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Research of Coalbed Methane Development Well-Type Optimization Method Based on Unit Technical Cost

Shiqun Li * and Baosheng Zhang

School of Business Administration, China University of Petroleum (Beijing), Beijing 102249, China; bshshysh@cup.edu.cn

* Correspondence: lishiqun@cnpcint.com

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Abstract: Coalbed Methane (CBM) is a high-quality unconventional energy resource. The successful development and utilization of a CBM resource needs to consider technical feasibility and economic viability. These factors are also necessary for the improvement of production safety in coal mines, reducing carbon emission, and optimizing energy structure. Because of its unique resource characteristics, surface drilling is the prevailing development approach all over the world. Directional and horizontal wells are generally the two major well-types for CBM development. Development well-type is an important factor affecting CBM efficient development, as it is a key factor in the process of the economic and effective development of CBM resource. In this paper, a method based on Unit Technical Cost (UTC) will be constructed from the perspective of economic viability, and will be used for more simple and accurate optimization of CBM. This method is used for practical well-type optimization in two major CBM development basins in China, and the application results prove that this method is scientifically accurate and feasible.

Keywords: Unit Technical Cost (UTC); well-type optimization; CBM development

1. Introduction

1.1. CBM Resource and Development Situation

Coalbed Methane (CBM)—known as coal seam gas—is formed during the process of coal formation. It is stored as gas adsorbed on the surface of coal matrix particles, and also as free gas in coal pores, with methane being the main composition [1–3]. With constant progress of oil and gas development technologies, this formerly fatal harmful gas has become an important source of unconventional energy resources. The United States achieved the successful commercial development of CBM in the 1990s. Annual CBM production was more than 60 billion cubic meters, which once accounted for about 10% of its annual natural gas production. Around 2000, Canada and Australia also realized commercial development of CBM, adopting CBM development technologies from the United States, and developed unique development technology suitable for their own CBM resources [4–9]. China also has rich CBM resources. Thanks to constant research, exploration, and testing over the past 30 years, CBM exploration and development technology systems have advanced considerably. Together with sound supporting industrial policies, the annual CBM production has increased steadily in recent years, and commercial development of CBM resource in China has been realized [10,11]. During the past 13 years, the annual production of coalbed methane in China has grown from just 0.02 billion cubic meters in 2003 to 4.4 billion cubic meters in 2015 (Figure 1) [12].

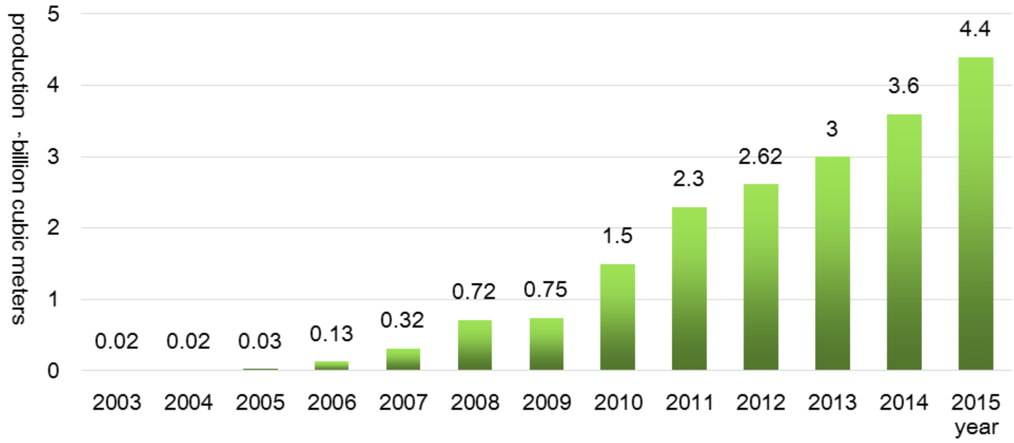

Figure 1. Annual production of coalbed methane in China 2003–2015, Cubic meters.

