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The Rock Physical Phase Partition Method of Multilayer Sandstone Reservoir Based on Fuzzy Inference Networks

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Abstract. A kind of discrimination method based on weighted fuzzy inference networks is put forward in this paper according to the rock physical phase division problem of heterogeneous multilayer sandstone reservoir. In this method, the fuzziness of rock physical phase classification and meeting character of characteristic parameters are fully considered, and the cumulated expert experience in research are combined with the quantitative indexes which reflect the rock physical phase change. The rock physical phase classification types and deviding indexes are defined by the core analysis data of coring well and explaining results of expert, then the classification standard pattern library of rock physical phase is established. The rock physical appearance discrimination model of heterogeneous multilayer sandstone reservoir based on weighted fuzzy inference networks is established by adopting the adaptive learning mechanism. The experimental results demonstrate that the method has good application effect by processing the actual data from Daqing oilfield.

Keywords: physical phase, heterogeneous, sandstone reservoir, fuzzy inference network, pattern recognition

1. Introduction

Rock physical phase is an important geological concept of fine reservoir geological study and the dynamic analysis application of oil field development in recent years, it also is the genetic unit formed by multiple geological functions, such as reservoir sediment, digenetic and post-transformation. Reservoir rock physical phase is an important index which expresses some characteristics including reservoir rock character, properties, heterogeneous character, micro-pore structure and law of fluid flow, it plays an important control function for the distribution of fluid field and pressure field, flooding situation and residual oil's spatial distribution of the underground reservoir. For the heterogeneous multilayer sandstone reservoir, because of the geological conditions and the complexity of sedimentary environment, there isn't a clear distinction boundary for mode characteristically values which express various rock physical phase, the change of index data also has the continuity and crossed character when classifying, it brings great difficult for the practical phase division work[1]. For this fuzziness occurring in objective reality, when the accurate mathematical discriminated model established by using the traditional method carrying out automatic partition of rock physical phases, the discrimination results are difficult to meet the actual.

According to the rock physical phase partition of heterogeneous multilayer sandstone reservoir which occurs fuzziness and crossed character, a kind of discrimination method based on weighted fuzzy inference networks is proposed in this paper. Fist of all, The rock physical phase classification types and delimiting indexes of the study area are defined according to the core analysis data of coring well and the explaining results of expert, and the standard pattern library of reservoir rock physical phase classification is established, then the weighted fuzzy inference network model is established according to the specific standards of block

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rock physical phase partition, it can automatically adjust the network connection weights and property parameters by studying the typical modes of various rock physical phase, to make the discrimination model be adaptive to the actual distribution of block rock physical phase[2]. As the research of rock physical phase must build on the basis of sedimentary rock phase and the digenesis analysis, and by means of the integrative quantitative indexes to express, therefore, the reservoir porosity, permeability, clay content, median grain diameter and the characteristic parameters FZI reflecting pore structure are selected on the choice of phase mode characteristic index.

It carried out to practical application for the north three east regions of Daqing oilfield Shabei development zone by adopting the research method proposed in the paper. There are five types of the rock physical phase of reservoir according to the actual geological conditions and rock physical characteristics of this block. This block's standard pattern library of rock physical phase is established according to the core analysis data of seven coring well and the explaining results of expert. It achieved a good application results by executing rock physical phase partition for the actual litho logic segments of 175 non-standard pattern library, the coincidence rate reached to 87.4%.

2. The selection to the characteristic parameters of rock physical phase

The rock physical phase of reservoir is the complex between reservoir litho logy and physical properties, it should fully consider parameters which express reservoir litho logy and properties during the research, and complete by virtue of the comprehensive quantitative indicators. According to the existed expert studies and the specific circumstances to the reservoir litho logy, physical properties and heterogeneity distribution of north three east regions of Daqing oilfield Shabei development zone, the reservoir rock physical phase is divided by the following parameter indexes: porosity（ϕ）, permeability（k）which reflect the physical properties of reservoir; clay content（V_{sh}）, median grain diameter（M_d）which reflect the reservoir rock phase features; FZI[3] which reflect the micro-pore structure features of reservoir. FZI is defined by the following formula:

