Academic Journal of Science and Technology
ISSN: 2771-3032 | Vol. 6, No. 2, 2023

Literature Review on Pre-Fracturing Reservoir Selection for Hydraulic Fracturing

Yu Fu, Qinghui He

Petroleum Engineering School, Southwest Petroleum University, Chengdu, China

Abstract: In the context of enhancing production from tight low-permeability reservoirs, techniques such as horizontal well section fracturing, volume fracturing, and repeat fracturing have been widely applied. The pre-fracturing reservoir selection for hydraulic fracturing plays a crucial role in determining the success of the fracturing operation. Its objective is to evaluate the production potential of candidate reservoirs and select the most suitable ones for fracturing, in order to maximize the post-fracturing economic benefits. Considerable progress has been made by domestic and international researchers in the field of pre-fracturing reservoir selection, employing primarily two categories of analysis methods: conventional analysis and modern mathematical theory analysis. This paper provides a comprehensive review of relevant research literature, aiming to offer guidance for practical hydraulic fracturing operations.

Keywords: Low-permeability reservoirs, Pre-fracturing selection, Conventional analysis, Modern mathematical theory.

1. Introduction

With the continuous growth in energy demand, the development and utilization of tight low-permeability reservoirs have become increasingly important. In such reservoirs, hydraulic fracturing technology is a key technique that has been widely applied to increase oil and gas production. In the process of hydraulic fracturing, the pre-fracturing reservoir selection is considered a critical factor in determining the success of fracturing. By conducting a comprehensive evaluation of candidate reservoirs and selecting the most promising ones for fracturing, the production enhancement and economic benefits can be maximized.

2. Reservoir Selection for Pre-Fracturing

Various techniques, such as horizontal well section fracturing, volume fracturing, and repeated fracturing, have been widely applied for production enhancement in tight low-permeability reservoirs. The pre-fracturing reservoir selection in hydraulic fracturing is a key step in determining the success of fracturing. Its essence lies in evaluating the production potential of candidate reservoirs and selecting the most suitable ones for fracturing to maximize the post-fracturing production and economic benefits. Significant achievements have been made by domestic and international scholars in the research on pre-fracturing reservoir selection, and the analysis methods can be mainly categorized into two types: conventional analysis and modern mathematical theory analysis.

2.1. Conventional Analysis in Pre-Fracturing Reservoir Selection Research and Application

Conventional analysis approaches start from the perspective of the energy and recoverable reserves of candidate fracturing reservoirs. They combine a large amount of development data, such as drilling, logging, and completion data, with production history data to assess whether ideal industrial oil and gas flow can be achieved after fracturing. Different evaluation criteria are formulated for different reservoirs.

2.1.1. Analysis of Factors Affecting Fracturing Effect

In 1999, Reeves et al. proposed that permeability and skin factor of oil and gas wells were the main factors influencing the post-fracturing effect in the evaluation of pre-fracturing reservoir selection. They considered wells with high permeability and high contamination as excellent "high potential" candidate wells for fracturing.

In 2009, Liu Changyin analyzed the factors influencing the selection of fracturing wells and layers in different types of reservoirs. For fracturing well and layer selection in sandstone oil and gas reservoirs, factors such as oil and gas content, reservoir properties, effective thickness, formation pressure, fluid properties, formation contamination, and reservoir depletion need to be considered. In the case of horizontal wells, the properties of adjacent reservoirs sometimes need to be analyzed as well.

In 2014, Ma et al. analyzed the Sugele tight sandstone gas reservoir located in the Ordos Basin. Although a large number of horizontal wells were put into production in this area, the reservoir heterogeneity was extremely severe, and some gas wells still had low production rates.

Literature indicates that the reservoir selection process is closely related to the existing data of candidate wells, and factors such as reservoir permeability, skin factor, effective thickness, oil and gas content, lithology, and physical properties are important considerations in pre-fracturing well and layer selection.

2.1.2. Evaluation Criteria for Pre-Fracturing Reservoir Selection

In 2010, Zhao Yonggang et al. studied the correlation between reservoir thickness, oil and gas content, and post-fracturing productivity. They found that wells with greater effective thickness, better oil and gas content, and higher reservoir energy coefficient would result in higher production after fracturing, indicating the significance of fracturing construction.

