frontiers | Frontiers in Energy Research

TYPE Original Research
PUBLISHED 15 January 2024
DOI 10.3389/fenrg.2023.1309777

OPEN ACCESS

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RECEIVED 08 October 2023
ACCEPTED 26 December 2023
PUBLISHED 15 January 2024

CITATION
Li Y, Zhu L, Lv R and Ni X (2024), Construction and application of workover priority evaluation model for surface coalbed methane low production wells based on Entropy-TOPSIS.
Front. Energy Res. 11:1309777.
doi: 10.3389/fenrg.2023.1309777

Construction and application of workover priority evaluation model for surface coalbed methane low production wells based on Entropy-TOPSIS

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Affected by geology and mining, a certain number of low-yield wells will appear after a period of production in coalbed methane wells, and technical repairs are urgently needed to restore their production capacity to the maximum. Therefore, it is of great significance to establish a reasonable and feasible theoretical standard to evaluate the workover priority of CBM wells for the efficient utilization of CBM resources. From the perspectives of technical feasibility and economic rationality, eight key indicators that affect the cost performance of CBM well workover are screened. Combining the entropy value method and the TOPSIS comprehensive ranking method, the surface coalbed methane well repair priority entropy value-TOPSIS comprehensive evaluation model was constructed, and the surface coalbed methane well repair priority evaluation was carried out by taking 9 surface coalbed methane wells that urgently needed to be repaired in a mine as the evaluation objects. The evaluation results show that among the economic indicators, the average gas production per meter in the 30 days before the coal bed methane well was stopped and the cumulative gas production per meter before the stop had a relatively high weight, which were 29.68% and 13.83% respectively, This shows that in coalbed methane well workover operations, the long-term gas production potential of the coalbed methane well and the gas production capacity when disturbed by harmful factors are the decisive factors affecting the priority of coalbed methane well workover; Among the technical indicators, the degree of casing deformation and the depth of the coalbed methane well have a relatively high weight, accounting for 11.34% and 9.90% respectively, This shows that the smaller the deformation of the wellbore casing and the shallower the depth of the coalbed methane well, the higher the priority of the workover of the coalbed methane well; The ranking of the production recovery rates of the three coalbed methane wells in the Pingdingshan mining area after workover operations is consistent with the results output by the evaluation model, which proves that the evaluation model is reasonable for determining the priority of workovers for damaged

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Abbreviations: CBM, Coalbed methane; TOPSIS, Technique for Order Preference by Similarity to an Ideal Solution.

wellbores; This evaluation model can provide a theoretical reference for small and medium-sized coalbed methane development companies to determine the priority of workovers.

KEYWORDS

coalbed methane, workover, entropy method, TOPSIS, evaluation model

1 Introduction

China's coal production and consumption are the first in the world, and the amount of coal resources is the third in the world after the United States and Russia. (LH et al., 2020). As a clean energy associated with coal, coalbed methane has great development potential and strategic economic value. According to the survey, by the end of 2019, China's cumulative proven coalbed methane geological reserves reached 658.6 billion m^3 (SUN et al., 2021). In recent years, with the support of national science and technology projects such as the 12th Five-Year Plan ' and national industrial development policies, CBM exploration and development work has achieved great results in technology application and industrial development scale (QIN, 2021; HUANG et al., 2022; JIANG et al., 2022; ZHANG et al., 2023). Data show (LC et al., 2021): By the end of 2020, a total of 21,217 CBM wells have been constructed in China, including 19,540 vertical wells and 1,677 horizontal wells.