1.2. Development Approach

Due to its unique accumulation and occurrence characteristics, CBM development is not only different from conventional oil and gas, but also different from that of unconventional oil and gas (such as shale oil and gas, and tight sandstone oil and gas). CBM resource development includes underground extraction and surface drilling. Underground extraction refers to the extraction of gas from existing underground coal mines, with the utilization of additional underground drilling. Surface drilling refers to wells that are drilled from the ground, with pumping units and other equipment being used for water drainage and gas recovery. Currently, surface drilling is a popular development approach for the efficient large scale development of CBM resources all over the world. The well-type optimization studied in the paper is also based on the surface drilling development approach [13,14].

1.3. Well-Type

The type of well is an important factor affecting the efficient development of CBM for surface drilling. Specific well types mainly include vertical wells, directional wells (cluster wells), single-lateral horizontal wells, multiple-lateral horizontal wells, U-shaped wells, etc. Among them, directional wells and multiple-lateral horizontal wells are the most common well-types used in practical development activities in China [15–23].

1.4. Research Content

Well-type optimization is important for the economic and effective development of CBM resources. In this paper, a set of evaluation criteria based on Unit Technical Cost (UTC) is constructed from the perspective of economic viability and optimization. This method is used for the simple and accurate optimization of CBM development well-type.

2. Literature Review

2.1. Technical Evaluation Method

Sunil Ramaswamy (2007) identified 13 main geological parameters which affected the decision-making of CBM drilling, completion, and stimulation in North America. The optimum engineering practices of vertical and horizontal wells for specific combinations of geological parameters in principal CBM basins—along with the corresponding methods of well completion and stimulation—were analyzed. Well-type optimization and supporting technical optimization methods were constructed accordingly [24]. Ian Palmer (2011) analyzed CBM drilling and well completion methods all over the world. Permeability is to be a key parameter in determining CBM well drilling and completion. Optimization of drilling and completion is usually established based on permeability [25]. Zhang Jiawei (2011) analyzed the characteristics of different CBM development techniques, their advantages and disadvantages, and provided specific recommendations for well-type selection for Fanzhuang block, a main CBM resource basin in China [26]. Zhao Qingbo et al. (1999), Pan jienan et al. (1999), He Jing et al. (2001), and Xu Dehong et al. (2003), respectively, analyzed the parameters having important impacts on recoverable CBM resources, and provided implications for well-type selection [27–30]. Keim (2011) reported on the optimization of CBM completion strategies, selection criteria, and production prediction [31]. Cabarello (2013) analyzed drilling and completion technique selection methodology for CBM from the aspect of geology and engineering [32].

2.2. Analytic Hierarchy Process

Fu Li et al. (2011) utilized the Analytic Hierarchy Process (AHP) to establish an analytic hierarchy system structure of CBM well drilling and completion approaches [33]. The weighted influence of all geological parameters on well drilling and completion approaches are obtained by calculation. The analytic hierarchy process analysis results, combined with field engineering practices and CBM well drilling and completion approaches under different geological parameters are optimized using this combined approach.

2.3. Economic Evaluation Method

Chu Wangtao et al. (2009), based on vertical well and horizontal well strategies, used the Discounted Cash Flow (DCF) method to evaluate the economic viability of the virtual development plan of full vertical well and full multiple-lateral horizontal well for the same well control area, without considering production takeover. The technical and economic potential of these two drilling technologies in China's CBM development were compared and analyzed [34]. Yang Yongguo et al. analyzed economic evaluation methods and indices for CBM development projects, as these methods and indices have been applied for economic evaluation of specific projects under different geological and technical conditions [35–49].

In the first method, the important role of key technical parameters in CBM development well-type optimization is analyzed, which helps to guide industrial practices. In this method, the economic viability of CBM development well-type optimization decision-making is ignored, which is not beneficial for decision-makers to come up with the highest economic benefits under current low oil prices.

