US 20200240243A1

(19) United States
(12) Patent Application Publication
(10) Pub. No.: US 2020/0240243 A1
LI et al.
(43) Pub. Date: Jul. 30, 2020

(54) **METHOD FOR INTELLIGENTLY DETERMINING HYDRATE DRILLING AND PRODUCTION RISKS BASED ON FUZZY JUDGMENT**

(71) Applicant: **SOUTHWEST PETROLEUM UNIVERSITY**, Chengdu City (CN)

(72) Inventors: **Haitao LI**, Chengdu City (CN); **Na WEI**, Chengdu City (CN); **Jinzhou ZHAO**, Chengdu City (CN); **Luling LI**, Chengdu City (CN); **Zhenjun CUI**, Chengdu City (CN); **Lin JIANG**, Chengdu City (CN); **Wantong SUN**, Chengdu City (CN); **Luyue YANG**, Chengdu City (CN); **Xi LI**, Chengdu City (CN); **Yinghe HONG**, Chengdu City (CN); **Yu QIAO**, Chengdu City (CN)

(21) Appl. No.: **16/747,294**

(22) Filed: **Jan. 20, 2020**

(30) **Foreign Application Priority Data**

Jan. 29, 2019 (CN) 201910086578.6

Publication Classification

(51) **Int. Cl.**

E21B 41/00	(2006.01)
E21B 47/00	(2006.01)
E21B 49/00	(2006.01)
E21B 49/08	(2006.01)

(52) **U.S. Cl.**

CPC ***E21B 41/0092*** (2013.01); ***E21B 47/00*** (2013.01); *E21B 2041/0028* (2013.01); ***E21B 49/08*** (2013.01); ***E21B 49/00*** (2013.01)

(57) **ABSTRACT**

A method for intelligently determining hydrate drilling and production risks based on fuzzy judgment. First classifying monitoring parameters in a hydrate drilling and production process into layers from top to bottom: a target layer, a primary evaluation factor layer and a secondary evaluation factor layer; then calculating relative weight values of each primary evaluation factor and each secondary evaluation factor contained therein; then connecting in series the relative weight values of the primary evaluation factors with the relative weight values of the secondary evaluation factors to obtain an overall weight value of the secondary evaluation factors; repeating the foregoing steps; finally constructing the overall weight value of each secondary evaluation factor of each risk into a column vector to obtain a comprehensive determining weight matrix of hydrate drilling and production risks, and determining the risks in the hydrate drilling and production process by combining monitoring parameter change vectors.

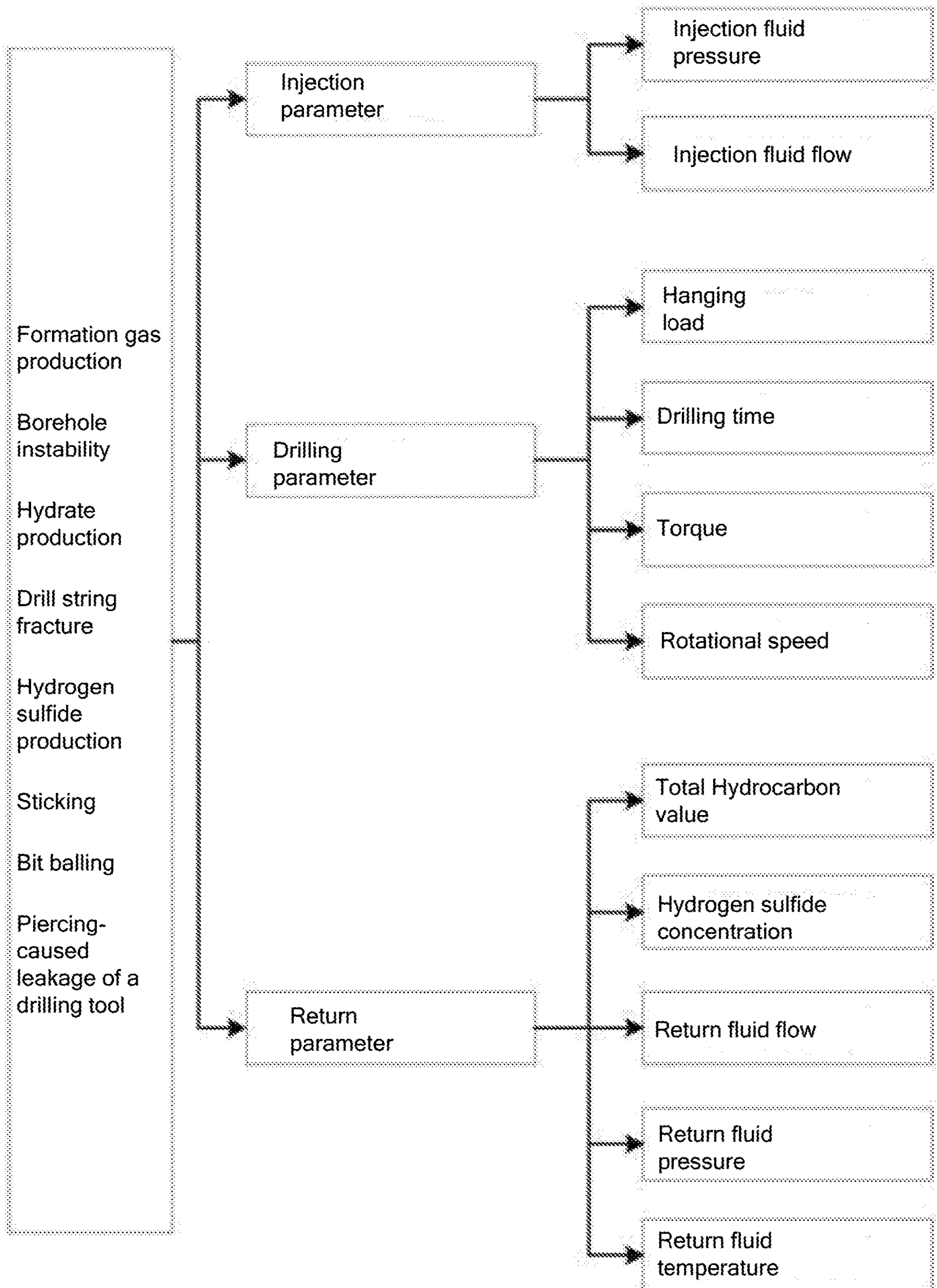
Formation gas production
Borehole instability
Hydrate production
Drill string fracture
Hydrogen sulfide production
Sticking
Bit balling
Piercing-caused leakage of a drilling tool
Injection parameter
Drilling parameter
Return parameter
Injection fluid pressure
Injection fluid flow
Hanging load
Drilling time
Torque
Rotational speed
Total Hydrocarbon value
Hydrogen sulfide concentration
Return fluid flow
Return fluid pressure
Return fluid temperature