$$FZI = [\frac{1-\phi}{\phi}]\sqrt{(k/\phi)} \quad (1)$$

3. Fuzzy Inference networks

For the values of different rock physical phase, the single characteristic parameters often have larger range and crossed property during the dividing to the rock physical phase of heterogeneous reservoir, it can't accurately define the ownership of reservoir phase types by characteristic parameters, only gives the possibility that research object belongs to some rock physical phase, that is the fuzzy classification. Therefore, it can better solve such problems if we comprehensively considered each index values by subjection degree and adopted fuzzy inference method based on learning mechanism to divide the reservoir rock physical phase.

3.1. Fuzzy Inference Rules

The general rules of fuzzy logical inference can be described as follows: if there is K items fuzzy inference rules of fuzzy system, which rule k: if x_1 is A_{k1} , x_2 is A_{k2} , $\cdots$, x_n is A_{kn} , thus y_1 is B_{k1} , y_2 is B_{k2} , $\cdots$, y_m is B_{km} , $k = 1,2,...,K$. Where A_{ki} and B_{kj} are the fuzzy set of universe U_i and V_j separately, and $X = (x_1, x_2, \cdots x_n) \in U_1 \times U_2 \times \cdots \times U_n$ and $Y = (y_1, y_2, ..., y_m) \in V_1 \times V_2 \times \cdots \times V_m$ are the inputs and outputs of fuzzy logical system separately [4]. A_{ki} denotes the value range of index parameter x_i , B_{kj} denotes the types of reservoir rock physical phase according to the partition problems of rock physical phase.

3.2. Network Topology

The values of selected characteristic index of rock physical phase generally are in an interval range, the value interval generally is different for different phase types, and the meeting probability also is different [5]. The probability curves generally obey normal distribution by statistically analyzing to the data of numerous coring wells, but the value interval, mean and variance are different. Therefore, the membership that reservoir belongs to some rock physical phase can be defined by the value of characteristic parameters and satisfied probability distribution function. The membership function of the kth phase type relative to characteristic parameters x_i can be expressed by $\mu_{A_{ki}}$, and suppose that x_i has n_i item nodes used by fuzzy partition, therefore, the discrimination system with K items fuzzy inference rules can be denoted by fig1[6][7].

3.2.1. Fuzzy Inference Neural Network:

- The first layer: Input layer

The input vector can be not only accurate numeric vectors, also can be fuzzy quantities, this layer completes the inputs from characteristic parameter values to networks.

- The second layer: Fuzzy layer

Because the characteristic parameters for the values of each type rock physical phase all obey the normal distribution, therefore, this layer can use the Gaussian function as membership function. The index x_i of input layer and the output of the jth node corresponding to this layer is defined by the following formula:

$$\mu_{A_{ij}}(x_i) = \exp(-(\frac{x_i - m_{ij}}{\sigma_{ij}})^2) \qquad (2)$$

Where, m_{ij} and σ_{ij} are the mean and variance which denote A_{ij} separately. Make: $N = \sum_{i=1}^{n} n_i$. This layer has N nodes.

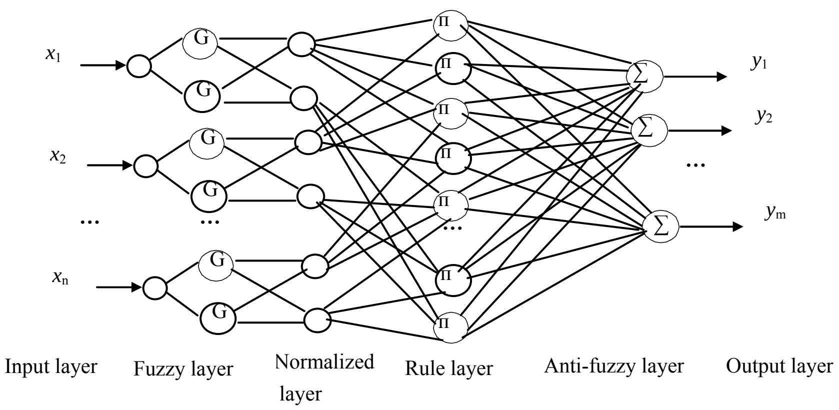

Fig. 1: Fuzzy Inference Neural Network

- The third layer: Normalized layer

This layer carries out the regularization operator to the outputs of the second layer that is, normalizing to membership.