In the second method, AHP is utilized by comprehensively considering the impact of the most important factors on CBM development; however, only geological factors and engineering technological factors are considered, while economic viability (which has a great impact) is not considered. In addition, this method can affect decision-making negatively due to inaccurate methods for the determination of the weights of all factors.

The third method takes into account economic viability, which requires the creation of virtual development programs under different well drilling and completion approaches. This involves the collection of investment, cost, engineering, and other data, and then carrying out economic evaluations complying with project economic evaluation requirements. Well drilling and completion approaches are conducted based on the evaluation results. However, it is difficult to obtain most technical and economic parameters at the early stages of the project, or, in many cases, the obtained parameters are not accurate enough. Ultimately, the method has the problem of poor operability and inaccurate evaluation results. Therefore, a faster and more accurate method with stronger operability is needed for the optimization of CBM development well-type decision-making, thereby enhancing the economic effectiveness of coal-bed methane development projects.

3. Method

3.1. Definitions

Unit Technical Cost (UTC) is also known as Long Run Marginal Cost (LRMC). It is defined as the ratio of the total cost (Capital Expenditure, CAPEX and Operating Expense, OPEX) over the economic life of a project to the total expected outputs from the project. It is a comprehensive economic index for investors to make project decisions. The positive point about UTC is that it is independent of the price of the product involved [50]. It gives an indication of what the product costs to develop and produce, and provides a measure of the economic cushion available when compared to actual estimated product prices. Oil and gas projects have the characteristics of long construction and operation duration, large investment capital, high risk level, etc. Currently, many large international oil companies (Shell, BP, etc.) have gradually introduced UTC into the evaluation systems of oil and gas projects. It is applied for the investment decision-making of oil and gas projects (especially unconventional oil and gas projects).

CBM is a typical kind of unconventional gas, and a CBM well is regarded as an independent evaluation unit. UTC can reflect more comprehensive information for the total cost (CAPEX and OPEX) of unit output for the duration of a project. The difference between a UTC and a conventional cost index is that it takes into account the time value of total cost (CAPEX and OPEX) and future output. Therefore, UTC becomes a short-term cost index as long-term through discount, and reflects the real cost of unit output throughout the economic life of a project. An evaluation index (EI) can be formed when compared to product price when evaluating whether a project is economically viable. Meanwhile, it is consistent with commonly-used project evaluation index systems (Net Present Value (NPV), Internal Rate of Return (IRR), etc.) based on a discounted cash flow approach.

3.2. Modeling

Theoretically, the UTC may be undiscounted and/or discounted. However, the discounted UTC is more accurate and in accordance with the decision-making practice of the oil and gas industry. As such, the UTC in this paper is assumed to be discounted. The calculation of discounted UTC requires both yearly costs and production be discounted to the present value by using the same discount rate used for the calculation of Net Present Value.

For a CBM well, UTC is equal to the present value of construction investment and operating cost of the CBM well on the discounted value of the project's future production. Specific calculation formulas are shown as follows:

$$UTC = \frac{PV_I + PV_C}{PV_{PD}} \tag{1}$$

wherein,

$$PV_I = \sum_{t=1}^{x} \frac{I_t}{(1+i)^t} \tag{2}$$

$$PV_C = \sum_{t=1}^{n} \frac{C_t}{(1+i)^t} \tag{3}$$

$$PV_{PD} = \sum_{t=1}^{n} \frac{PD_t}{(1+i)^t} \tag{4}$$

where n refers to the sum of the construction and operation period of a CBM well; x refers to the construction completion year of the well; i refers to the discount rate set for the well (the minimum acceptable rate of return)—it refers to construction investment spending in year; C_t refers to operating cost in year t. PDt refers to CBM production of the well in year t. PV_I, PV_C and PV_{PD} are, respectively, discounted values of investment, cost, and production within the economic life of the well.

