. The mezzanine distribution pattern and its control of the remaining oil Journal of Southwest Petroleum Institute, 2006, 28(5): 6-10.
[4] Davau F. Pressure analysis for horizontal wells[J]. SPE-14251-PA, 1988, 3(4):716-724.
[5] Permadi, Kurnia A. Modeling simultaneous oil and water flow with single-phase analytical solutions[M]. College Station, Texas: Texas A and M University, 1997.
[6] ZHANG Ji, ZHANG Liehui, HU Shuyong. The genesis and characteristics and identification of intercalations in reservoir of clastic rock[J]. Petroleum Geology & Oilfield Development in Daqing, 2003, 22 (4): 1-3.
[7] Feitosa M C B, Querino R B, Hamada N. Association of Anagrus amazonensis Triapitsyn, Querino & Feitosa (Hymenoptera, Mymaridae) with aquatic insects in upland streams and floodplain lakes in central Amazonia, Brazil [J]. Revista Brasileira de Entomologia, 2016, 60(3):267-269.
[8] Xiaodong Y U, Luoping P, Xueli A N. Denoising algorithm of pressure fluctuation signals of hydraulic turbines based on VMD and permutation entropy[J]. Journal of Hydroelectric Engineering, 2017.
[9] An X L, Zeng H. Pressure fluctuation signal analysis of a hydraulic turbine based on variational mode decomposition [J], Proc IMechE Part A: J Power and Energy, 2015, 229(8): 978-991.
[10] LUO Zhonghui, WANG Xiaozhen, XUE Xiaoning, et al. Study on early fault diagnosis of motor bearing based on wavelet transform EMD [J]. Proceedings of The Chinese Society of Electrical Engineering, 2005, 25(14): 125-129. (in Chinese)
[11] SU Li, NAN Haipeng, YU Xiangyang, et al. Application of wavelet denoising analysis based on improved threshold function in vibration signals of hydroelectric generating set [J]. Journal of Hydroelectric Engineering, 2012, 31(3): 246-251. (in Chinese)
[12] WU Hongbiao, LIU Liming, CHEN Qinlei, et al. Theoretical study on four-dimension well testing [J]. Acta Petrolei Sinica, 2003, 24(5): 57－62.
[13] SONG Liming, ZHANG Xiaogang, LI Guangxuan, et al. Description based on well testing theory of horizontal well reservoir [J]. Well Testing, 2014, 23(5) : 36－39.