However, due to the influence of *in-situ* stress (WJ et al., 2022), hydraulic fracturing (DAI et al., 2022), reservoir structure (ZHOU et al., 2019; ML et al., 2021), coal body structure (XZ, 2017) and other factors, the low gas production efficiency of coalbed methane wells caused by the deformation and damage of wellbore casing has become one of the problems that restrict the production of surface coalbed methane wells for a long time. In the process of coalbed methane development, a certain number of coalbed methane wells will be deformed and damaged. However, as well workover operations are supporting measures for drilling projects in the process of coalbed methane resource development, the industry pays little attention to the engineering problems in well workover operations, Current research on well workovers mainly focuses on workover equipment (LIU et al., 2016; HAN et al., 2017), workover tools (LI et al., 2012; Tao, 2015), and workover technology (TONG et al., 2018) under high water content, low permeability, ultra-deep, and ultra-high pressure reservoir conditions. Large coalbed methane development companies have complete engineering supporting tools and can complete the repair work of large quantities of damaged wellbores in a short period (Lei et al., 2020). However, small and medium-sized coalbed methane development enterprises lack complete well workover equipment and tools, and do not have the conditions to operate multiple well workover equipment at the same time. Therefore, they mostly determine the repair plan for damaged wellbores based on empirical methods, that is, giving priority to repairing coalbed methane wells with low damage or high production. During the development of coal-bed methane in the Pingdingshan mining area, we found that coal-bed methane wells with low degree of damage still had poor gas production after the workover work was completed, Coalbed methane wells with high output are characterized by high workover difficulty and long workover period. Under the constraints of budget and construction period, the empirical method will reduce production efficiency to a certain extent and cause economic losses to the enterprise. Therefore, establishing a reasonable and feasible evaluation model to determine the priority of CBM well repair is of great significance for small and medium-sized CBM development enterprises to reduce costs and increase efficiency.

The current mainstream evaluation methods include subjective methods and objective methods. As the two most commonly used subjective evaluation methods, the analytic hierarchy process (LEE, 2015; CHEN et al., 2022) and the fuzzy comprehensive evaluation method (WEN, 2008; ZHANG et al., 2021) have the advantages of wide evaluation range and strong flexibility, and are mostly used in finance, environment, agriculture and other fields. However, the subjective method completely relies on the subjective consciousness of the evaluator in terms of index weighting and quantitative processing of qualitative indicators. The academic level of the evaluator will directly affect the accuracy of the evaluation results. For the same evaluation object, different evaluators may even arrive at completely different evaluation results. Unlike the subjective method, the conclusions drawn through the objective method are entirely based on sample data and are not affected by the subjective consciousness of the evaluator. Meanwhile, different objective evaluation methods have different requirements for the number of samples, and the evaluator needs to choose an appropriate objective evaluation method for the evaluation object. As an objective evaluation method for solving multi-objective decision-making problems, TOPSIS has strong operability in its application and has low requirements on sample size. For evaluation objects with small sample size, TOPSIS can calculate relatively accurate ranking results (CHEN, 2019; SILVA and de ALMEIDA, 2020; CHEN, 2021; WANG et al., 2022).

In view of this, this article combines the case of Pingdingshan surface coalbed methane development, determines evaluation indicators around technical feasibility and economic rationality, and combines the entropy value method and the TOPSIS comprehensive ranking method, a surface coalbed methane well repair priority evaluation model is constructed to provide a theoretical reference for small and medium-sized coalbed methane development enterprises to determine the well repair priority.

2 Priority evaluation index system for workover of surface coalbed methane wells

Based on the field exploration and data collection, 8 key first-level indicators are determined around the two aspects of technical

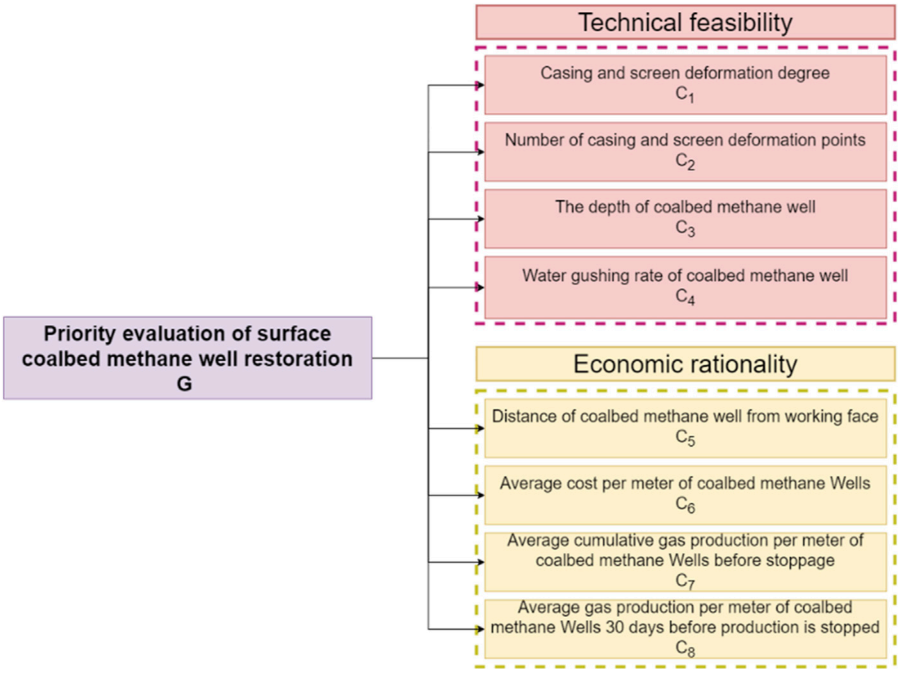

FIGURE 1
Surface coalbed methane well rehabilitation priority evaluation index system.

feasibility and economic rationality, so as to construct the evaluation index system of surface CBM well repair priority, as shown in Figure 1.