It is assumed that the operation cost is directly related to production. Unit operation cost is UnitC, which will remain the same during the production period. Annual operating cost is equal to UnitC multiplied by annual production. The above Formula (1) can be simplified as follows:

$$UTC = \frac{PV_I}{PV_{PD}} + UnitC \tag{5}$$

Therefore, the Evaluation Index (EI) is shown as follows:

$$EI = P - UnitC \tag{6}$$

wherein P is the unit sale price of CBM.

3.3. Intrinsic Consistency between EI and NPV

A discounted cash flow method is generally adopted in the oil and gas industry. Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period (PP) are the main evaluation indices. Among them, Net Present Value (NPV) is a widely used index; it is obtained by subtracting the present value of periodic cash outflows from the present value of periodic cash inflows. The present value is calculated using the weighted average cost of the capital of the investor, and is also referred to as the discount rate or minimum acceptable rate of return [51]. Though the EI index is substantially different from NPV by definition, EI and NPV are internally consistent with the results of the evaluation of project economic viability. The NPV calculation formula is shown as follows:

$$NPV = \sum_{t=1}^{n} \frac{P_t \times PD_t}{(1+i)^t} - \left(\sum_{t=1}^{x} \frac{I_t}{(1+i)^t} + \sum_{t=1}^{n} \frac{C_t}{(1+i)^t} \right) \tag{7}$$

It is assumed that the product price is kept stable at P within the evaluation period. Both sides of the formula are divided by discounted value of project output synchronously, then:

$$\begin{aligned} \frac{NPV}{\sum_{t=1}^{n} \frac{PD_t}{(1+i)^t}} &= P - \frac{\left(\sum\limits_{t=1}^{x} \frac{I_t}{(1+i)^t} + \sum\limits_{t=1}^{n} \frac{C_t}{(1+i)^t} \right)}{\left(\sum\limits_{t=1}^{n} \frac{PD_t}{(1+i)^t} \right)} \\ &= P - UTC \end{aligned} \tag{8}$$

whereby,

$$EI = \frac{NPV}{\sum_{t=1}^{n} \frac{PD_t}{(1+i)^t}} = \frac{NPV}{PV_{PD}} \tag{9}$$

Since the discounted value of project output will always be greater than zero, EI and NPV have the same property on the positive and negative attributes. The UTC-based evaluation index EI is consistent with the commonly-used evaluation index NPV based on a discounted cash flow method.

3.4. Characteristics

The UTC-based evaluation index EI is regarded as the difference between product price and the total unit cost of project output. Compared with the conventional evaluation index NPV (which is based on a discounted cash flow method), the UTC-based evaluation index EI is more intuitive, efficient, practical, and convenient for the economic evaluation and optimization of CBM development well-type.

UTC is also internally consistent with the evaluation indices NPV and IRR under a conventional discounted cash flow method because of its theoretical connotation. In other words, this method arrives at the same conclusion as the conventional economic evaluation method, and has the advantage of high intuition, efficiency, and operability.

3.5. Decision-Making Process and Criteria

If the CBM resource base is large enough, it is assumed that both directional wells and horizontal wells are equally feasible from the perspective of geology and engineering. The well-type will be made from an economic perspective, and the decision-making processes and principles are shown as follows:

(1) The output profiles under different well-types are anticipated according to resources, geology, engineering, pilot production, and analog data, and then capital investment and operating cost of different well-types. Using this information, the product prices are estimated.

(2) The UTCD and UTCH are calculated for directional well and horizontal wells, respectively.