FIG. 1

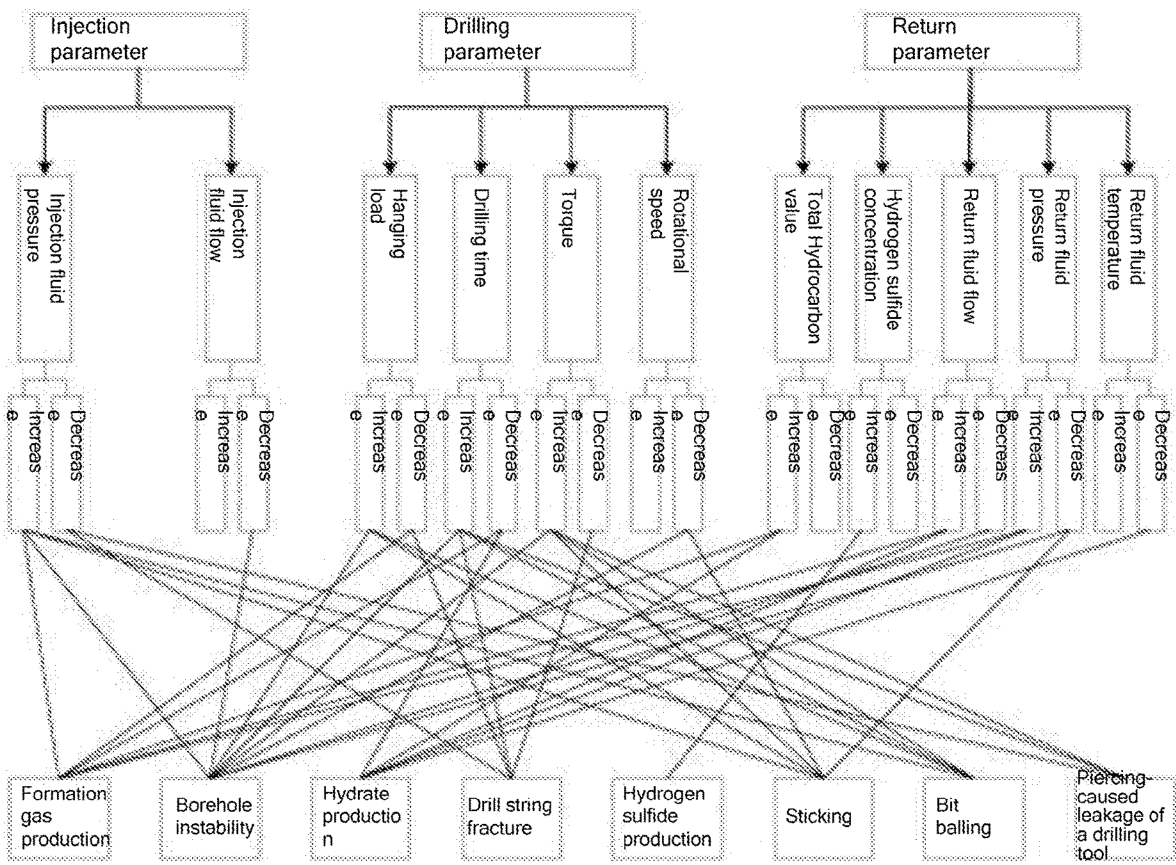
Injection parameter
Drilling parameter
Return parameter
Injection fluid pressure
Injection fluid flow
Hanging load
Drilling time
Torque
Rotational speed
Total Hydrocarbon value
Hydrogen sulfide concentration
Return fluid flow
Return fluid pressure
Return fluid temperature
Increase
Decrease
Formation gas production
Borehole instability
Hydrate production
Drill string fracture
Hydrogen sulfide production
Sticking
Bit balling
Piercing-caused leakage of a drilling tool

FIG. 2

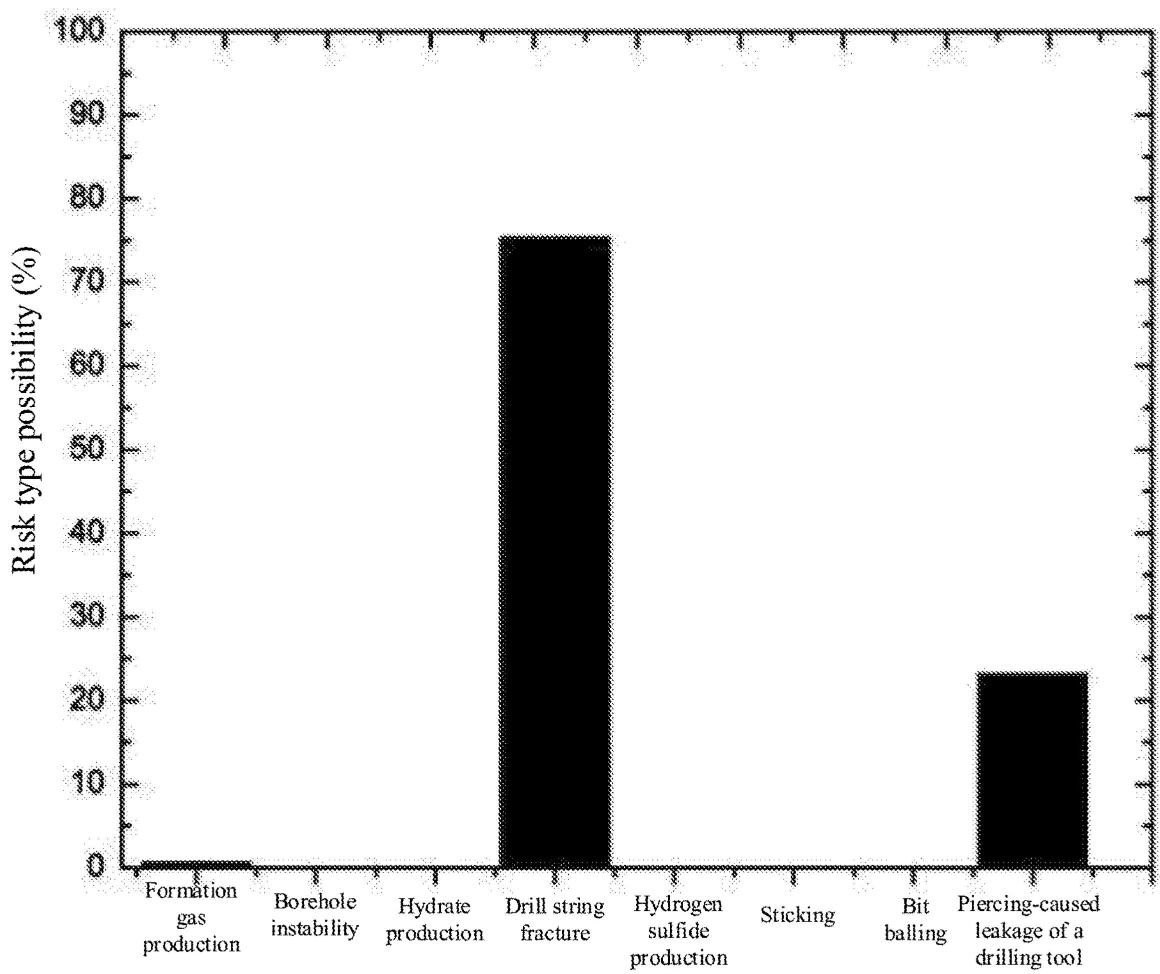
100
90
80
70
60
50
40
30
20
10
0
Risk type possibility (%)
Formation gas production
Borehole instability
Hydrate production
Drill string fracture
Hydrogen sulfide production
Sticking
Bit balling
Piercing-caused leakage of a drilling tool

FIG. 3

METHOD FOR INTELLIGENTLY DETERMINING HYDRATE DRILLING AND PRODUCTION RISKS BASED ON FUZZY JUDGMENT

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] Not applicable.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0002] Not applicable.

