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Method for Evaluating the Effect of Drainage Construction Based on Deviation Maximization Approach

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Abstract

Drainage gas recovery technologies are primarily utilized to control the effusion in the gas well bore and maintain the gas well's regular production. The primary evaluation method for the application effect of the drainage gas production process is the production parameter evaluation after construction. However, the evaluation index system lacks a reasonable drainage gas production construction effect evaluation index system. To address this gap, this paper examines the principles and characteristics of six common drainage and gas production processes and analyzes the evaluation construction effect in detail from four perspectives, including object, process, data, and goal. Six basic principles for the construction of the index system are established. Based on grounded theory and deviation maximization approach, this paper proposes 30 effect evaluation indicators, including four categories of production layer status, process requirements, downhole conditions, and equipment status, and statistical independence and significance indicators are screened. The factor analysis method is used to test the rationality of the construction effect evaluation indicators, and the contribution rate of selected indicator information is found to be greater than 90%, indicating that the constructed drainage and gas production construction effect evaluation indicator system is reasonable.

Keywords: Drainage and gas production, effect evaluation, indicator screening, evaluation index system, grounded theory

1. Introduction

Gas well fluid accumulation is a common problem in natural gas production, and more than 80% of the gas fields that have been put into development in China are water-producing fields[1]. Gas well fluid accumulation not only leads to a rapid decline in gas well production or even flooding and shutdown but also leads to ineffective recovery of many natural gases due to reservoir blockage[2]. Dewatered gas recovery is a common and effective means of solving gas well fluid accumulation[3-15].

Since the beginning of the last century, many theories and technologies have been developed for drainage gas recovery technology. At present, six processes, namely foam drainage, preferred tubular column, gas lift, jet pump, electric submersible pump, and machine pumping, are mainly used in several regions of China[16]. Various drainage gas recovery technologies are based on different principles and utilize distinct operational procedures with unique adaptations and technical characteristics. Additionally, differences in geological characteristics and production features of water-bearing gas wells result in substantially diverse post-construction effects. However, due to the diversity of construction processes and the complexity of site conditions, there is still no set of methods that can effectively compare and evaluate the construction effects on-site, and therefore the effectiveness of the processes cannot be effectively judged[17]. Establishing a scientific and reasonable construction effect evaluation index system is the first and most important step of construction evaluation[18]. Through research, it is found that the common evaluation methods are centered on the production effect after construction, and the evaluation indexes are highly subjective.

In view of this, this paper follows scientific and reasonable construction principles and steps based on the characteristics of the drainage gas production process and gas field development needs. It establishes the construction effect evaluation index system by screening evaluation indexes based on the rooting theory[19-21] using mathematical methods such as the deviation maximization method[22-27]. This provides guidance and reference for the construction of the drainage gas production construction effect evaluation index system.

2. Research Design

2.1 Research method

Due to their reliance on human a priori knowledge, understanding, and existing literature, common methods such as the Deffel method and the hierarchy of objectives method are highly subjective[28]. The evaluation index system constructed may differ greatly from the actual situation. The core of rooting theory is "rooted" in reality and data, i.e., the index builder directly analyzes and refines the collected information without making any theoretical assumptions about the index system. Repeatedly analyzing and summarizing the information finally forms a theory[29]. Therefore, this paper explores the index system of drainage gas extraction construction effect evaluation by using the method of rooting theory. Its process is mainly as follows: data collection - preliminary construction of the index system - index independence screening - index significance screening - index system reasonableness test.

2.2 Data collection

Based on the methodological requirements of the root theory and in consideration of the actual conditions of the study, this paper employs the following approach to collect and obtain the original information required for the construction of the technical index system for the preferential drainage gas extraction method:

(1) On-site data collection: collecting relevant information or data generated by PetroChina Southwest Oil and Gas Field Branch, Sinopec Southwest Oil and Gas Company, and PetroChina Coalbed Methane Company in the process of drainage gas extraction construction.

(2) Interviews with relevant subjects: One-on-one interviews or group discussions were conducted with representatives of construction subjects, such as on-site construction managers, experts in relevant fields, and executors or decision makers of the evaluation. The interviews mainly focused on the following questions:

a. the importance of evaluating the construction effect of drainage gas extraction,

b. indicators for evaluating the construction effect of drainage gas extraction,

c. indicators that are not fixed in the process of drainage gas extraction construction. The information gathered from the interviews was compiled.

