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OPINION
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Dominant Channels Identification Method for Multi-Fractured Horizontal Wells in Tight Reservoirs: Progress and Challenges

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INTRODUCTION

As an important form of energy supply, tight reservoirs have been found in most countries and regions of the world (Zhang et al., 2015) (**Figure 1**). According to statistics, the total global reserves of tight resources are 67,840 × 10^8 barrels, and the technically recoverable reserves are 3,362 × 10^8 barrels. More than two-thirds of tight resources are concentrated in Russia, the United States, China, Libya, Argentina, and Australia (Kuuskraa et al., 2013).

At present, tight oil development is mainly based on volume fracturing (Jinhu et al., 2014; Hu et al., 2018; Sheng et al., 2019). After long-term waterflooding, the permeability and porosity of the reservoir increase significantly. The fractured tight reservoir has obvious heterogeneity and can easily form a dominant channel (Wang et al., 2011). After the formation of the dominant channel, the injected water is easier to quickly reach the production well along the large channel with less resistance, resulting in the ineffective circulation of injected water and reduced water flooding efficiency. Therefore, it is of great significance to identify the dominant channels for the further remaining oil development. There are many existing methods for identifying the dominant channels. According to the theoretical and technical characteristics of these methods, they can be roughly divided into five categories: the method of using tracer monitoring data, the method based on single well dynamic and static data, the method using well test data, the method using water absorption profile logging data, and the method using numerical simulation. This article summarizes the existing dominant channels identification methods and discusses the advantages and disadvantages of each method to summarize the latest progress and challenges of dominant channels identification.

Identification of Dominant Channels Using Tracer Monitoring Data

The tracer monitoring technology injects radioactive isotopes into water injection wells and then detects them in the surrounding production wells to determine the output of tracers and draw the output curve. Through the quantitative interpretation by the interwell tracer interpretation software, the high permeability regions in the formation can be qualitatively determined, and some formation parameters can be quantitatively calculated.

Brigham and Smith (1965) published related articles on the seepage status of tracer mining curve in a five-point well pattern, which included an important theoretical basis of tracer monitoring curve. Cooke (1971) put forward a method and theory of interwell tracer to study residual oil in reservoirs and made a great contribution to tracer application. Abbaszadeh-Dehghani and Brigham (1984) proposed the Abbaszadeh-Brigham flow tube model (A-B model). This model realizes the transformation of the interwell tracer monitoring method from qualitative analysis to quantitative interpretation and points out the direction for the application of tracer monitoring