2.1 Technical feasibility

(1) Deformation degree of casing and screen C_1

Due to the strong geological structure changes in China's CBM production areas and the transformation of artificial reservoirs, some production casings of CBM wells are deformed, corroded, damaged, and broken, which seriously affects the normal drainage of CBM wells (LIU et al., 2017). In addition, the casing repair is difficult, expensive, and the construction period is long, and the gas production effect of the repaired coalbed methane well is uncertain. Therefore, the greater the degree of casing deformation, the lower the priority of wellbore repair, and C_1 is a negative index.

(2) Casing and screen deformation point C_2

The number of casing and screen deformation points directly affects the construction difficulty and construction period, so C_2 is a negative index.

(3) Well depth of CBM low production well C_3

With the increase of the depth of coalbed methane low-yield wells, the *in-situ* stress and water pressure on the wellbore increase exponentially. At the same time, the stress form of deep strata is changeable, which increases the construction difficulty and construction period (GAO et al., 2022). Therefore, C_3 is a negative indicator.

(4) Water inflow rate of low-yield CBM wells C_4

Under the action of extrusion and shear stress, the failure of cementing quality will lead to casing deformation and dislocation, which will lead to groundwater inflow into the wellbore and cause well flooding (TONG et al., 2021). The influx of groundwater into the wellbore will hinder the exploration vision of the endoscope and increase the difficulty of wellbore repair construction. Therefore, C_4 is a negative indicator.

2.2 Economic rationality

(1) Distance between CBM well and mining face C_5

Working face mining will cause coal seam pressure relief, accelerate gas desorption, promote the development of coal seam cracks, and increase gas migration channels (TIAN et al., 2015). When the mining face advances to the position of the coalbed methane well, the overlying strata on the coal mining face collapses, and the gas desorbed from the coal seam migrates to the fracture zone, thus promoting the production of the coalbed methane well (XU et al., 2022). Therefore, the closer the CBM well is to the mining surface, the higher the priority of wellbore repair should be, and C_5 is a positive index.

(2) The average cost per meter of CBM wells C_6

This index is mainly used to characterize the repair cost of low-yield CBM wells, and the corresponding repair cost of low-cost CBM wells is lower. Under the limited budget, the low cost CBM well repair priority is higher, so it is the C_6 negative index.

(3) Accumulated gas production per meter before stopping mining C_7

This index is mainly used to characterize the lasting gas production capacity of coalbed methane wells. The higher the index value, the higher the priority of wellbore repair. C_7 is a positive indicator.

(4) The average gas production per meter in 30 days before stopping mining C_8

The index is used to characterize the gas production capacity of coalbed methane wells after suffering damage factors. The higher the index value, the higher the priority of wellbore repair. C_8 is a positive indicator.

3 Construction of entropy-TOPSIS evaluation model

3.1 Entropy method to determine the objective weights of indicators

1) The original data of y indexes of x samples are used to construct the initial evaluation matrix A (YANG et al., 2022). In this article, x is the 9 coalbed methane wells that need to be evaluated, y is the evaluation indicators C1-C8, and a11 is the value of the indicator C1 corresponding to the first coalbed methane well.

$$A = \begin{pmatrix} a_{11} & \cdots & a_{1y} \\ \vdots & \ddots & \vdots \\ a_{x1} & \cdots & a_{xy} \end{pmatrix} \tag{1}$$

2) The range method is used to standardize the initial evaluation matrix to obtain the matrix $B = (b_{xy})$.