NAMES OF THE PARTIES TO A JOINT RESEARCH AGREEMENT

[0003] Not applicable.

INCORPORATION-BY-REFERENCE OF MATERIALS SUBMITTED ON A COMPACT DISC

[0004] Not applicable.

TECHNICAL FIELD

[0005] The present invention relates to the technical field of intelligent judgment and research on natural gas hydrate drilling and production risks, and in particular to a method for intelligently determining hydrate drilling and production risks based on fuzzy judgment.

BACKGROUND

[0006] Natural gas hydrate is a non-stoichiometric clathrate crystal substance generated by water and natural gas in a high-pressure and low-temperature environment. It is unconventional energy with high density and high heat value, mainly distributed in marine and terrestrial permafrost sediments. The amount of marine natural gas hydrate resources is about 100 times that of terrestrial permafrost. The exploitation of the marine natural gas hydrate has attracted much attention. The natural gas hydrate is generally considered to be the most potential replacement energy in the 21st century and is also new energy with the largest reserves yet to be developed.

[0007] For such a huge amount of resources, the drilling safety of natural gas hydrate reservoirs has become a major problem that restricts the development of a natural gas hydrate drilling and production technology. Hydrate drilling and production are often faced with eight types of risks, which are formation gas production, borehole instability, hydrate production, drill string fracture, H_2S production, sticking, bit balling and piercing-caused leakage of a drilling tool. Basic risk monitoring and judgment methods have been established in the drilling process of conventional oil and gas reservoirs, but the methods are not perfect. At present, no scholars have proposed a method for determining risks in the natural gas hydrate drilling and production process. In order to ensure the safe and efficient exploitation of natural gas hydrate, there is an urgent need to provide a method for intelligently determining risks of natural gas hydrate during drilling.

BRIEF SUMMARY OF THE INVENTION

[0008] The present invention provides a method for intelligently determining hydrate drilling and production risks based on fuzzy judgment. The method has a reliable working principle and simple and convenient operations, and can quickly and accurately determine a risk type and generate an alarm when risks occur in the hydrate drilling and production process. The method enables a hydrate drilling and production operation process to be monitored in real time, thereby ensuring safe hydrate drilling and production, and filling the gap in intelligently determining risks in hydrate drilling and production.

[0009] To achieve the foregoing objective, the present invention adopts the following technical solutions.

[0010] Monitoring parameters in a hydrate drilling and production process are first hierarchically structured by using a fuzzy analytic hierarchy process and then classified into layers from top to bottom, including a target layer (composed of 8 risks), a primary evaluation factor layer (composed of monitoring parameter types, where a primary evaluation factor is a monitoring parameter type), and a secondary evaluation factor layer (composed of monitoring parameters, where a secondary evaluation factor is a monitoring parameter). Then a relative weight value of each primary evaluation factor is calculated (for example, when a certain risk occurs, the stronger the response of a certain primary evaluation factor to the risk, the greater the relative weight of this primary evaluation factor to this risk, that is, the greater the relative weight value of this primary evaluation factor). Then a relative weight value of each secondary evaluation factor contained in each primary evaluation factor is calculated respectively (for example, when a certain risk occurs, the stronger the response of a certain secondary evaluation factor to the risk, the greater the relative weight of this secondary evaluation factor to this risk, that is, the greater the relative weight value of this secondary evaluation factor). Then the relative weight value of each primary evaluation factor is respectively connected in series with the relative weight values of all secondary evaluation factors included in the primary evaluation factor (that is, the relative weight value of each primary evaluation factor is respectively multiplied with the relative weight values of all secondary evaluation factors included in this primary evaluation factor), and the relative weight values of the secondary evaluation factors connected in series are overall weight values of the secondary evaluation factors (that is, when the risk occurs, the greater the intensity of the comprehensive response of which secondary evaluation factor to the risk, the greater the overall weight value of this secondary evaluation factor). The foregoing steps are repeated to calculate a relative weight value of each primary evaluation factor of the remaining risks in the target layer and respectively calculate a relative weight value of each secondary evaluation factor contained in each primary evaluation factor and overall weight values of the secondary evaluation factors. Finally the overall weight values of the secondary evaluation factors of each risk are constructed into column vectors in the same order, and a comprehensive determining weight matrix, namely a comprehensive determining weight matrix of hydrate drilling and production risks, is constructed after the constructed column vectors are arranged in sequence, and the risks in the hydrate drilling and production process are quickly, accurately and intelligently determined by combining monitoring parameter change vectors.

[0011] In the specification, if a factor does not specifically refer to an evaluation factor, it is simply referred to as an evaluation factor.

[0012] A method for intelligently determining hydrate drilling and production risks based on fuzzy judgment includes the following steps in sequence.

[0013] Step 1: building a hierarchical structure model hierarchically structuring monitoring parameters in a hydrate drilling and production process by using a fuzzy analytic hierarchy process and classifying into layers from top to bottom, which include a target layer, a primary evaluation factor layer and a secondary evaluation factor layer, where the target layer is composed of 8 risks which are formation gas production, borehole instability, hydrate production, drill string fracture, H_2S production, sticking, bit balling and piercing-caused leakage of a drilling tool respectively; the primary evaluation factor layer is composed of 3 kinds of monitoring parameters, which are an injection parameter, a drilling parameter and a return parameter respectively; the secondary evaluation factor layer is composed of 11 monitoring parameters, which are injection fluid pressure, injection fluid flow, hanging load, drilling time, torque, rotational speed, total hydrocarbon value, hydrogen sulfide concentration, return fluid flow, return fluid pressure and return fluid temperature respectively, to construct a hierarchical structure model.

[0014] Step 2: constructing a determining matrix

[0015] in the constructed hierarchical structure model, constructing a sub-region according to each primary evaluation factor (monitoring parameter type) of a selected risk and the next evaluation factor layer (monitoring parameters) dominated by this primary evaluation factor, establishing a determining matrix for the sub-region, and evaluating relative importance of each evaluation factor in the sub-region by a nine-scale method, with the process as follows: based on a selected risk in the target layer (namely a first layer), first using the nine-scale method to compare primary evaluation factors of the primary evaluation factor layer (namely a second layer) and determine a scale value, then establishing a primary evaluation factor determining matrix based on the determined scale value, and then based on each primary evaluation factor of the primary evaluation factor layer respectively, establishing a secondary evaluation factor determining matrix for secondary evaluation factors of the secondary evaluation factor layer (namely a third layer) contained in each primary evaluation factor.