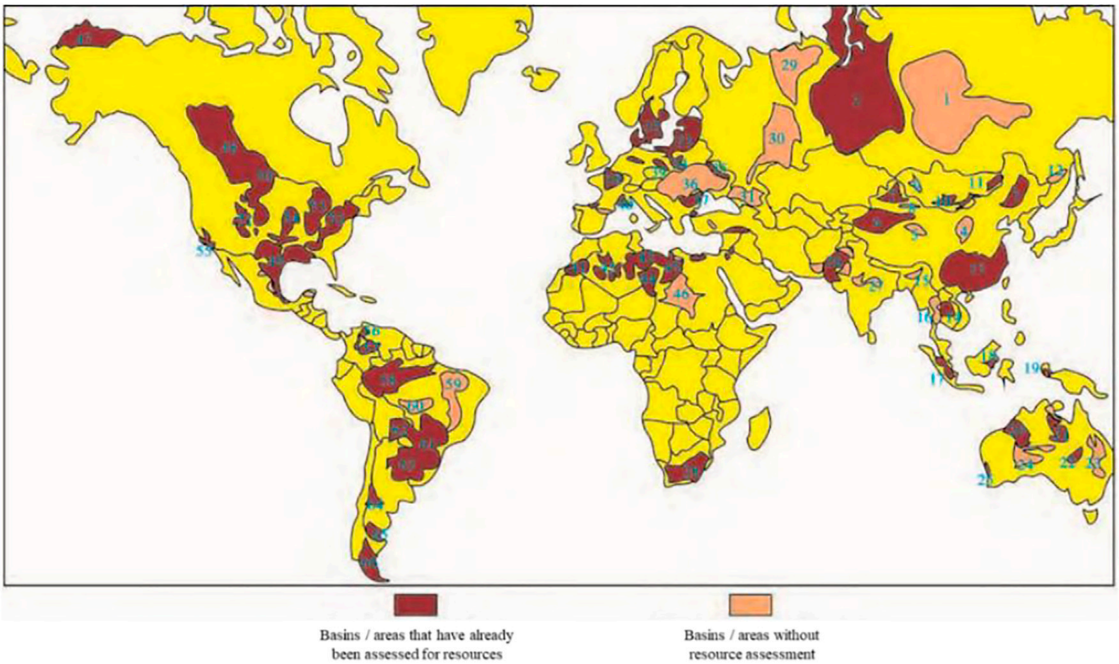

FIGURE 1 | Global distribution of tight reservoirs (Zhang et al., 2015).

technology. Ghori and Heller (1990) used theoretical models and experiments to determine the vertical distribution of reservoir parameters and named this method interwell tracer geostatistical analysis. Feng and Li (2005) proposed a tracer concentration interpretation model. The model is automatically fitted by a genetic algorithm, which solves the problems of the low interpretation accuracy and heavy workload of tracer concentration fitting. Liu et al. (2008) studied the distribution of the remaining oil in the reservoir using the interwell tracer monitoring technology.

The method of using the tracer monitoring data to identify dominant channels has undergone a transformation from qualitative analysis to quantitative interpretation, and the combination with numerical simulation is becoming the trend of this method. However, the existing tracer interpretation models have good adaptability for high porosity and high permeability reservoirs. However, for unconventional reservoirs, due to their particularity and water flooding characteristics in water injection development, these models are often ineffective. Therefore, the accurate establishment of the tracer interpretation model for unconventional reservoirs is a challenge for tracer monitoring technology to identify water dominant channels.

Identification of Dominant Channels by Dynamic and Static Data

Dou et al. (2001) used the physical simulation experiments combined with the reservoir engineering theory and grey correlation method to determine whether the dominant channels exist. Liu et al. (2003) used the fuzzy comprehensive evaluation method to identify dominant channels in strata. Yousef et al. (2006) established a model considering the conduction effect and compressibility in the reservoir, which uses the volatility of injection-production ratio to realize the identification of interwell channels. Peng et al. (2007) introduced the concept of the large channel composite index and used the fuzzy comprehensive evaluation method to quantitatively identify the distribution of dominant channels. Liu et al. (2010) used the K-means weighted clustering algorithm to quantitatively identify dominant channels, which is suitable for low-permeability thick reservoir reservoirs. Izgec and Kabir (2011) drew the Hall curve and its derivative curve on the same graph. They obtained that, in the bedrock, the two curves overlap, while when the dominant channels exist, the derivative curve is parallel to the Hall curve, and the dominant channels in the reservoir are identified according to this feature.

The method makes full use of the actual data of the oilfield, and the recognition results have certain feasibility. However, this method requires complete and accurate field data. It is well known that the field data are inaccurate in most cases, and some data are difficult or even impossible to obtain, so this method is not applicable in all cases. From the development process, the method of identifying water dominant channels using dynamic and static data has experienced the evolution from qualitative identification to quantitative identification, from combining with reservoir engineering method to combining with numerical simulation method. It can be seen that this kind of method needs to be developed towards a more accurate and efficient trend.

Identification of Dominant Channels Channel by Well Testing Data

Well testing can test high permeability channels and their directions through pressure drop and pressure recovery and can qualitatively predict reservoir dominant channels.