For the positive indicators that the greater the partial value, the better the impact on the evaluation results, the standardized formula is:

$$B_{xy} = \frac{a_{xy} - \min(a_x)}{\max(a_x) - \min(a_x)} \tag{2}$$

On the contrary, the formula for the standardization of negative indicators is:

$$B_{xy} = \frac{\max(a_x) - a_{xy}}{\max(a_x) - \min(a_x)} \tag{3}$$

3) According to the definition of information entropy, the information entropy acquisition formula of a set of data is:

$$E_y = \frac{-\sum_{x=1}^{n} d_{xy} \ln d_{xy}}{\ln n} \left(y = 1, \cdots, m\right) \tag{4}$$

$$\text{Among: } d_{xy} = \frac{B_{xy}}{\sum_{x=1}^{n} B_{xy}} \left(x = 1, 2, \cdots, n\right) \tag{5}$$

4) Calculate the index weight

The weight of the y index is:

$$W_y = \frac{K_y}{\sum_{y=1}^{m} K_y} \left(y = 1, 2, \cdots, m\right) \tag{6}$$

$$\text{Among: } K_y = 1 - E_y \left(y = 1, 2, \cdots, m\right) \tag{7}$$

3.2 Entropy-TOPSIS quantitative evaluation model

TOPSIS (Technique for Order Preference by Similarity to Ideal Solution)is a ranking method introduced by C.L.Hwang and K.Yoon in 1981. Its idea stems from the discriminant problem in multivariate statistical analysis and aims to determine the final solution from limited alternatives (XZ and JS, 2019). This method finds the optimal solution (ideal solution) and the worst solution (negative ideal solution) of the scheme from the original matrix, and then calculates the Euclidean distance between each scheme and the optimal solution and the worst solution to obtain the corresponding relative proximity. If there is a scheme that is closest to the ideal solution and far away from the negative ideal solution, the scheme is the best solution. The calculation steps are as follows.

(1) Construct the initial matrix

Suppose that there are n evaluation targets S_1, S_2, ... S_n, and each target has m evaluation indexes D_1, D_2 . . . . . . Dm, then the matrix S is constructed:

$$S = \begin{pmatrix} D_{11} & D_{\ldots} & D_{1m} \\ D\ldots & D\ldots & D\ldots \\ D_{n1} & D_{\ldots} & D_{nm} \end{pmatrix} \tag{8}$$

(2) Weighted normalized decision matrix

Because the units and evaluation criteria of each evaluation index are not uniform, matrix F is obtained by standardizing the evaluation indexes according to Formula 2 to Formula 3. The weighted normalized decision matrix refers to the column vector of the normalized matrix F multiplied by the index weight W_{nm} obtained by the entropy method, and the matrix U is obtained. $U_{nm} = W_{nm} {}^* F_{nm}$, can be expressed as:

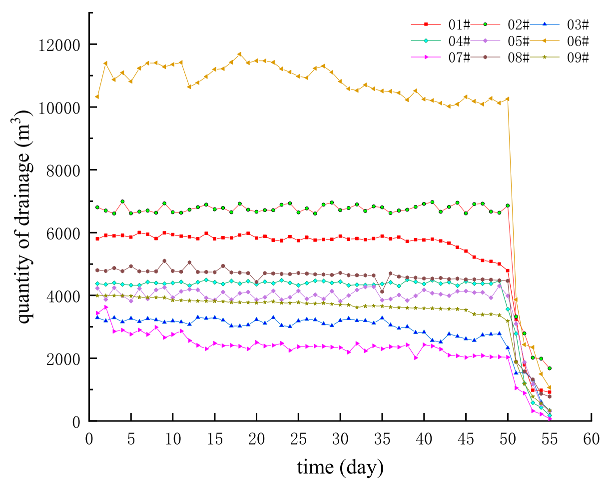

FIGURE 2
Gas production data of 9 low-yield coalbed methane wells in the 50 days before the sudden drop in production.

$$U = \begin{pmatrix} W_1F_{11} & W...F... & W_mF_{1m} \\ W...F..._{..} & W...F... & W...F... \\ W_1F_{n1} & W...F... & W_mF_{nm} \end{pmatrix} \tag{9}$$

(3) Determining positive and negative ideal points q$^+$ and q$^-$

In the decision matrix U, the vector composed of the maximum elements of each column is the positive ideal point q$^+$; the vector composed of the minimum elements of each column is called a negative ideal point q$^-$;

$$\text{Among:} \begin{cases} q^+ = (q_1{}^+, q_2{}^+, ...q_n{}^+), q_i{}^+ = \max\{q_{nm}\}, i = 1, 2, ...m \\ q^- = (q_1{}^-, q_2{}^-, q_n{}^-), q_i{}^- = \min\{q_{nm}\}, i = 1, 2, ...m \end{cases} \tag{10}$$

(4) Calculate the distance D$^+$ and D$^-$ from each definition point u$_i$ to the ideal solution.

$$\begin{cases} D^+ = \sqrt{\sum_{i=1}^{n} (q_{nm} - q_m{}^+)^2} \\ D^- = \sqrt{\sum_{i=1}^{n} (q_{nm} - q_m{}^-)^2} \end{cases} \tag{11}$$

where, the smaller D$^+$ indicates the closer to the positive ideal solution; the smaller the D$^-$, the closer to the negative ideal solution.