(3) Literature research: To gather relevant information for constructing the technical index system for the preferential drainage gas extraction method, the authors searched databases on the internet using keywords such as "drainage gas extraction process," "drainage gas extraction construction effect," and "drainage gas extraction evaluation index."

3. Initial Construction of Indicator System

3.1 Characteristics of the indicator system

The technology of drainage gas extraction process has undergone significant development since the beginning of the last century, with six processes being predominantly used in several atmospheric regions in China, including foam drainage, preferred pipe column, gas lift, jet pump, electric submersible pump, and machine pumping[7]. These processes are based on different principles, utilize different operational processes, and have different adaptations and technical characteristics. In addition, differences in geological characteristics and production features of water-bearing gas wells lead to fundamentally different post-construction effects. A simple evaluation based solely on two indicators of gas or water production cannot reflect the construction characteristics of each process measure, nor can it judge how the final benefits of the whole measure are achieved. Therefore, it cannot effectively evaluate the construction effect, especially when comparing the construction effects of processes with different well conditions. Moreover, such evaluations are highly subjective and discriminatory. To overcome these issues, it is necessary to establish an evaluation index system suitable for evaluating the construction effect of drainage and gas extraction from the technical aspect, using reasonable mathematical methods and steps.

However, the complexity of constructing an evaluation index system for the construction effect of each drainage process arises from the differences in principles, scope of application, and construction effect of each process, as well as the varied causes and conditions of gas well liquid accumulation. These differences require a detailed analysis of the reasons why simple indicators cannot effectively evaluate the construction effect, and the use of reasonable mathematical methods and steps to establish an evaluation index system.

(1) Evaluation objects are diverse: Different drainage gas production processes have unique principles and characteristics, making it difficult to evaluate each process with a single index. Therefore, it is crucial to establish indicators that cover the main characteristics of each process, ensuring that the indicator system is comprehensive and specific.

(2) The evaluation process is complex: The evaluation of the drainage and gas extraction process involves multiple processes and various gas well accumulation conditions, which increases the complexity of the evaluation. Therefore, it is essential to follow scientific construction steps, using mathematical methods to compare and filter indicators, to ensure a rigorous evaluation.

(3) Abstract nature of evaluation data: The gas well production process generates vast amounts of diverse data that do not directly reflect the effect of each process. Hence, it is crucial to screen and process the data to ensure that the data can demonstrate the characteristics of the process and lead to accurate evaluation results.

(4) Dynamic evaluation objectives: The cost of the process, technology and equipment, and the condition of the gas well accumulation may change over time, leading to changing characteristics and objectives of the comprehensive evaluation over time. Therefore, it is vital to consider the dynamic nature of the evaluation and select appropriate methods to address it while constructing the index system.

Therefore, when establishing an effective construction effectiveness evaluation index system, it is essential to clarify the sources and solutions to the various complexities involved. It is then necessary to base the system on scientific and reasonable guidelines and steps while utilizing effective mathematical methods to process and test the indexes. The dynamics of the evaluation should also be taken into account to ensure that the evaluation is accurate and comprehensive.

3.2 Guidelines for establishing an index system

The complex nature of the evaluation index system for the construction effect of drainage gas extraction makes it challenging to use existing construction methods to create a scientific and rational evaluation index system. Therefore, it is crucial to analyze and examine the fundamental guidelines and reference steps for establishing the index system. This analysis can provide guidance and references for constructing the evaluation index system of the drainage and gas extraction construction effect, as illustrated in figure 1.