(3) EI values under different well-types are calculated. If EID ≥ 0 and EIH ≥ 0, selected well-types are economic and feasible under current technical and economic conditions. Then, the well-type with the larger EI value is selected as a recommended well-type for the development of CBM resources. If EID < 0 and EIH < 0, the primarily selected well-types are not economic and feasible under current technical and economic conditions. The well-type with higher EI can be recommended as a potential alternative well-type, which means key technological research should be focused on the well-type with lower UTC. If EID $\times$ EIH < 0, one of the two well types is economic and feasible while the other one not; in this regard, the well-type with positive EI should be selected as the optimal one.

4. Application

China has rich CBM resources, and it is the third largest CBM resource country only to Canada and Russia. CBM resources with burial depth less than 2000 m are estimated to be 36.8 trillion cubic meters [52]. The Ordos and Qinshui Basins are the two largest basins among China's nine CBM basins, with resources higher than 1 trillion cubic meters. The resource quantity for these two basins is 9.8 trillion cubic meters and 3.9 trillion cubic meters, respectively, which accounts for 40% of the total CBM in China. As of 2014, the production of the Qinshui Basin and the Ordos Eastern Margin Basin accounted for 94.1% of the total national CBM production in the surface development approach in China. Qinshui Basin and Ordos Eastern Margin Basin have large-scale commercial development, which are built into state-level CBM development industry demonstration bases [53].

Surface development approaches are widely used in these two basins, and directional wells and horizontal wells have been tested, utilized, and proven to be relatively mature technologies for CBM development. The two well types (directional and horizontal) have equal technical feasibility, whereas the economic variability of the two well-types and their differences can be evaluated by UTC. The method is adopted for evaluating and optimizing typical well-type plans for the two basins.

4.1. Qinshui Basin

Qinshui Basin is located in the southeastern part of Shanxi Province. The coal-bearing area is 2.4 square kilometers; it is the key area of CBM production capacity in China during the "11th five-year plan" and the "12th five-year plan" periods. The proven reserves were more than 460 billion cubic meters, and cumulative annual production capacity was more than four billion cubic meters at the end of 2014. The annual production was about three billion cubic meters in 2014. It is anticipated that the maximum accumulative available reserves of this industry base can reach up to 800 billion cubic meters, and an additional cumulative annual production capacity of 14–16 billion cubic meters can be constructed. All of these factors make it a key area of CBM production capacity construction during the "13th five-year plan" period. The production profiles of typical directional and horizontal wells in Qinshui Basin are shown in Figure 2 [54,55], and evaluation parameters of well-types in Qinshui Basin are shown in Table 1.

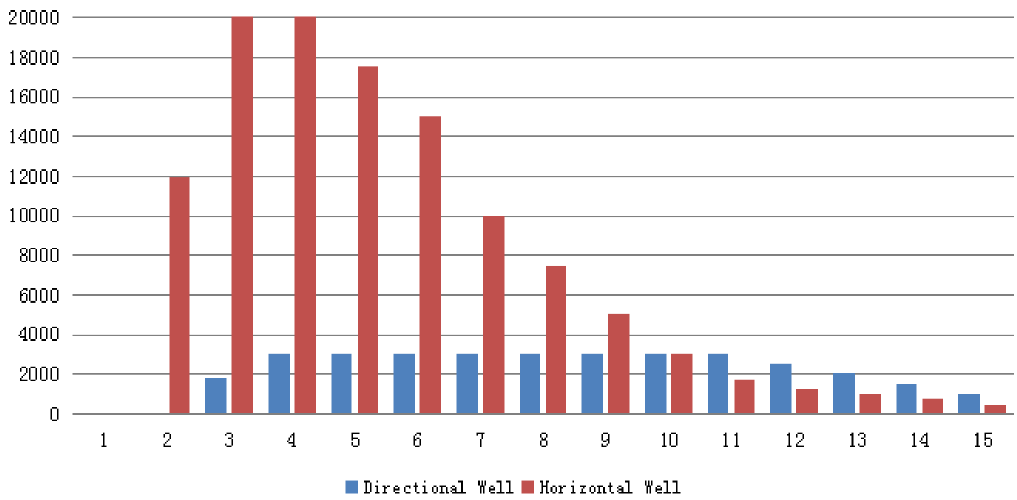

Figure 2. Comparative production profile of typical directional and horizontal wells in Qinshui Basin. Blue bar: directional well; Red bar: horizontal well. Data are compiled from open source.