(5) Calculate the closeness K_i

$$K_i = \frac{D_i{}^-}{(D_i{}^+ + D_i{}^-)}, i = 1, 2, ...n \tag{12}$$

In the formula, the closeness degree K$_i$ of the evaluation object reflects the degree that the overall index of the evaluation object is close to the positive ideal solution, and the value range is between 0 and 1.

4 Entropy-TOPSIS evaluation model engineering application and verification

Nine surface coalbed methane wells in a mine are surface coalbed methane extraction wells built in the same batch. All nine wells are mining wells, among which # 1, # 2, # 3, # 4, # 5, # 8, and # 9 are vertical wells, # 6 and # 7 are horizontal wells. Affected by the damage factors, the gas production of 9 wells was greatly reduced. The daily gas production data of 9 wells 50 days before the gas production drop are shown in Figure 2.

4.1 Entropy method to calculate index weight

In this paper, the original data of 9 surface coalbed methane wells that need to be repaired urgently are collected, and the specific index data are shown in Table 1.

Indicator C$_1$ is a qualitative indicator, which is quantified using the expert scoring method. The processed indicator data is shown in Table 2.

The index data in Table 2 are standardized according to Eqs 2, 3, and the output results are shown in Table 3.

Using MATLAB software, the data in Table 3 are processed according to Formula 4 to Formula 7, and the objective weights of each index are output. The output results are shown in Table 4.

4.2 Entropy-TOPSIS evaluation model engineering example application

The quantified original index data (Table 2) are standardized according to Formula 2 to Formula 3 to obtain matrix *F*.

$$F = \begin{pmatrix} 0.143 & 0.667 & 0.874 & 0.981 & 0.000 & 0.914 & 0.468 & 0.096 \\ 1.000 & 0.833 & 0.286 & 1.000 & 0.077 & 0.957 & 0.536 & 1.000 \\ 0.286 & 0.000 & 0.375 & 0.000 & 0.307 & 0.932 & 0.069 & 0.049 \\ 0.571 & 0.500 & 0.178 & 0.952 & 0.438 & 0.976 & 0.225 & 0.312 \\ 0.714 & 1.000 & 0.339 & 0.468 & 0.688 & 1.000 & 0.194 & 0.007 \\ 0.857 & 0.500 & 0.000 & 0.669 & 0.989 & 0.100 & 1.000 & 0.181 \\ 0.000 & 0.167 & 0.554 & 0.165 & 1.000 & 0.000 & 0.000 & 0.079 \\ 0.571 & 0.833 & 1.000 & 0.808 & 0.743 & 0.843 & 0.334 & 0.064 \\ 0.143 & 0.333 & 0.804 & 0.685 & 0.446 & 0.904 & 0.185 & 0.000 \end{pmatrix}$$

The matrix U is obtained by weighting the data of matrix F and the index weight W obtained by entropy method.

$$U = \begin{pmatrix} 0.016 & 0.057 & 0.087 & 0.078 & 0.000 & 0.073 & 0.065 & 0.028 \\ 0.113 & 0.072 & 0.028 & 0.080 & 0.008 & 0.076 & 0.074 & 0.297 \\ 0.032 & 0.000 & 0.037 & 0.000 & 0.033 & 0.074 & 0.010 & 0.014 \\ 0.065 & 0.043 & 0.018 & 0.076 & 0.047 & 0.078 & 0.031 & 0.093 \\ 0.081 & 0.086 & 0.034 & 0.037 & 0.073 & 0.080 & 0.027 & 0.002 \\ 0.097 & 0.043 & 0.000 & 0.053 & 0.106 & 0.008 & 0.138 & 0.054 \\ 0.000 & 0.014 & 0.055 & 0.013 & 0.107 & 0.000 & 0.000 & 0.024 \\ 0.065 & 0.072 & 0.099 & 0.064 & 0.079 & 0.067 & 0.046 & 0.019 \\ 0.016 & 0.029 & 0.080 & 0.055 & 0.048 & 0.072 & 0.026 & 0.000 \end{pmatrix}$$

After substituting the data of matrix U into MATLAB software and calculating according to Eqs 10–12, the

TABLE 1 Original index data of 9 ground coalbed methane Wells in a mine.