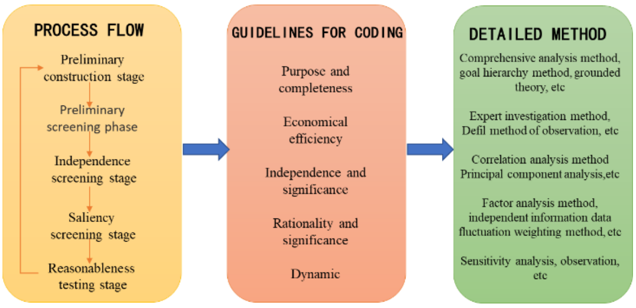

Figure 1 5-stage method for evaluation index system construction

3.3 Construction of index system

Upon obtaining the original information and data, a sample of 30 copies were randomly selected for theoretical coding, while the remaining six copies were utilized for the theoretical saturation test to create the initial index system for evaluating the construction effect of drainage gas extraction, as illustrated in Table 1.

Table 1 Evaluation index system of drainage and gas production construction effect

Target layer	Code layer	Number	Indicator layer	Remark
Construction effect of drainage and gas production process	Production layer condition	I1,1	Remaining reserves	The requirements of each process for the remaining reserves of gas wells are evaluated by means of expert scoring
		I1,2	Gas well energy	Requirement of gas well energy for each process
		I1,3	Formation static pressure	Formation pressure is required for the normal operation of each process
		I1,4	Gas well condition	Adaptation of different processes to different gas well conditions (flooded shut-in wells/intermittent injection wells/weak injection)
		I1,5	Well slope condition	The maximum well slope angle and the influence of the bending of the tubular column on the normal operation of different processes
		I1,6	Well structure	The influence of tubing diameter and well facilities on the normal operation of different processes
		I1,7	Types of fluid accumulation	Range of adaptation of each process to different types of fluid accumulation (formation water, energy deficiency, condensate)
	Process requirements	I2,1	Depth of gas formation	Maximum depth of gas formation that can be reached for normal operation of the process
		I2,2	Pipeline depth	Maximum pipeline entry depth that can be achieved by normal operation of the process
		I2,3	Daily gas production	The maximum daily gas production that can be achieved under normal process operation
		I2,4	Daily discharge volume	Maximum daily discharge volume that can be achieved in normal process operation
		I2,5	Work regime	Complexity of the work regime for maintaining the process operation
		I2,6	Speed of effect	Time from construction to desired effect
		I2,7	Inner diameter of tubing	Condition of inner diameter of tubing required for process operation
	Downhole conditions	I3,1	Carbon dioxide content	The maximum carbon dioxide content that can be tolerated for normal operation of each process under normal conditions
		I3,2	Hydrogen sulfide content	The maximum hydrogen sulfide content that each process can withstand under normal operating conditions
		I3,3	Sand emergence	The effect of sand emergence from the strata on the normal operation of each process
		I3,4	Fouling condition	Influence of fouling on normal operation of each process
		I3,5	Mineralization of produced layer of water	Maximum mineralization content that can be tolerated for normal operation of each process under normal conditions
		I3,6	Formation temperature	Maximum downhole temperature that each process can normally withstand in normal operation
		I3,7	Condensate content	Maximum condensate content that can be tolerated during

				normal operation of the process
	Equipment condition	I4,1	Energy supply requirements	Additional energy supply required to maintain process operation
		I4,2	Operational stability	Duration of stable operation of the equipment
		I4,3	Management difficulty	The difficulty of managing the equipment
		I4,4	Difficulty of maintenance	The difficulty of maintenance after equipment failure
		I4,5	Flexibility of adjustment	Ease of subsequent adjustment according to demand
		I4,6	Process supporting facilities	Whether each process requires special facilities (e.g. bubble drainage device)
		I4,7	Personnel requirements	The level of personnel requirements for process operation, equipment management, and other steps
		I4,8	Requirements for packers	Whether process operation requires special requirements
		I4,9	Lifting efficiency	The ratio of equivalent output power to equivalent input power of lifting system

4. Independence and Significance Screening

This stage aims to improve the overall significance of the evaluation index system by reducing or eliminating the correlation between evaluation indexes while ensuring that the index system information is independent of each other and can characterize the main features.