Table 1. Evaluation parameters of well-types in Qinshui Basin.

Parameter	Unit	Value
Directional well stable daily production rate	Cubic meter/day	20,000
Horizontal well stable daily production rate	Cubic meter/day	3000
Directional well investment	Ten thousand Yuan	220
Horizontal well investment	Ten thousand Yuan	1200
Price	Yuan/Cubic meter	1.00
Basic discount rate	%	10%

4.2. Ordos Eastern Margin Basin

The Ordos Eastern Margin Basin spans across three provinces—namely, Shanxi, Shaanxi, and Inner Mongolia—with the coal-bearing area being 2.5 square kilometers. The Ordos Eastern Margin Basin is another key area of CBM production capacity construction in China anticipated for the "12th five-year plan" period. The proven reserves are close to 150 billion cubic meters, and a cumulative annual production capacity of more than 1.5 billion cubic meters was obtained at the end of 2014, and an annual production of about 600 million cubic meters was obtained in 2014. It is anticipated that the final accumulative available reserves of this industry base can reach up to 500–550 billion cubic meters, with a cumulative production capacity of 10–11 billion cubic meters being anticipated, making it a key area of production capacity construction during the "13th five-year plan" period. The production profile of typical directional and horizontal wells in the Ordos Eastern Margin Basin are shown in Figure 3, and evaluation parameters of well-types in the Ordos Eastern Margin Basin are shown in Table 2.

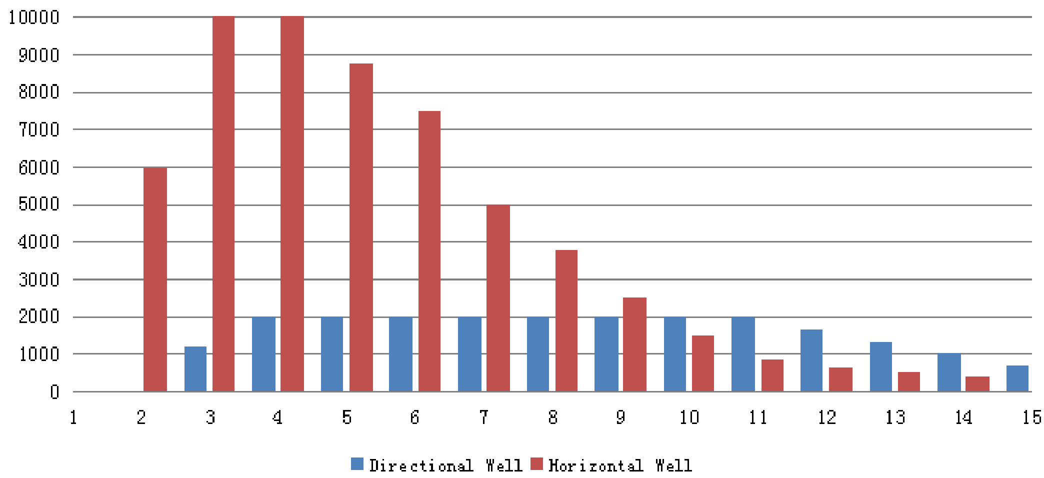

Figure 3. Comparative production profile of typical directional and horizontal wells in the Ordos Eastern Margin Basin. Blue bar: directional well; Red bar: horizontal well. Data are compiled from open source.

Table 2. Evaluation parameters of well-types in the Ordos Eastern Margin Basin.