Well number/ index	C_1	C_2	C_3/ m	C_4 (%)	C_5/ m	C_6 RMB/m	C_7/ m3·m^{-1}	C_8/ m3·m^{-1}
01#	Casing deformation at 423m; casing deformation and water spray at 467 m deep; misalignment and fracture at the connection between technical casing and production screen tubing; production screen tubing ruptured and dropped slag in many places	7	764.14	15.72	92.5	1631	7.51	0.109
02#	Casing slightly deformed at well depths of 79.21m, 122m, 157.1m, 169.4m, 237.3m, 352.59 m	6	830	14.40	147.1	1570	8.15	0.925
03#	The casing was slightly deformed at 80.66m, 171.9m, 355.8 m and 378.5m, the connection between the technical casing and the production screen pipe was broken and leaking, and the production screen pipe was severely ruptured in many places	11	820	85.36	309.7	1605	3.72	0.066
04#	Slight deformation of the casing at 88.1m, 130.7m, 185.5 m and 275.6m, multiple ruptures and leaks in the production sieve tube at 510–700 m	8	842.09	17.81	403	1543	5.2	0.304
05#	Casing at 88.5m, 164.4m, 196.4 m deformation, rupture, water spray; casing at 273.7 m connection inch break	5	824	52.17	579.9	1510	4.9	0.028
06#	The casing ruptured, deformed and leaked at 70.5m, 121.7m, 183.4m, 251.1m and 273.7 m	8	862	37.89	793	2770	12.56	0.186
07#	The casing was deformed in many places within the depth of 110 m–210.9m, and the well flooded at 210.9m; the casing was severely deformed at 276m, and the endoscope could not go deep	10	800	73.63	800.7	2910	3.06	0.094
08#	The casing was slightly deformed at 75.7 m and 227.3m, and severely deformed at 366m; the well was flooded at 540 m	6	750	28	618.6	1730	6.23	0.080
09#	The casing is deformed in many places at 110.6–260.4m, and at 488.4m, the casing is broken up and down and water is sprayed	9	772	36.73	408.4	1644	4.82	0.022

TABLE 2 The index data after quantification of qualitative indicators.

Well number/index	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
01#	20	7	764.14	0.1572	92.5	1631	7.51	0.109
02#	80	6	830	0.144	147.1	1570	8.15	0.925
03#	30	11	820	0.8536	309.7	1605	3.72	0.066
04#	50	8	842.09	0.1781	403	1543	5.2	0.304
05#	60	5	824	0.5217	579.9	1510	4.9	0.028
06#	70	8	862	0.3789	793	2770	12.56	0.186
07#	10	10	800	0.7363	800.7	2910	3.06	0.094
08#	50	6	750	0.28	618.6	1730	6.23	0.080
09#	20	9	772	0.3673	408.4	1644	4.82	0.022

evaluation results are output. The details of the evaluation results are shown in Table 5.

4.3 Entropy-TOPSIS evaluation model engineering verification

Based on the above evaluation results, 9 low-production coalbed methane wells were repaired in sequence. At present, the repair work of 02#, 06#, and 04# has been completed one after another, and the daily gas production has recovered well. The well workover construction period and the gas production time after the well workover are shown in Table 6.

This article collected the gas production data of 02#, 06#, and 04# after completing the workover operations, and verified the accuracy of the evaluation model by comparing the production recovery ratio of each coalbed methane well. The gas production data of 02#, 06# and 04# wells after workover are shown in Figure 3.

TABLE 3 Index data after standardization.

Well number/index	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
01#	0.143	0.667	0.874	0.981	0.000	0.914	0.468	0.096
02#	1.000	0.833	0.286	1.000	0.077	0.957	0.536	1.000
03#	0.286	0.000	0.375	0.000	0.307	0.932	0.069	0.049
04#	0.571	0.500	0.178	0.952	0.438	0.976	0.225	0.312
05#	0.714	1.000	0.339	0.468	0.688	1.000	0.194	0.007
06#	0.857	0.500	0.000	0.669	0.989	0.100	1.000	0.181
07#	0.000	0.167	0.554	0.165	1.000	0.000	0.000	0.079
08#	0.571	0.833	1.000	0.808	0.743	0.843	0.334	0.064
09#	0.143	0.333	0.804	0.685	0.446	0.904	0.185	0.000

TABLE 4 Ground coalbed methane low-yield well repairs the priority evaluation Index weighting.