In 2016, Bhattacharya et al. incorporated economic constraints into the aforementioned studies and found that higher reservoir permeability corresponded to a greater number of suitable horizontal wells for fracturing.

In 2017, Wang Yajuan et al. reanalyzed the geological, logging, and well testing data of the Shenmu gas field in the eastern part of the Ordos Basin. They found that the main factors affecting the post-fracturing unrestricted flow rate of gas wells were reservoir effective thickness, permeability, porosity, and gas saturation.

In 2018, Tang Xiujuan's research on pre-fracturing reservoir selection concluded that better fracturing effects can be achieved by selecting wells with greater effective reservoir thickness, relatively complete injection-production systems, and higher flow resistance or contamination near the wellbore.

Furthermore, empirical methods have also been applied in well and layer selection for fracturing. Empirical methods primarily rely on well testing curves to determine which well and which interval is suitable for fracturing based on mining data and previous well selection experience. This method carries certain risks, but through years of research efforts, the technology of using well testing curves for well and layer selection has become relatively mature.

However, with the increase in the number of wells in a block, the analysis of data becomes more challenging, and the obtained evaluation criteria are more empirical and specific, lacking generalizability. Therefore, many scholars have embarked on exploring new, rapid, and scientific methods for well and layer selection.

2.2. Research and Application of Modern Mathematical Theory in Pre-Fracturing Reservoir Selection

Modern mathematical theory quantifies the problem of well and layer selection, thereby minimizing subjective and empirical factors. Domestic and foreign scholars have mainly utilized modern mathematical methods such as fuzzy recognition, fuzzy comprehensive decision-making, grey correlation analysis, artificial neural network systems, and comprehensive evaluation to analyze and screen candidate well layers through the establishment of integrated mathematical-engineering decision-making systems.

2.2.1. Calculation of Influencing Factors' Weights

The first step in the application of modern mathematical theory is to analyze and calculate the weights of the factors influencing fracturing. This is done through different models to obtain the decision-making results.

2.2.1.1 Principal Component Analysis (PCA)

PCA is a dimensionality reduction technique that identifies mutually independent common factors with maximum preservation of original information in a group of statistically correlated data. It replaces the original variables with several uncorrelated principal components.

2.2.1.2 Analytic Hierarchy Process (AHP)

AHP determines the weights of various parameters for the objective by comparing them with each other and forming a judgment matrix. Each compared parameter is considered as both a row and a column in the matrix. By using the 1-9 ratio scale method, experts in the field assign scores to the comparisons, which form the judgment matrix A.

2.2.1.3 Grey Correlation Analysis

Grey correlation analysis is an objective method to determine weights by seeking the primary and secondary relationships among factors in a system and identifying the key factors affecting the evaluation indexes. It determines the consistency of development trends between two sequences by comparing the similarity of their geometric shapes.

2.2.1.4 Comprehensive Weighting

The above models can all derive the weights of factors influencing fracturing effectiveness. The AHP weights mainly rely on the subjective knowledge and experience of expert scholars, while the grey correlation analysis considers the influence of factor variations on the objective function. The entropy weight method is based solely on the relationships among the values of the various influencing factors of the evaluation objects. To comprehensively utilize the advantages and disadvantages of the above weighting methods, a multiplication-weighted method is proposed to obtain the combined weights of the influencing factors.

$$w(i) = \frac{w(i)_{AHP}\, w(i)_{GR}\, w(i)_{IA}\, w(i)_{EW}}{\sum_{i=1}^{m} w(i)_{AHP}\, w(i)_{GR}\, w(i)_{IA}\, w(i)_{EW}} \quad i = 1, 2, ..., m \tag{1}$$

2.2.2. Fuzzy Recognition Method

Due to the inherent ambiguity and uncertainty in well and layer selection, evaluating candidate well layers for pre-fracturing becomes challenging.

In 2005, Yang Xiaosong et al. analyzed the influencing factors of gas well fracturing using fuzzy mathematics and established a model to assess these factors. After analyzing data from six sample wells, they identified permeability, skin factor, recoverable remaining reserves, water saturation, reservoir thickness, viscosity, formation pressure, and porosity as important factors influencing well and layer selection. Among them, permeability and skin factor were considered particularly important, which aligns with Reeves' viewpoint. The quantification of these experimental results enhanced the understanding of factors affecting gas well fracturing and provided reference for future research.