Parameter	Unit	Value
Directional well stable daily production rate	Cubic meter/day	2000
Horizontal well stable daily production rate	Cubic meter/day	10,000
Directional well investment	Ten thousand Yuan	250
Horizontal well investment	Ten thousand Yuan	1300
Price	Yuan/Cubic meter	1.50
Basic discount rate	%	10%

Note: Data are compiled from open source.

4.3. Evaluation Index Calculation and Analysis

The model and data shown above are utilized for calculating EI under different well-types in the Qinshui and Ordos Eastern Margin Basins, respectively. The results are shown in Table 3.

Table 3. Well-type optimization evaluation results for the Qinshui and Ordos Eastern Margin Basins.

Parameter	Unit	Value	
		Qinshui Basin	Ordos Eastern Margin Basin
Directional well UTC	Yuan/Cubic meter	0.810	1.192
Horizontal well UTC	Yuan/Cubic meter	0.661	1.359
Directional well EI	Yuan/Cubic meter	0.190	0.308
Horizontal well EI	Yuan/Cubic meter	0.339	0.141
Preference decision		Horizontal well	Directional well

Note: Data are compiled from open source. EI: evaluation index; UTC: Unit Technical Cost.

For the Qinshui Basin, the above-mentioned evaluation result shows that the UTCD and UTCH are greater than zero, meaning that directional and horizontal wells are economical and feasible under current technical and economic conditions. However, since the UTCH is smaller than UTCD and the EIH is larger than EID, it can be concluded that the economic benefits of developing CBM resources by horizontal well well-types are better than directional well well-type at the same price level.

Regarding the Ordos Eastern Margin Basin, the evaluation above shows that the UTCD and UTCH are larger than zero, meaning that directional and horizontal wells are economically feasible under current technical and economic conditions. However, since the UTCH is larger than UTCD, and the EIH is lower than EID, it can be concluded that the economic benefits of developing CBM resources by directional well well-types are better than horizontal well well-types at the same price level.

In summary, the well-types for the development and utilization of CBM resources are different under different resource, technological, and economic conditions. The evaluation method based on unit technical cost can be used for conveniently, quickly, and accurately choosing the best well-type, thereby providing fast decision-making support for the efficient development of CBM resources in China.

5. Discussion and Conclusions

Reasonable optimization of development well-type is an important decision-making issue in the process of effective and economic development of CBM resources under specific resource, technological, and economic conditions. Traditional well-type optimization methods, such as technical evaluation methods and AHP are based on geological and engineering parameters, and the economic considerations are insufficient; the traditional economic evaluation method based on a project development plan takes the economic aspects into account, but its operability is not so strong. Based on UTC theory, this paper built a new coalbed methane development well-type optimization method, established a detailed calculation model, and constructed the decision-making process and criteria. This method reflects the geological and engineering parameters by production profile, and reflects the economic parameters through investment, costs, and prices. It can be adopted for optimizing development well-type more easily and accurately. The method has internal consistency with the conventional evaluation index. It is also more intuitive and stronger from an operational standpoint. The method is applied for major CBM resource development zones in China's Qinshui Basin and Ordos Eastern Margin Basin. The optimization results show that the horizontal well type has better economic viability for the Qinshui Basin, while the directional well type has better economic viability for the Ordos Eastern Margin Basin. The conclusion has important guidelines for the economic and efficient development of CBM resources in these two basins. At the same time, this method may be applied to China's other coalbed methane basins that have not yet achieved large-scale commercial development, providing more important implications for efficient development.

A UTC-based CBM development well-type optimization method can help to select optimal well-type, and also to evaluate the economic viability of different well-type scenarios. Under current low oil prices, this feature provides special value for this method. It can also help companies understand the benefits of coal-bed methane wells using different well-types, so as to make rational investment decisions.

EI values of different well-types are affected by many factors, such as production profile, price, investment, cost, etc. Therefore, EI values and well-type optimization results of different CBM basins are dynamic. Timely dynamic evaluation and updates are needed to ensure successful CBM development.

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