$$\mu'_{A_{ij}}(x_i) = \frac{\mu_{A_{ij}}(x_i)}{\sum_{j=1}^{n_i} \mu_{A_{ij}}(x_i)} \qquad (3)$$

Where, $\mu'_{A_{ij}}(x_i)$ denotes the normalized output of $\mu_{A_{ij}}(x_i)$. The nodes are same to the second layer, which is there are N nodes.

- The fourth layer: Rule layer

This layer connects the antecedent (normalized nodes) with conclusion nodes (output nodes). The connection rules are: each rule node only connects with a normal node which is fuzzed by each input component. Therefore, there is $K = \prod_i n_i$ rule nodes in the initializing structure of this layer, the output of the kth rule node is:

$$z_k = \prod_{i=1}^{n} \mu'_{A_{is}}(x_i) \qquad (4)$$

where, $s = s(k,i)$, and $1 \le s \le n_i$.

- The fifth layer: Anti-fuzzy layer

All the rule nodes of the fourth layer are all connect with the output nodes of this layer. This layer completes anti-fuzzy operation averagely in centre. Suppose there are m nodes in this layer, the jth output component is:

$$y_j = \sum_{k=1}^{K} v_{kj} z_k = \sum_{k=1}^{K} v_{kj} \prod_{i=1`}^{n} \mu'_{A_{isi}}(x_i) \qquad (5)$$

In formula (5), v_{kj} are the adjustable parameters of network, denote the fuzzy association degree between the characteristic parameters and phase types.

3.3. Learning algorithm

According to the classification modes of known reservoir rock physical phase, it adaptively adjusts the parameters of fuzzy neural network using gradient descent learning algorithm. The minimizing error function is:

$$E = \frac{1}{2}\|D - Y\|^2 \qquad (6)$$

In formula (6), Y is the actual output vector of fuzzy neural network; D is the expected output vector [8]. If w_{ij} are the parameters to be adjusted, the learning rule is:

$$w_{ij}(t+1) = w_{ij}(t) - \eta \frac{\partial E}{\partial w_{ij}} + \alpha \Delta w_{ij}(t)$$
$$\Delta w_{ij}(t) = w_{ij}(t) - w_{ij}(t-1) \qquad (7)$$

In formula (7), η is the learning speed, α is the inertial coefficient, t is the iteration number. Make w_{ij} are selected v_{kj}, m_{ij} and σ_{ij} separately, get:

$$\frac{\partial E}{\partial v_{kj}} = (y_j - d_j) z_k \qquad (8)$$

$$\frac{\partial E}{\partial m_{ij}} = \sum_{j'=1}^{p} (y_{j'} - d_{j'}) \sum_{k=1}^{K} b_{kj'} \left(\frac{\delta(j, s(k,i))}{X} - \frac{Y}{X^2}\right) \frac{\partial \mu_{A_{ij}}(x_i)}{\partial m_{ij}} \qquad (9)$$

$$\frac{\partial E}{\partial \sigma_{ij}} = \sum_{j'=1}^{p} (y_{j'} - d_{j'}) \sum_{k=1}^{K} b_{kj'} \left(\frac{\delta(j, s(k,i))}{X} - \frac{Y}{X^2}\right) \frac{\partial \mu_{A_{ij}}(x_i)}{\partial \sigma_{ij}} \qquad (10)$$

on where,

$$X = \sum_{j=1}^{n_i} \mu_{A_{ij}}(x_i), Y = \mu_{A_{i,s(k,i)}}(x_i), \frac{\partial \mu_{A_{ij}}(x_i)}{\partial m_{ij}} = \frac{2(x_i - m_{ij})}{\sigma_{ij}^2} \mu_{A_{ij}}(x_i),$$
$$\frac{\partial \mu_{A_{ij}}(x_i)}{\partial \sigma_{ij}} = \frac{2(x_i - m_{ij})^2}{\sigma_{ij}^3} \mu_{A_{ij}}(x_i), \delta(j, s(k,i)) = \begin{cases} 1, j = s(k,i) \\ 0, j \ne s(k,i) \end{cases}. \qquad (11)$$