In 2016, Liu Changyin et al. applied mathematical statistics and fuzzy recognition theory to analyze data from over 100 gas wells in low-permeability reservoirs. They identified gas saturation, sand body thickness, formation pressure coefficient, clay content, permeability, and porosity as the main factors affecting the production enhancement effect of post-fracturing gas wells. They also analyzed the influence of each parameter on the post-fracturing unobstructed flow rate and assigned weight coefficients of 0.25, 0.25, 0.2, 0.1, 0.1, and 0.1 to the aforementioned parameters, respectively. They established mathematical formulas to quantify these parameters and calculated the "layer selection coefficient" by summing up the quantified values of all parameters.

The intersection analysis between the layer selection coefficient and the post-fracturing unobstructed flow rate revealed that when the selection coefficient is greater than 0.5, fracturing the layer can generate the desired gas flow and achieve ideal production enhancement. When it is less than 0.5, the ideal production enhancement cannot be achieved.

Based on the proposed layer selection method, a pre-fracturing assessment was conducted for 28 horizontal layers in nine wells in the block. Combining the field fracturing results, the method showed a compliance rate of over 90%, demonstrating the applicability of the layer selection coefficient method for well and layer selection in this block of horizontal wells.

2.2.3. Fuzzy Comprehensive Evaluation Method

The fuzzy comprehensive evaluation method involves establishing a well and layer selection index system that includes primary indicators such as formation, engineering, development, and rock, as well as refined secondary indicators. It utilizes the analytic hierarchy process (AHP) to determine the weights of these indicators and conducts comprehensive evaluations of candidate wells to achieve intelligent ranking of production enhancement potential.

In 2018, Li Wei et al. conducted a study on a complex geological and highly heterogeneous gas reservoir in Block B. They found that the large number of gas wells in the block made it difficult to perform well selection using conventional methods. The field construction results confirmed an increase in daily gas production by 0.61 × 104 m3/d after fracturing for well h1-14, thus validating the practicality and accuracy of the method.

The advantages of this method include a rich selection of well indicators and relatively high reliability of the well selection results. However, the classification boundaries and weights of the indicators depend on experience and need to be adjusted according to the variation in the reservoir block. Therefore, it is highly specific and lacks universal applicability.

2.2.4. Grey Correlation Analysis Method

Grey correlation analysis converts the discreteness of system factors into linear relationships through linear interpolation, and then constructs a correlation degree model based on the linear geometric shape. The aim is to explore the relationships between various factors in the system and identify the main factors influencing the target value.

In 2002, Zhang Guodong et al. attempted to use grey system theory for grey modeling. Through grey correlation analysis, they demonstrated the close relationship between parameters such as reservoir effective thickness, water saturation, porosity, resistivity, permeability, and clay content with fracturing effectiveness.Field construction results showed that this method is more suitable for evaluating high gas-producing wells, while it may have relatively larger errors when applied to low gas-producing wells.

In 2016, Shang Shilong et al. applied the grey correlation comprehensive method to analyze the influencing factors of well and layer selection for the tight low-permeability sandstone gas reservoir in the Dauniudet gas field. It can also guide well and layer selection work and has the potential for wider application.

2.2.5. Artificial Neural Network Method

The artificial neural network method involves establishing a sample library for well and layer selection in hydraulic fracturing and using artificial neural network models for learning and predicting the potential of candidate wells. It can analyze input data and reflect how different input parameters affect output parameters among various complex factors. Additionally, it has strong anti-interference capabilities.

In 2013, Lv Zhikai et al. believed that the efficiency and accuracy of neural network models were relatively low. Therefore, they established a scientific, fast, and high-precision BP neural network model as a decision-making system for well and layer selection in hydraulic fracturing. After training and precision calibration using data from 54 wells in the region, they made predictions for eight wells in the same block, which all yielded good results after fracturing.

In 2013, Kaydani et al. obtained reservoir permeability accurately from well logging data using an optimized artificial neural network model, providing a basis for well and layer selection in hydraulic fracturing.