Items	Entropy value *E*	Utility value *d*	Weighting factor *W (%)*
C_1	0.8755	0.1245	11.34
C_2	0.9055	0.0945	8.61
C_3	0.8914	0.1086	9.90
C_4	0.9125	0.0875	7.97
C_5	0.8829	0.1171	10.67
C_6	0.9123	0.0877	7.99
C_7	0.8483	0.1517	13.83
C_8	0.6744	0.3256	29.68

TABLE 5 Entropy-TOPSIS evaluation result.

Well number/Evaluation results	Ideal solution distance D^+	Negative ideal solution distance D^-	Closeness degree K	Sort results
01#	0.315	0.166	0.345	5
02#	0.138	0.353	0.719	1
03#	0.355	0.097	0.214	9
04#	0.26	0.173	0.399	3
05#	0.328	0.17	0.342	6
06#	0.277	0.218	0.44	2
07#	0.353	0.124	0.26	8
08#	0.299	0.191	0.39	4
09#	0.344	0.136	0.284	7

It can be seen from the evaluation results that the workover priority of the 9 surface coalbed methane wells in the Pingdingshan mining area is: 02# > 06#>04# > 08#>01# > 05#>09# > 07#>03#.

As can be seen from Figure 3, the average 50-day gas production of 02#, 06#, and 04# under normal production conditions are 6767.1 m^3, 10,826.5 m^3, and 4393.1 m^3 respectively. The average daily gas production of 02#, 06#, and 04# after workover was 5915.3 m^3, 8593.2 m^3, and 3108.6 m^3 respectively, and the gas production recovery rates reached 87.4%, 79.4%, and 70.8% respectively. The ranking of the extraction volume recovery rate is consistent with the ranking of the evaluation results in Table 5, which verifies the reliability

TABLE 6 02#, 06#, 04# construction period and gas production time after completion of workover operations.

Well number	Construction cycle (day)	Gas production time (day)
02#	18	70
06#	31	42
04#	22	22