4.1 Independence screening

For independence screening, this study uses the correlation coefficient in statistics. If there are n indicators after the screening, with each indicator having m observations, I_i and I_j denote the i-th indicator and j-th indicator, respectively. Additionally, I_{ik} and I_{ik} denote the k-th observation of I_i and I_j respectively, and r_{ij} denotes the correlation coefficient between the i-th and j-th indicators, where i=1,2,...,n; j=1,2,...,n; and k=1,2,...,m. The specific calculation formula (1) is as follows:

$$r_{ij}=\frac{m\sum I_{ik}I_{jk}-\sum I_{ik}\sum I_{jk}}{\sqrt{m\sum I_{ik}{}^2-(\sum I_{ik})^2}\sqrt{m\sum I_{jk}{}^2-(\sum I_{jk})^2}} \tag{1}$$

where:

m: the number of indicator observations.

n: the number of indicators.

I_i, I_j: indicators.

I_{ik}, I_{jk}: observations of the indicator.

The larger the r_{ij}, the higher the information overlap between the indicators. Generally, if $|r_{ij}|<0.9$, the information overlap between the two indicators is considered to be within an acceptable range, and the opposite requires the deletion of one of them.

Focusing solely on technical indicators such as extraction conditions can yield better drainage results in the early stages of gas field development. However, in the later stages, faulty implementation and management may occur, requiring equipment condition indicators for compensation. Therefore, the acquisition cost of evaluation index data should not be excessively high, and the indexes should align with market reality and technological development trends. The correlation coefficients of the indicators were calculated during the initial screening, and a critical value of $|r_{ij}| = 0.9$ was established for independent screening. The correlation coefficients and independence screening results for each indicator are presented in Table 2.

Table 2 Independent screening results of evaluation indicators for drainage and gas production construction effect

Primary Indicator	Name	Delete Indicator	Name	Correlation Factor
I1,7	Types of fluid accumulation	I1,2	Gas well energy	0.868
I2,1	Depth of gas formation	I2,2	Pipeline depth	0.997
I2,1	Depth of gas formation	I1,3	Formation static pressure	0.971
I2,1	Depth of gas formation	I3,6	Formation temperature	0.96
I4,3	Management difficulty	I4,4	Difficulty of maintenance	0.91
I4,3	Management difficulty	I4,2	Operational stability	0.891
I4,7	Personnel requirements	I2,5	Work regime	0.891
I4,9	Lifting efficiency	I4,8	Requirements for packers	0.959
I4,9	Lifting efficiency	I2,4	Daily discharge volume	0.864

4.2 Significance screening

In this paper, the outlier maximization method is chosen to perform indicator significance screening. In the comprehensive evaluation problem with multiple indicators and multiple solutions, the evaluation solution set is denoted by A={A1,A2,...,Am}, the evaluation indicator set by G={G1,G2,...,Gn}, and the main steps are as follows.

Collect the original evaluation data of all indicators and normalize them to obtain the decision matrix. The qualitative indicators are selected from the utility theory processing data, and the standardized scores are given directly by expert judges. The quantitative indicators are selected according to their types and processed accordingly[30].

Construct the weight solution model. The total deviation of all evaluation indicators under all evaluation schemes should be $D=\sum_{j=1}^{n}\sum_{i=1}^{m}\sum_{k=1}^{m} w_j|u_{ij}-u_{kj}|$, (i=1,2,...,m; j=1,2,...,n; k=1,2,...,m). Since the weighted vector W=(w1, w2 ,...,wn) is the largest if the total deviation and D, the optimization model is as follows.

$$\begin{cases} D=\sum_{j=1}^{n}\sum_{i=1}^{m}\sum_{k=1}^{m} w_j|u_{ij}-u_{kj}| \\ \qquad\qquad \sum_{j=1}^{n} {w_j}^2=1 \\ s.t: \\ \qquad\qquad w_j>0, j=1,2,\dots,\ n \end{cases} \tag{2}$$

where: D - total deviation

W - weighting vector

u_{ij} - the j-th indicator corresponding to the i-th scheme.

Solve the model to obtain the indicator weight vector. Using the Lagrangian function to solve the model, the optimal solution of the model is obtained as $W^*=({W_1}^*,{W_2}^*,\cdots {W_n}^*)$.

$${W_j}^*=\frac{\sum_{i=1}^{m}\sum_{k=1}^{m}|u_{ij}-u_{kj}|}{\sqrt{\sum_{j=1}^{n}[\sum_{i=1}^{m}\sum_{k=1}^{m}|u_{ij}-u_{kj}|]^2}}\quad (j=1,2,\cdots n) \tag{3}$$

The indicator weights of the index system after normalization are:

$$W_j=\frac{{W_j}^*}{\sum_{j=1}^{n}{W_j}^*} \tag{4}$$

Significance screening: set the critical value M. When $W_j \geq$ M, the indicator is considered to be more significant and can be retained; otherwise, it is deleted. Usually, the critical value is taken as the reciprocal of the number of indicators.