In 2017, Kulga et al. established a model for predicting hydraulic fracturing parameters for horizontal wells in tight gas reservoirs using artificial neural networks and numerical reservoir models. They predicted post-fracturing parameters for candidate wells and validated the model on-site, showing an average error of 4.9%. This method has good practicality.

2.2.6. TOPSIS Method

The Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) was first proposed by C.L. Hwang and K. Yoon in 1981. This method compares the values of various factors for each evaluated object with the ideal values. The solution that is closest to the positive ideal solution and farthest from the negative ideal solution is considered the best solution.

In 2010, Amiri used the Analytic Hierarchy Process (AHP) for structural analysis of project selection problems to determine the weights of criteria. Then, the fuzzy TOPSIS method was applied to obtain the final ranking of candidate solutions. This method successfully replaced the original project selection decision-making method and selected the best project among six candidate methods for the Iranian Oil Company. Their research also emphasized the importance of weight calculation for parameters, as different weight calculation results lead to different final rankings.

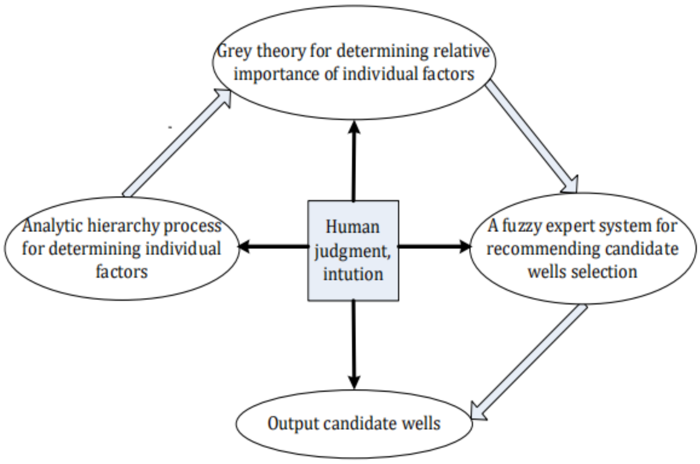
In 2019, Khojastehmehr et al. utilized a database built with real rock and fluid data from 65 reservoirs to perform the optimization of field development plans using the TOPSIS method. Compared to conventional decision-making methods, this technique had faster calculation speed, higher efficiency, lower research costs, and strong generalizability.

2.2.7. Comprehensive Evaluation Method

The comprehensive evaluation method combines multiple analysis methods mentioned above to obtain a more accurate evaluation and prediction system.

In 2013, Ma Xiaobin et al. combined fuzzy mathematics with gray correlation analysis. They used the fuzzy analytic hierarchy process to determine the weight coefficients of various influencing factors and obtained the gray correlation degree by weighting the gray correlation coefficients. They explored the application of this evaluation model in well and layer selection for hydraulic fracturing. Through the case analysis of six wells in the Fuchengzhai gas field, they obtained the comprehensive correlation degree and ranking of each well, selecting the most suitable well for fracturing.

In 2014, Wang et al. established an evaluation system for candidate wells in hydraulic fracturing based on neural networks and data analysis techniques. By collecting and screening reservoir geological properties, production history, static and dynamic parameters of 50 wells in a block, they analyzed and predicted the wells. Field results showed that the prediction accuracy of this model was above 90%, indicating its effectiveness in pre-fracturing well and layer selection.



In 2017, Zeng et al. developed a well selection method that combines human judgment, the analytic hierarchy process, gray theory, and fuzzy recognition system. The model was trained and improved using data from 14 sample wells, and then it was used for prediction and evaluation of five candidate wells. The feasibility of this method was demonstrated by the field results. The novelty of this method lies in combining various techniques and functional components using a task-sharing hybrid method with mutual communication. It also incorporates human judgment, which is not addressed in other methods.

In general, through the quantitative treatment of wellbore optimization problems using modern mathematical theory, it is possible to consider the mutual influence among various indicators and effectively reduce subjective experience and arbitrariness. This approach achieves fast, objective, and scientific evaluation results, making it a primary assessment method for future wellbore optimization.