[0016] Scale values of each primary evaluation factor and each secondary evaluation factor are determined by using the nine-scale method. An example of determining a scale value is as follows: when the monitoring parameter i corresponding to the selected risk is compared with the monitoring parameter j, the scale value is determined according to a response intensity (namely importance) of the monitoring parameter i and the monitoring parameter j to the risk, and the scale value is quantitatively expressed by the triangular fuzzy number

$$\underset{\sim}{a_{ij}} = (a_1, a_2, a_3).$$

The scale value is a judgment result of the importance of the monitoring parameter i and the monitoring parameter j to this risk. According to the scale values of the primary evaluation factor layer and the secondary evaluation factor layer, a primary evaluation factor determining matrix and a secondary evaluation factor determining matrix are respectively constructed, the constructed determining matrixes of the primary evaluation factors and the secondary evaluation factors are expressed by $\underset{\sim}{A}$, and an example of $\underset{\sim}{A}$ is as follows:

$$\underset{\sim}{A} = \begin{bmatrix} \underset{\sim}{a}_{11} & \cdots & \underset{\sim}{a}_{1m} \\ \vdots & \ddots & \vdots \\ \underset{\sim}{a}_{m1} & \cdots & \underset{\sim}{a}_{mm} \end{bmatrix} = \left(\underset{\sim}{a}_{ij}\right)_{m\times m}$$

[0017] where i refers to the i-th evaluation factor of a certain layer in the hierarchical structure model (a value of i is 1, 2, 3, . . . , m), j refers to the j-th evaluation factor of the same layer in the same hierarchical structure model as j (a value of j is 1, 2, 3, . . . , m), and in refers to the number of primary evaluation factors or the number of secondary evaluation factors.

[0018] Step 3: establishing a comprehensive determining matrix and calculating a fuzzy weight value

[0019] setting the number of judging experts to be n to obtain a comprehensive determining matrix by using a fuzzy average method, as shown in the following formula:

$$\underset{\sim}{A}_M = \frac{1}{n}\left[\underset{\sim}{A}_1 + \underset{\sim}{A}_2 + \cdots + \underset{\sim}{A}_n\right]$$

[0020] where $\underset{\sim}{A}_M$ refers to the comprehensive determining matrix, and $\underset{\sim}{A}_1$, $\underset{\sim}{A}_2$, and $\underset{\sim}{A}_n$ refer to determining matrixes constructed according to scale values determined by judgment results of the first expert, the second expert and the n-th expert respectively.

[0021] Further, a determining matrix established by the k-th expert by evaluation is expressed as

$$\underset{\sim}{A}_k = [a_{cd}^k],\ a_{cd}^k$$

indicates a scale value determined by the k-th expert according to the importance of a same layer evaluation factor c relative to an evaluation factor d, and a comprehensive determining matrix is calculated as follows:

$$\underset{\sim}{A}_M = \frac{1}{n}\left[\sum_{k=1}^{n} a_{cd}^k\right] = \begin{bmatrix} (1, 1, 1) & \cdots & \frac{1}{n}\left[\sum_{k=1}^{n} a_{1m}^k\right] \\ \vdots & \ddots & \vdots \\ \frac{1}{n}\left[\sum_{k=1}^{n} a_{m1}^k\right] & \cdots & (1, 1, 1) \end{bmatrix}$$

[0022] Further, a geometric average fuzzy weight calculation method (similar to an nth root method) is used to calculate the relative fuzzy weight value of each evaluation factor in the matrix (the relative fuzzy weight of each evaluation factor has already taken the normalization of a fuzzy number into account).

[0023] A geometric mean of the i-th evaluation factor in the comprehensive determining matrix A_M is:

$$r_i=(a_{i1}\times a_{i2}\times a_{i3}\times \ldots \times a_{im})^{1/m}$$

[0024] A relative fuzzy weight value of the i-th evaluation factor is:

$$w_i=r_i\times(r_1+r_2+r_3+ \ldots +r_n)^{-1}$$

[0025] Step 4: converting the relative fuzzy weight value of the i-th evaluation factor into an explicit value

[0026] expressing the relative weight fuzzy weight value w_i of the i-th evaluation factor in the form of a triangular fuzzy number, where $w_i=(R_i, M_i, L_i)$, L_i is left extension of the triangular fuzzy number, R_i is right extension of the triangular fuzzy number, and M_i is a median of the triangular fuzzy number; converting the relative weight fuzzy weight value of the i-th evaluation factor into an explicit weight value DF_i of the i-th evaluation factor, where a calculation formula of DF_i is as follows:

$$DF_i = \frac{[(R_i - L_i) + (M_i - L_i)]}{3} + L_i$$

[0027] Step 5: normalizing the explicit weight value of the i-th evaluation factor

[0028] In order to compare the relative importance of each primary evaluation factor (including an injection parameter, a drilling parameter and a return parameter) and secondary evaluation factors (including injection fluid pressure, injection fluid flow, hanging load, drilling time, torque, rotational speed, total hydrocarbon value, hydrogen sulfide concentration, return fluid flow, return fluid pressure and return fluid temperature), an explicit weight value of the i-th evaluation factor is normalized, and a normalization formula is:

$$w_i' = \frac{DF_{ij}}{\Sigma DF_{ij}}$$

[0029] w'_i is the relative weight value of the normalized i-th evaluation factor.

[0030] Step 6: connecting relative weight values of each interlayer evaluation factor in series

[0031] respectively connecting in series the relative weight value of each primary evaluation factor with the relative weight values of all secondary evaluation factors contained in the primary evaluation factor (namely multiplying the relative weight value of each primary evaluation factor respectively with the relative weight values of all secondary evaluation factors contained in this primary evaluation factor), where the relative weight values of the secondary evaluation factors connected in series are the overall weight values of the secondary evaluation factors.

[0032] w'_{Ti} is the overall weight value of the i-th secondary evaluation factor, w'_{1i} is the relative weight value of the primary evaluation factor corresponding to the i-th secondary evaluation factor, and w'_{2i} is the relative weight value of the i-th secondary evaluation factor. The overall weight of the i-th secondary evaluation factor relative to a certain risk is as follows:

$$w'_{Ti}=w'_{1i}\times w'_{2i}$$

[0033] Further, steps 2-6 are repeated, a relative weight value of each primary evaluation factor of the remaining risks in the target layer is calculated, a relative weight value of each secondary evaluation factor contained in each primary evaluation factor and overall weight values of the secondary evaluation factors are respectively calculated. Then the overall weight values of the secondary evaluation factors of each risk are constructed into column vectors in the same order, and a comprehensive determining weight matrix, namely a comprehensive determining weight matrix A_T of hydrate drilling and production risks, is constructed after the constructed column vectors are arranged in sequence, where A_T is shown as follows:

$$A_T = \begin{bmatrix} w'_{T11} & \cdots & w'_{T1e} \\ \vdots & \ddots & \vdots \\ w'_{Tm1} & \cdots & w'_{Tme} \end{bmatrix}$$

[0034] where e is the number of risks (e=8).