To conduct significance screening, relevant data generated by PetroChina Southwest Oil and Gas Field Branch, Sinopec Southwest Oil and Gas Company, and PetroChina Coalbed Methane Company in 2021 during the construction of drainage gas extraction were used. The weights of each indicator after independence screening can be obtained by the deviation maximization method after data normalization, as shown in Table 3.

Table 3 Screening results of significance of evaluation indicators for drainage and gas production construction effect

Indicator	name	weight

I1,5	Well slope condition	0.0516
I1,6	Well structure	0.0590
I1,7	Types of fluid accumulation	0.0516
I2,1	Depth of gas formation	0.0565
I2,6	Speed of effect	0.0479
I2,7	Inner diameter of tubing	0.0590
I3,1	Carbon dioxide content	0.0505
I3,2	Hydrogen sulfide content	0.0481
I3,4	Fouling condition	0.0479
I4,1	Energy supply requirements	0.0516
I4,3	Management difficulty	0.0590
I4,5	Flexibility of adjustment	0.0516
I4,6	Process supporting facilities	0.0663
I4,7	Personnel requirements	0.0590
I4,9	Lifting efficiency	0.0511

5. Reasonableness Test of the Index System

Using factor analysis to examine the rationality of the index system. Assuming the original number of indicators is h, and the number of indicators after screening is l, the formula for calculating the information contribution rate In of the index system before and after screening is:

$$In = \frac{trS_l}{trS_h} * 100\% \tag{5}$$

Here, trS_l denotes the trace of the covariance matrix of the evaluation index data after quantitative screening, and trS_h denotes the trace of the covariance matrix of the original index data before screening. Generally speaking, if In is equal to or greater than 90%, the construction of the index system is considered reasonable.

Table 1 shows the labeled indicators, where 1 represents retention, 2 represents operability deletion, 3 represents relevance deletion, and 4 represents significance deletion. The variance for both the final indicators and the operability indicators was computed. Subsequently, leveraging Equation (5), the information contribution rate of the selected indicators was determined relative to the initial set of screened indicators. This analytical approach quantifies how effectively the chosen metrics contribute to the understanding derived from the primary selection of indicators. The calculated rate was In = 90.2%, which is greater than 90%. Therefore, the evaluation index system of gas extraction construction effect constructed in this study is reasonable.

6. Conclusion

In this study, we conducted a study on the criteria, process, and methods for the construction of the evaluation index system for the drainage and gas extraction based on actual production in the field. Our findings can be summarized as follows:

(1) An analysis was conducted from four dimensions—object, process, data, and goal—to dissect the evaluation perspective of construction effectiveness. Six guiding principles emerged for index formulation: purposefulness, comprehensiveness, economy, prominence, independence, and dynamism.

(2) Drawing upon these foundational principles, an expansion was made to the conventional three-phase methodology of index development, introducing a refined five-step approach encompassing preliminary construction, preliminary screening, independence and significance filtering, rationality verification, and feedback validation.

(3) Within the framework of index system creation, the stages of initial structuring, quantitative filtration, and reasonableness examination were addressed through the strategic selection of methodologies such as Grounded Theory, statistical techniques, the Deviation Maximization Method, and Factor Analysis. This amalgamation of methods facilitated a more scientifically sound and logically coherent assembly of the index system.

(4) Grounded in the outlined theoretical underpinnings, an index system for assessing the efficacy of drainage and gas extraction construction was formulated. Adhering to the tenet of "cost reduction and efficiency enhancement,"

a streamlined set of 15 indices was extracted from an initial pool of 30. The calculated information contribution rate of the retained indices exceeded 90%, affirming the rationality and validity of the devised evaluation system for drainage and gas extraction construction outcomes.

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