3. Conclusion and Prospects

Based on the literature review, it can be observed that wellbore selection and layer selection in hydraulic fracturing are crucial steps in determining the fracturing effect. Choosing the most favorable oil and gas wells and reservoirs is one of the main ways to reduce fracturing construction risks and improve economic benefits. Currently, there are many conventional methods and modern mathematical theory methods available for wellbore selection and layer selection in horizontal well fracturing, which have demonstrated good field benefits. However, there are still some deficiencies and prospects for improvement in the selection of wellbore and layer in gas reservoir horizontal wells:

3.1. In-depth analysis of logging data:

Many experiments have confirmed the indispensable role of logging data in wellbore and layer selection. Almost all methods require the use of logging data for research. Therefore, further analysis of logging data is necessary.

3.2. Comprehensive consideration of quantified factors:

Quantitative processing can reduce the experiential and arbitrary nature of assessments, improving the accuracy and efficiency of fracturing decision-making. In future model development, it is necessary to consider as many indicators as possible that affect wellbore and layer selection in hydraulic fracturing, making the prediction system more comprehensive and widely applicable.

3.3. Integration of "big data" for optimization analysis:

The literature shows that there are numerous factors that influence the effectiveness of fracturing operations, and these factors are interrelated in complex ways. Therefore, when faced with an increasing amount of production well data, it is imperative to establish a systematic, scientific, and intelligent big data network to achieve efficient, economical, and reliable fracturing for production enhancement.

3.4. Strengthen research on pre-fracturing wellbore and layer selection in gas reservoir horizontal wells:

Based on the literature, most of the experiments and articles focus on vertical and oil wells, while research on wellbore and layer selection in horizontal gas wells is not yet sufficiently in-depth. Although in some cases, evaluation methods for oil and vertical wells can provide reference for wellbore and layer selection in horizontal gas wells, it is still necessary to conduct specialized research specifically for wellbore and layer selection in horizontal gas wells.

References

[1] Su Jianzheng. Discussion on wellbore and layer selection in horizontal well fracturing[J]. Fault-Block Oil and Gas Field, 2010, 17(04): 455-457.

[2] Bhattacharya S, Nikolaou M. Comprehensive optimization methodology for stimulation design of low-permeability

unconventional gas reservoirs[C].//SPE. Annual Technical Conference and Exhibition, Denver, 2011.

[3] Wang Yajuan, Zhang Yanming, He Mingfang, et al. Research on production enhancement technology of multi-layer tight sandstone gas reservoirs in Shumudi Gas Field[J]. Well Testing, 2017, 26(03): 66-68+78.

[4] Tang Xiujuan. Research on methods to improve fracturing effectiveness[J]. Petrochemical Technology, 2018, 25(11): 43.

[5] Moore L P, Ramakrishnan H. Restimulation: candidate selection methodologies and treatment optimization[C].//SPE. Annual Technical Conference and Exhibition, San Antonio, Texas, USA, 24-27 September, 2006.

[6] Huang Yuming, Zheng Wenlong. Evaluation of fracturing and fracturing effect of coalbed methane wells based on principal component analysis[J]. Coal Engineering, 2018, 50(02): 137-141+144.

[7] Dang Hailong, Cui Pengxing, Liu Shuangshuang, et al. Research and application of wellbore and layer selection in low-permeability oil reservoir fracturing[J]. Systems Engineering Theory and Practice, 2018, 38(04): 1082-1088.

[8] Wang Xin, Ji Xiaohong, Shan Feng, et al. Calculation and comparison of influencing factors on production capacity in carbonate horizontal wells[J]. Journal of Yangtze University (Natural Science Edition), 2016, 13(28): 19-24+4.

[9] Liang Tao, Chang Yuwen, Guo Xiaofei, et al. Ranking the influence degree of single well productivity parameters in Bakken tight oil reservoirs[J]. Petroleum Exploration and Development, 2013, 40(03): 357-362.

[10] Yin Wenying, Zhou Wei, Liu Fuming, et al. Equipment renewal decision-making of mining enterprises based on grey correlation TOPSIS method[J]. Coal Technology, 2016, 35(08): 304-306.

[11] Yang Xiaosong, Sun Liangtian, Sun Lei, et al. Application of fuzzy mathematics in analysis of factors for wellbore and layer selection in well fracturing and acidizing[J]. Drilling & Production Technology, 2005, 28(04): 39-43.