[0035] Step 7: constructing a monitoring parameter change vector

[0036] When a risk occur, what kind of risk occurs underground is determined based on a change trend of monitoring parameter values and the magnitude of the relative change rate of monitoring parameter values. The relative change rate of each monitoring parameter value at a certain well depth is used as a constituent element of the monitoring parameter change vector, and the relative change rate of monitoring parameter values reflects the response intensity of monitoring parameters to the risk. Since the monitoring parameters such as injection fluid pressure, injection fluid flow, hanging load, drilling time, torque, rotational speed, total hydrocarbon value, hydrogen sulfide concentration, return fluid flow, return fluid pressure and return fluid temperature fluctuate within a normal range during normal construction (during construction without risks), in order to avoid the influence of fluctuation within the normal range of each monitoring parameter on risk judgment, a reasonable change range of monitoring parameters is established by analyzing monitoring data of a large number of drilled wells and combining the experience of field engineers. When the monitoring parameters fluctuate within this range, it is determined that the monitoring parameters do not change, otherwise, it is determined that the monitoring parameters have changed. During the construction process, there are two changes of the monitoring parameter value: increase and decrease. The "+" indicates the increase of the monitoring parameter value and the "−" indicates the decrease of the monitoring parameter value. In the calculation process, an initial value of the monitoring parameter falls into two conditions: "0" and "not 0". Based on the above principle, the calculation formula for a constituent element of a monitoring parameter change vector is established as follows:

$$b_i = \frac{\Delta S_i}{S_{iL}} \quad \text{(a)}$$

$$b_i = \frac{S_{ic} - (S_{iL} + \Delta H_i)}{(S_{iL} + \Delta H_i)} \quad \text{(b)}$$

$$b_i = \frac{S_{ic} - (S_{iL} - \Delta H_i)}{(S_{iL} - \Delta H_i)} \quad \text{(c)}$$

[0037] where b_i is a relative change rate of the i-th monitoring parameter (namely the i-th evaluation factor); ΔS_i is a variation of a value of the i-th monitoring parameter; S_{ic} is a measured value of the i-th monitoring parameter; S_{iL} is a theoretical value of the i-th monitoring parameter; and ΔH_i is a reasonable change range of the value of the i-th monitoring parameter. When an initial value of the i-th monitoring parameter is not 0, the relative change rate of the i-th monitoring parameter is calculated by formula a; when the initial value of the i-th monitoring parameter is 0, an increase of the measured value of the i-th monitoring parameter is calculated by using formula b; and a decrease of the measured value of the i-th monitoring parameter is calculated by using formula c. When the value of the i-th monitoring parameter changes within a reasonable change range, it is defined as 0; when the change range of the i-th monitoring parameter is greater than or equal to 100%, it is defined as 1; and when the change range of the i-th monitoring parameter is between the reasonable change range and 100%, the value is taken as b_i.

[0038] Elements of the monitoring parameter change vector are sorted according to the arrangement sequence of the monitoring parameter in the column vector of the constructed comprehensive determining weight matrix, and finally the monitoring parameter change vector is constructed. The monitoring parameter change vector is expressed as follows:

$$B=(b_1 b_2 \ldots b_m)$$

[0039] Step 8: determining a risk

[0040] After the comprehensive determining weight matrix and monitoring parameter change vector are established, the product between the two is a judgment result of hydrate drilling and production risks, as shown in the following formula:

$$Z = BA_T = (b_1\ b_2\ \cdots\ b_m)\begin{bmatrix} w'_{T11} & \cdots & w'_{T1e} \\ \vdots & \ddots & \vdots \\ w'_{Tm1} & \cdots & w'_{Tme} \end{bmatrix}$$

[0041] where a value in Z indicates a possibility of each kind of risk; apparently, the greater the value of the element in Z, the greater the possibility of the corresponding risk; and in contrast, the smaller the value, the smaller the possibility of the corresponding risk.

[0042] In view of the risk judgment problem faced in the natural gas hydrate drilling and production process, according to the present invention, the method for intelligently determining hydrate drilling and production risks based on fuzzy judgment is established by using the fuzzy analytic hierarchy process. This method can quickly and accurately realize functions of intelligent judgment, alarm and the like, and is used to monitor and determine in real time whether underground risks occur during the natural gas hydrate drilling and production operation, thereby ensuring the safety of the natural gas hydrate drilling and production operation.

BRIEF DESCRIPTION OF THE DRAWINGS

[0043] FIG. **1** is a hierarchical structure diagram of a method for intelligently determining hydrate drilling and production risks based on fuzzy judgment according to the present invention;

[0044] FIG. **2** is a risk and monitoring parameter response diagram of the present invention; and

[0045] FIG. **3** is a judgment result diagram of the present invention.

DETAILED DESCRIPTION

[0046] The following further describes the present invention in detail with reference to the accompanying drawings and embodiments.

Embodiment 1

[0047] A method for intelligently determining hydrate drilling and production risks based on fuzzy judgment specifically includes the following steps.

[0048] A hierarchical structure model is built.

[0049] As shown in FIG. **1**, a target layer is composed of 8 risks which are formation gas production, borehole instability, hydrate production, drill string fracture, H_2S production, sticking, bit balling and piercing-caused leakage of a drilling tool respectively. A primary evaluation factor layer is composed of an injection parameter, a drilling parameter and a return parameter respectively. A secondary evaluation factor layer is composed of injection fluid pressure, injection fluid flow, hanging load, drilling time, torque, rotational speed, total hydrocarbon value, hydrogen sulfide concentration, return fluid flow, return fluid pressure and return fluid temperature.

[0050] A determining matrix is constructed.

[0051] With formation gas production an example, a sub-region is constructed according to each primary evaluation factor of this risk and the next evaluation factor layer dominated by this primary evaluation factor, and a determining matrix is established for this sub-region (see Table 1): based on the formation gas production in the target layer (namely a first layer), the nine-scale method is first used to compare primary evaluation factors of the primary evaluation factor layer (namely a second layer) and determine a scale value, then a primary evaluation factor determining matrix of the formation gas production is established based on the determined scale value, and then based on each primary evaluation factor of the primary evaluation factor layer respectively, a secondary evaluation factor determining matrix of the formation gas production is established for secondary evaluation factors of the secondary evaluation factor layer (namely a third layer) contained in each primary evaluation factor. Scale values of each primary evaluation factor and each secondary evaluation factor are determined by using the nine-scale method to construct an evaluation matrix A as follows:

$$\underset{\sim 1}{A}=\begin{bmatrix}(1,1,1) & (0.14,0.17,0.2) & (0.14,0.17,0.2)\\ (5,6,7) & (1,1,1) & (0.33,0.5,1)\\ (5,6,7) & (1,2,3) & (1,1,1)\end{bmatrix}$$

$$\underset{\sim 2}{A}=\begin{bmatrix}(1,1,1) & (1,1,1) & (0.33,0.5,1)\\ (1,1,1) & (1,1,1) & (1,1,1)\\ (1,2,3) & (1,1,1) & (1,1,1)\end{bmatrix}$$

$$\underset{\sim 3}{A}=\begin{bmatrix}(1,1,1) & (0.33,0.5,1) & (0.14,0.17,0.2)\\ (1,2,3) & (1,1,1) & (0.33,0.5,1)\\ (5,6,7) & (1,2,3) & (1,1,1)\end{bmatrix}$$