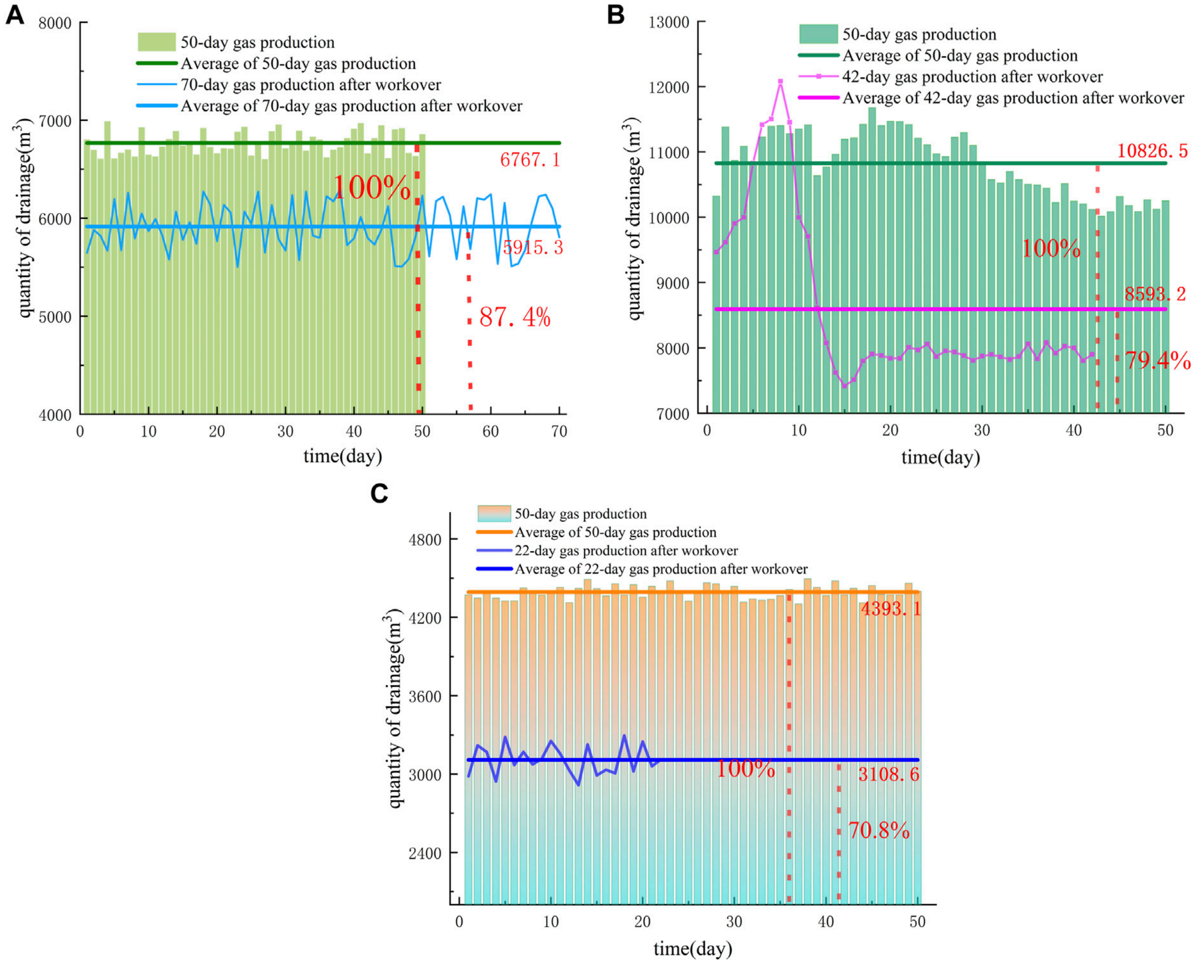

FIGURE 3
Gas production recovery data after workover of 02#, 06#, 04#. **(A)** Gas production recovery data after workover of 02#. **(B)** Gas production recovery data after workover of 06#. **(C)** Gas production recovery data after workover of 04#.

of the workover priority evaluation model for surface coalbed methane low-yield wells built in this paper.

5 Conclusion

Based on the case of surface coalbed methane development in Pingdingshan Mining Area, this paper selects 8 key indicators that affect the priority of workover of low-yield surface coalbed methane wells, combines the entropy method and the TOPSIS comprehensive ranking method, a well workover priority evaluation model for low-yield surface coalbed methane wells was built. Nine low-yield ground coalbed methane wells in the Pingdingshan mining area were evaluated, and the following conclusions were drawn.

1) It was determined that the main factors affecting the priority of surface coal-bed methane well repair include 8 key indicators such as the deformation degree of casing and screen, and the deformation point of casing and screen, and based on this, an evaluation index system for the priority of surface coal-bed methane well repair was established;
2) According to the indicator weight results, among the economic indicators, indicators C_7 and C_8 account for 13.83% and 29.68% respectively relative to the weight of the target layer,

this shows that in coalbed methane well workover operations, long-term gas production capacity and short-term gas production capacity after interference due to harmful factors are the decisive factors in determining the priority of coalbed methane well workover. Among the technical indicators, the weights of indicators C_1 and C_3 are 11.34% and 9.90% respectively, this shows that the deformation degree of the wellbore casing and the burial depth of the coalbed methane well are the key factors that determine the priority of workover of the coalbed methane well.

3) A quantitative evaluation model for the workover priority of surface coal-bed methane wells was constructed, and the engineering application was carried out with 9 surface coal-bed methane wells to be repaired in the Pingdingshan mining area. The evaluation results show that the workover priorities of the 9 surface coalbed methane wells are as follows: 02# > 06#>04# > 08#>01# > 05#>09# > 07#>03#. The gas production recovery rates of 02#, 06#, and 04# that completed workover operations on site were 87.4%, 79.4%, and 70.8%, respectively. The order of recovery rates is consistent with the order of the workover priority evaluation results, which verifies the reliability of the evaluation model.
4) The workover priority evaluation model for surface coalbed methane low-yield wells constructed in this paper can provide theoretical reference for small and medium-sized coalbed methane development companies in well workover operations.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

YL: Writing–review and editing, Resources, Software, Supervision. LZ: Writing–original draft, Data curation, Formal Analysis, Software. RL: Methodology, Supervision, Writing–review and editing. XN: Investigation, Funding acquisition, Writing–review and editing.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. This work was financially supported by the National Natural Science Foundation of China (Grant No. 42072189).

Conflict of interest

Author YL was employed by the Pingdingshan Tianan Coal Mining Co., Ltd.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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