Shi et al. (2003) described the measured points using the pressure drop formula of unstable well testing and drew a curve. The curve was fitted with the typical curve obtained when there were dominant channels in the formation. The fitting process and fitting results were analyzed to identify and judge whether there were dominant channels around the well. Yang (2005) realized the identification of dominant channels in reservoirs according to the change of curve shape, trend, and slope by studying permeability change on a double logarithmic curve. Feng et al. (2010) established a well testing interpretation model of a micro compressible fluid in homogeneous reservoirs and proposed a new method to determine the permeability and effective thickness of dominant channels.

Using well test data to identify dominant channels is simple, fast, and very economical, which can make full use of production data. However, the premise requires the reservoir to be an elastic porous medium of equal thickness and horizontal, homogeneous, and isotropic, which is completely realized in the case of an ideal model. It is far from the actual reservoirs, and the calculated results will inevitably have errors. Therefore, a more accurate and rigorous well testing model is needed.

Identification of Dominant Channels Using Water Absorption Profile Logging Data

After the formation of dominant channels in long-term water injection development, some logging data measured in the field will change significantly. These data include the data obtained by testing the water injection profile and some conventional logging data. According to the changes of these data and inversion of formation parameters by fitting logging curves, dominant channels identification can be carried out.

Du and Jing (1999) obtained that, under the same lithology of sedimentary rocks, reservoir water flooding was the main reason for the change of the curve. Therefore, the curve analysis can show the change of the reservoir. Xu et al. (2002) applied natural gamma logging curve to dominant channels identification, which enriched the theoretical system of the dominant channels identification method. Joshi et al. (2010) used a special measurement tool to distinguish the heavy oil and water, which are difficult to distinguish because of the close density, and then measured the moisture content. The advanced mathematical method was used to systematically analyze the test results to effectively identify the high permeability layer and inter-layer channels.

The water absorption profile method is simple and intuitive to identify water channels, but it has many defects. The accuracy of dominant channels identification using this method needs to be further verified. The high cost and long time consumed in obtaining the water absorption profile logging data are the current challenges of this method.

Identification of Dominant Channels by Numerical Simulation

The numerical simulation method uses complex geological modeling and actual production simulation to quantitatively determine the dominant flow. Feng et al. (2009) established a fluid-solid coupling mathematical model, where the relationship between permeability and cumulative linear flow reflects the evolution process of large pores. Yu et al. (2016) introduced the permeability variation model into the numerical simulation and established a new method for calculating the plane distribution of dominant channels. Zhao et al. (2015) proposed a new connectivity model numerical simulation method. Based on this numerical simulation method, Xu et al. (2017) predicted polymer flooding channels for the first time and applied them in actual oilfields. Shen et al. (2018) identified the dominant channels of fractured reservoirs by calculating the water injection splitting of water injection wells to surrounding wells.

The traditional numerical simulation method to identify water dominant channels has a certain guiding role for reservoir development in the early stage and conventional reservoir development. However, for most wells in the middle and late stages of reservoir development, acid fracturing, profile control, and water plugging are carried out. This method cannot accurately identify dominant channels. Currently, connectivity methods are mainly limited to a single medium and unsuitable for reservoirs with fractures and matrices. Moreover, these methods can only be identified by splitting coefficients, and the identification process is not intuitive enough to accurately determine the type of dominant channels.

CONCLUSION

(1) Using tracer monitoring data to identify dominant channels, the calculated parameters have high precision and a solid theoretical basis. Nevertheless, this method is not effective for unconventional reservoirs.
(2) Identification of dominant channels using dynamic and static data takes advantage of the actual oilfield data, which has a certain credibility. However, this method is only applicable to reservoirs with complete and accurate field data.
(3) Using well testing data to identify dominant channels are simple and fast. However, the method has many assumptions and is too ideal, which is far from the actual reservoirs.
(4) Identification by the water injection profile method is simple and intuitive. However, the accuracy of water dominant channels identification by this method needs to be further verified, and the acquisition of water injection profile logging data is costly and time-consuming.
(5) Identification of dominant channels by numerical simulation has a certain guiding role in the early stage of reservoir development. However, its accuracy is poor in the middle and late stages of reservoir development.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

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