$$\underset{\sim 4}{A}=\begin{bmatrix}(1,1,1) & (0.14,0.17,0.2) & (0.14,0.17,0.2)\\ (5,6,7) & (1,1,1) & (0.33,0.5,1)\\ (5,6,7) & (1,2,3) & (1,1,1)\end{bmatrix}$$

$$\underset{\sim 5}{A}=\begin{bmatrix}(1,1,1) & (0.2,0.25,0.33) & (0.14,0.17,0.2)\\ (3,4,5) & (1,1,1) & (0.33,0.5,1)\\ (5,6,7) & (1,2,3) & (1,1,1)\end{bmatrix}$$

$$\underset{\sim 6}{A}=\begin{bmatrix}(1,1,1) & (0.14,0.17,0.2) & (0.14,0.17,0.2)\\ (5,6,7) & (1,1,1) & (0.33,0.5,1)\\ (5,6,7) & (1,2,3) & (1,1,1)\end{bmatrix}$$

$$\underset{\sim 7}{A}=\begin{bmatrix}(1,1,1) & (0.14,0.17,0.2) & (0.14,0.17,0.2)\\ (5,6,7) & (1,1,1) & (1,1,1)\\ (5,6,7) & (1,1,1) & (1,1,1)\end{bmatrix}$$

$$\underset{\sim 8}{A}=\begin{bmatrix}(1,1,1) & (0.2,0.25,0.33) & (0.14,0.17,0.2)\\ (3,4,5) & (1,1,1) & (0.33,0.5,1)\\ (5,6,7) & (1,2,3) & (1,1,1)\end{bmatrix}$$

$$\underset{\sim 9}{A}=\begin{bmatrix}(1,1,1) & (0.14,0.17,0.2) & (0.2,0.25,0.33)\\ (5,6,7) & (1,1,1) & (1,1,1)\\ (3,4,5) & (1,1,1) & (1,1,1)\end{bmatrix}$$

$$\underset{\sim 10}{A}=\begin{bmatrix}(1,1,1) & (0.2,0.25,0.33) & (0.14,0.17,0.2)\\ (3,4,5) & (1,1,1) & (1,1,1)\\ (5,6,7) & (1,1,1) & (1,1,1)\end{bmatrix}$$

TABLE 1

Evaluation scale table of a nine-scale method

Scale value	Meaning
(1, 1, 1)	Factors i and j are of equal importance.
(1, 2, 3)	The factor i is slightly more important than the factor j.
(3, 4, 5)	Compared with the factor j, the factor i is of great importance.
(5, 6, 7)	Compared with the factor j, the factor i is very important.
(7, 8, 9)	Compared with the factor j, the factor i is absolutely important.

[0052] A comprehensive determining matrix is established and a fuzzy weight value is calculated.

[0053] The established comprehensive determining matrix is as follows:

$$\underset{\sim M}{A}=\begin{bmatrix}(1,1,1) & (0.26,0.31,0.4) & (0.17,0.21,0.29)\\ (3.6,4.5,5.4) & (1,1,1) & (0.53,0.65,1)\\ (4,5,6) & (1.4,2,2.6) & (1,1,1)\end{bmatrix}$$

[0054] A geometric mean of each primary evaluation factor (monitoring parameter type) of the comprehensive determining matrix is solved:

$$r_1=[(1\times0.26\times0.17),(1\times0.31\times0.21),(1\times0.4\times0.29)]^{1/3}=(0.354,0.402,0.488)$$

$$r_2=[(3.6\times1\times0.53),(4.5\times1\times0.65),(5.4\times1\times1)]^{1/3}=(1.240,1.430,1.754)$$

$$r_3=[(4\times1.4\times1);(5\times2\times1),(6\times2.6\times1)]^{1/3}=(1.776,2.154,2.499).$$

[0055] The sum of the geometric mean is:

$$r=r_1+r_2+r_3=(3.37,3.987,4.741)$$

[0056] The relative fuzzy weight value of each primary evaluation factor calculated by formula (5) is as follows:

$$w_1=\frac{r_1}{r}=(0.075,0.101,0.145)$$

$$w_2=\frac{r_2}{r}=(0.262,0.359,0.521)$$

$$w_3=\frac{r_3}{r}=(0.375,0.540,0.742)$$

[0057] The relative fuzzy weight value of each evaluation factor is converted by formula (6) into an explicit value of the evaluation factor as follows:

$$DF_1=\frac{[(R_1-L_1)+(M_1-L_1)]}{3}+L_1=\frac{[(0.145-0.075)+(0.101-0.075)]}{3}+0.075=0.107$$

[0058] Similarly, the following can be obtained: DF_2=0.38, and DF_3=0.552.

[0059] The explicit weight value is normalized by formula (7) as follows:

$$w_1'=\frac{0.107}{0.107+0.38+0.552}=0.103$$

[0060] Similarly, the following can be obtained: w'_2=0.366, and w'_3=0.531.

[0061] Calculation results of relative weight values of the foregoing primary evaluation factor layer (monitoring parameter type) of formation gas production are summarized as shown in Table 2.

TABLE 2

Summary table of calculation results of relative weight of the primary evaluation factor layer (monitoring parameter type) of formation gas production

	Injection parameter	Drilling parameter	Return parameter
Geometric mean r_i	(0.354, 0.402, 0.488)	(1.24, 1.43, 1.754)	(1.766, 2.154, 2.499)
Fuzzy weight w_i	(0.075, 0.101, 0.145)	(0.262, 0.359, 0.521)	(0.375, 0.54, 0.742)
Explicit normalized weight w_i'	0.103	0.366	0.531

[0062] The weight calculation of the secondary evaluation factor layer is carried out in sequence, and then series connection is carried out between various layers, and finally the risk weight value of formation gas production is obtained as shown in Table 3.

TABLE 3

Summary table of risk weight of formation gas production

Target	Primary evaluation factor	Relative weight value of the primary evaluation factor	Secondary evaluation factor	Relative weight value of the secondary evaluation factor	Secondary evaluation factor Overall weight value
Formation gas production	Injection parameter	0.103	Injection fluid pressure	1	0.103
			Injection fluid flow	0	0
	Drilling parameter	0.366	Hanging load	0.548	0.201
			Drilling time	0.452	0.165
			Torque	0	0
			Rotational speed	0	0
	Return parameter	0.531	Total hydrocarbon value	0.625	0.332
			Hydrogen sulfide concentration	0	0
			Return fluid flow	0.126	0.067
			Return fluid pressure	0.249	0.132
			Return fluid temperature	0	0

[0063] Finally, the comprehensive determining weight matrix of hydrate drilling risks is obtained as follows:

$$A_T = \begin{bmatrix} w'_{T11} & \cdots & w'_{T1e} \\ \vdots & \ddots & \vdots \\ w'_{Tm1} & \cdots & w'_{Tme} \end{bmatrix} =$$

$$\begin{bmatrix} 0.103 & 0.154 & 0 & -0.17 & 0 & 0.185 & 0.224 & -0.796 \\ 0 & -0.035 & 0 & 0 & 0 & 0 & 0 & 0 \\ -0.201 & 0.109 & 0 & -0.637 & 0 & 0.199 & 0.103 & 0 \\ -0.165 & 0.074 & -0.165 & 0.087 & 0 & 0 & 0.432 & 0.063 \\ 0 & 0.207 & 0 & -0.106 & 0 & 0.407 & 0.241 & 0.091 \\ 0 & -0.084 & 0 & 0 & 0 & -0.041 & 0 & -0.05 \\ 0.332 & 0 & 0.389 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0.067 & -0.121 & 0.067 & 0 & 0 & 0 & 0 & 0 \\ 0.132 & -0.216 & 0.059 & 0 & 0 & -0.168 & 0 & 0 \\ 0 & 0 & -0.32 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

[0064] Columns of the comprehensive determining weight matrix sequentially represent eight risk types which are formation gas production, borehole instability, hydrate production, drill string fracture, H_2S production, sticking, bit balling and piercing-caused leakage of a drilling tool. In each column, overall weight values of injection fluid pressure, injection fluid flow, hanging load, drilling time, torque, rotational speed, total hydrocarbon value, hydrogen sulfide concentration, return fluid flow, return fluid pressure and return fluid temperature are represented sequentially.

[0065] A well A is a deep water well located in the South China Sea. Take the well A as an example for trial calculation. Basic data of this well is as follows:

Parameter name	Data	Parameter name	Data
Water depth (m)	1000	Geothermal gradient (° C./m)	0.025
Well depth (m)	5100	Submarine temperature (° C.)	4
Inlet temperature (° C.)	22	Outer diameter of drill string (mm)	127
Diameter of choke manifold (mm)	76.2	Inner diameter of riser (mm)	472
Drilling fluid density (g/cm^3)	1.3	Thermal conductivity of formation (W/(m · ° C.))	2.25
Displacement (L/s)	30	Thermal conductivity of drilling fluid (W/(m · ° C.))	1.5
Bit size (mm)	215.9	Specific heat of drilling fluid (J/(kg · ° C.))	1675
Bit pressure (kN)	40	Rotational speed (rad/min)	40 -50

[0066] Downhole anomalies occurred when the well was drilled to a depth of 4833.7 m. Theoretical values of various monitoring parameters at 4833.7 m were calculated through the model. During the construction process, an on-site monitoring device acquired measured values of various monitoring parameters at the well section at a depth of 4833.7 m. Table 4 shows the theoretical values and the measured values corresponding to various monitoring parameters when the well was drilled to a depth of 4833.7 m.

[0067] b_i is a relative change rate of the i-th monitoring parameter (namely the i-th evaluation factor); ΔS_i is a variation of a value of the i-th monitoring parameter; S_{ic} is a measured value of the i-th monitoring parameter; S_{iL} is a theoretical value of the i-th monitoring parameter; ΔH_i and is a reasonable change range of the value of the i-th monitoring parameter.

TABLE 4

Comparison table of model calculation values and field measured values at a drill depth of 4833.7 m

Parameter	Monitoring parameter: Injection fluid pressure (MPa)	Injection fluid flow (m^3/min)	Hanging load (kN)	Drilling time (min/m)	Torque (kN · m)	Rotational speed (rad/min)
Theoretical value	15.296	1.80	1745	5.5	11.85	50
Measured value	13.85	1.824	1653.55	6.3	6.82	50

Parameter value type	Monitoring parameter: Total hydrocarbon value (%)	Hydrogen sulfide concentration (ppm)	Return fluid flow (m^3/min)	Return fluid pressure (kPa)	Outlet temperature (° C.)
Theoretical value	4.06	0	1.80	14.57	22
Measured value	3.35	0	1.862	14.55	22

[0068] The relative change rate of each monitoring parameter was calculated and the monitoring parameter change vector was constructed by using the obtained monitoring parameter related data at the well depth of 4833.7 m (as shown in Table 4). The finally obtained judgment result is as follows:

$$Z=BA_T=(0.604\ 0\ 0\ 0\ 71.572\ 0\ 0\ 27.824)$$

[0069] The foregoing results correspond to the risk types to draw a histogram of risk occurrence probability (as shown in FIG. **3**). Through fuzzy judgment, it can be seen that the possibilities of piercing-caused leakage of a drilling tool and drill string fracture are relatively high, with the possibilities being 27.824% and 71.572% respectively. It can be determined that drill string fracture occurs when it is drilled to a depth of 4833.7 m. In actual drilling engineering, when it was drilled to 4833.7, a drill string fracture accident occurred. The results obtained by the method for intelligently determining hydrate drilling and production risks based on fuzzy judgment are consistent with the actual monitoring results on site.

[0070] The foregoing descriptions are only preferred implementations of the present invention. It should be noted that for a person of ordinary skill in the art, several improvements and modifications may further be made without departing from the principle of the present invention. These improvements and modifications also fall within the protection scope of the present invention.

What is claimed is:

1. A method for intelligently determining hydrate drilling and production risks based on fuzzy judgment, comprising the following steps in sequence:

step 1: building a hierarchical structure model

based on monitoring parameters in a hydrate drilling and production process, classifying into layers from top to bottom, which comprise a target layer, a primary evaluation factor layer and a secondary evaluation factor layer, wherein the target layer is composed of 8 risks which are formation gas production, borehole instability, hydrate production, drill string fracture, H_2S production, sticking, bit balling and piercing-caused leakage of a drilling tool respectively; the primary evaluation factor layer is composed of 3 monitoring parameters types which are an injection parameter, a drilling parameter and a return parameter respectively; the secondary evaluation factor layer is composed of 11 monitoring parameters, which are injection fluid pressure, injection fluid flow, hanging load, drilling time, torque, rotational speed, total hydrocarbon value, hydrogen sulfide concentration, return fluid flow, return fluid pressure and return fluid temperature respectively, to construct a hierarchical structure model;

step 2: constructing a determining matrix

based on a selected risk in the target layer, first using a nine-scale method to compare primary evaluation factors of the primary evaluation factor layer and determine a scale value, then establishing a primary evaluation factor determining matrix based on the determined scale value, and then based on each primary evaluation factor of the primary evaluation factor layer respectively, establishing a secondary evaluation factor determining matrix for secondary evaluation factors of the secondary evaluation factor layer contained in each primary evaluation factor, wherein the determining matrixes of the primary evaluation factors and the secondary evaluation factors are expressed with $\underset{\sim}{A}$:

$$\underset{\sim}{A} = \begin{bmatrix} \underset{\sim}{a}_{11} & \cdots & \underset{\sim}{a}_{1m} \\ \vdots & \ddots & \vdots \\ \underset{\sim}{a}_{m1} & \cdots & \underset{\sim}{a}_{mm} \end{bmatrix} = \left(\underset{\sim}{a}_{ij}\right)_{m\times m}$$

i refers to the i-th evaluation factor of a certain layer in the hierarchical structure model (a value of i is 1, 2, 3, . . . , m), j refers to the j-th evaluation factor of the same layer in the same hierarchical structure model as j (a value off is 1, 2, 3, . . . , m), and in refers to the number of primary evaluation factors or the number of secondary evaluation factors;

step 3: establishing a comprehensive determining matrix and calculating a fuzzy weight value

setting the number of judging experts to be n to obtain a comprehensive determining matrix $\underset{\sim}{A}_M$:

$$\underset{\sim}{A}_M = \frac{1}{n}\left[\underset{\sim}{A}_1 + \underset{\sim}{A}_2 + \cdots + \underset{\sim}{A}_n\right]$$

wherein $\underset{\sim}{A}_1$, $\underset{\sim}{A}_2$ and $\underset{\sim}{A}_n$ refer to determining matrixes

constructed according to scale values determined by judgment results of the first expert, the second expert and the n-th expert respectively;

a geometric mean of the i-th evaluation factor in the comprehensive determining matrix $\underset{\sim}{A}_M$ is:

$$r_i=(a_{i1}\times a_{i2}\times a_{i3}\times \ldots \times a_{im})^{1/m}$$

a relative fuzzy weight value of the i-th evaluation factor is:

$$w_i=r_i\times(r_1+r_2+r_3+ \ldots +r_m)^{-1};$$

step 4: converting the relative fuzzy weight value of the i-th evaluation factor into an explicit value

expressing the relative weight fuzzy weight value w_i of the i-th evaluation factor in the form of a triangular fuzzy number, wherein $w_i=(R_i, M_i, L_i)$, L_i is left extension of the triangular fuzzy number, R_i is right extension of the triangular fuzzy number, and M_i is a median of the triangular fuzzy number; converting the relative weight fuzzy weight value of the i-th evaluation factor into an explicit weight value DF_i of the i-th evaluation factor:

$$DF_i = \frac{[(R_i - L_i) + (M_i - L_i)]}{3} + L_i;$$

step 5: normalizing the explicit weight value of the i-th evaluation factor

normalizing the explicit weight value of the i-th evaluation factor, wherein the relative weight value of the normalized i-th evaluation factor is:

$$w_i' = \frac{DF_{ij}}{\Sigma DF_{ij}};$$

step 6: connecting relative weight values of each inter-layer evaluation factor in series

multiplying the relative weight value of each primary evaluation factor respectively with the relative weight values of all secondary evaluation factors contained in this primary evaluation factor to obtain an overall weight value w'_{Ti} of the i-th secondary evaluation factor:

$$w'_{Ti}=w'_{1i}\times w_{2i}$$

w'_{1i} is the relative weight value of the primary evaluation factor corresponding to the i-th secondary evaluation factor, and w'_{2i} is the relative weight value of the i-th secondary evaluation factor;

respectively calculating a relative weight value of each primary evaluation factor of the remaining risks in the target layer, a relative weight value of each secondary evaluation factor contained in each primary evaluation factor and overall weight values of the secondary evaluation factors, constructing the overall weight values of the secondary evaluation factors of each risk into column vectors in the same order, and constructing a comprehensive determining weight matrix after the column vectors are arranged in sequence, namely a comprehensive determining weight matrix A_T of hydrate drilling and production risks, wherein A_T is shown as follows:

$$A_T = \begin{bmatrix} w'_{T11} & \cdots & w'_{T1e} \\ \vdots & \ddots & \vdots \\ w'_{Tm1} & \cdots & w'_{Tme} \end{bmatrix}$$

e is the number of risks, e=8;

step 7: constructing a monitoring parameter change vector

$$b_i = \frac{\Delta S_i}{S_{iL}} \quad (a)$$

$$b_i = \frac{S_{ic} - (S_{iL} + \Delta H_i)}{(S_{iL} + \Delta H_i)} \quad (b)$$

$$b_i = \frac{S_{ic} - (S_{iL} - \Delta H_i)}{(S_{iL} - \Delta H_i)} \quad (c)$$

wherein b_i is a relative change rate of the i-th monitoring parameter; ΔS_i is a variation of a value of the i-th monitoring parameter; S_{ic} is a measured value of the i-th monitoring parameter; S_{iL} is a theoretical value of the i-th monitoring parameter; ΔH_i is a reasonable change range of the value of the i-th monitoring parameter; when an initial value of the i-th monitoring parameter is not 0, the relative change rate of the i-th monitoring parameter is calculated by formula a; when the initial value of the i-th monitoring parameter is 0, an increase of the measured value of the i-th monitoring parameter is calculated by using formula b; a decrease of the measured value of the i-th monitoring parameter is calculated by using formula c;

constructing a monitoring parameter change vector:

$B=(b_1 b_2 \ldots b_m)$;

step 8: obtaining a judgment result of hydrate drilling and production risks

$$Z = BA_T = (b_1\ b_2\ \cdots\ b_m) \begin{bmatrix} w'_{T11} & \cdots & w'_{T1e} \\ \vdots & \ddots & \vdots \\ w'_{Tm1} & \cdots & w'_{Tme} \end{bmatrix}$$

wherein a value in Z indicates a possibility of each kind of risk; the greater the value, the greater the possibility of the corresponding risk; and in contrast, the smaller the value, the smaller the possibility of the corresponding risk.

2. The method for intelligently determining hydrate drilling and production risks based on fuzzy judgment according to claim **1**, wherein

the scale values of each primary evaluation factor and each secondary evaluation factor in step 2 are determined by the nine-scale method; when the monitoring parameter i corresponding to the selected risk is compared with the monitoring parameter j, the scale value is determined according to a response intensity of the monitoring parameter i and the monitoring parameter j to the risk, and the scale value is quantitatively expressed by the triangular fuzzy number

$$\underset{\%}{a_{ij}} = (a_1, a_2, a_3).$$

3. The method for intelligently determining hydrate drilling and production risks based on fuzzy judgment according to claim **1**, wherein

the comprehensive determining matrix $\underset{\sim}{A}_M$ in step 3 is as follows:

$$\underset{\sim M}{A} = \frac{1}{n}\left[\underset{\sim 1}{A} + \underset{\sim 2}{A} + \cdots + \underset{\sim n}{A}\right]$$

wherein $\underset{\sim}{A}_1$, $\underset{\sim}{A}_2$ and $\underset{\sim}{A}_n$ refer to determining matrixes constructed according to scale values determined by judgment results of the first expert, the second expert and the n-th expert respectively;

a determining matrix established by the k-th expert by evaluation is expressed as $\underset{\sim}{A}_k=[a_{cd}^k]$, a_{cd}^k indicates a scale value determined by the k-th expert according to the importance of a same layer evaluation factor c relative to an evaluation factor d, and a comprehensive determining matrix is calculated as follows:

$$\underset{\sim M}{A} = \frac{1}{n}\left[\sum_{k=1}^{n} a_{cd}^k\right] = \begin{bmatrix} (1, 1, 1) & \cdots & \frac{1}{n}\left[\sum_{k=1}^{n} a_{1m}^k\right] \\ \vdots & \ddots & \vdots \\ \frac{1}{n}\left[\sum_{k=1}^{n} a_{m1}^k\right] & \cdots & (1, 1, 1) \end{bmatrix}.$$

* * * * *