The formulars（8~10）are induced into formula (6), that get the parameter update rules of fuzzy neural network.

4. The actual application

4.1. The partition of rock physical phase and the construction of standard pattern library

North three east regions of Daqing oilfield Shabei development zone is a sandstone reservoir with continental facing multiple layers, heterogeneity is serious, there is different rock physical phase, and the same litho logy corresponds to a wide range of physical parameter values. Select the coring well data of north 3-D4-255 well, north 3-D4-82 well, north 2-6-512 well etc. seven wells in this block and adjacent blocks, and carry out homing processing to core, define the rock type according to the analysis data of core. Compute the FZI value by count the porosity, permeability, clay content and median grain diameter of 537 natural layers or the relative homogeneous segment within layer, and divide 5 types rock physical phase of reservoir [9]. The clay content of class I rock physical phase is generally less than 10%, air permeability 600~5000*10-3um2, porosity is 26~33%, median grain diameter is 0.05~0.26, FZI is greater than 4, it is mainly distributed in the middle and lower river sand, is the major reservoir in oil Field development. The clay content of class Ⅱ rock physical phase is 6~16%, air permeability 100~1100*10-3um2, porosity is 23~33%, median grain diameter is 0.04~0.16, FZI is 2~4, it is mainly distributed in the middle and upper of various types of channel sand, physical property is poorer than class I. The clay content of class Ⅲ rock physical phase is 8~18%, air permeability 37~230*10-3um2, porosity is 21~30%, median grain diameter is 0.04~0.14, FZI is 2~4, it is mainly distributed in the top surfaces, Hejian of various types of channel sand. The clay content of class Ⅳ rock physical phase is 9~23%, air permeability 10~80*10-3um2, porosity is 20~29%, median grain diameter is 0.01~0.1, FZI is 0.6~1.2, it is mainly distributed in the Hejian or thin layer sand of front delta. The clay content of class Ⅴ rock physical phase is 10~42%, air permeability 2~13*10-3um2, porosity is 17~26%, median grain diameter is 0.01~0.08, FZI is less than 0.06. 219 representative sample layers are selected to form the classification standard pattern library of rock physical phase, among these layers, there are 53 samples of class Ⅰ rock physical phase, 76 samples of class Ⅱ, 50 samples of class Ⅲ, 30 samples of class Ⅳ, 10 samples of class Ⅴ.

4.2. The actual partition of reservior rock physical phase

The topology of fuzzy inference network is defined as: 5-25-25-243-5 according to the number of type, number of characteristic parameter and number of fuzzy classification of divided reservoir rock physical phase. The network is trained using the learning mechanism and algorithm steps introduced in the paper according to the established standard pattern library of reservoir rock physical phase, the discriminated model of fuzzy inference network is defined. In the actual application, the 175 reservoirs of North three east regions' 5 wells in Shabei development zone are divided according to the reservoirs porosity, permeability, clay content and median grain diameter defined by the interpretation of logging data and the counted FZI value, compare with the sedimentary facials' research results of small layer and the reservoir production performance data, and analyzed by experts verifying, 153 is conformed, the accuracy rate is 87.4%, it achieved the good partition results.

5. Conclusion

It can better solve the fuzziness occurred in the classification of reservoir rock physical phase and the crossed character that exists in the getting values from different rock physical phase of single characteristic parameter by adopting the partition method to reservoir rock physical phase based on fuzzy inference network. It can automatically extract the characteristics of phase class by adaptive learning to the known various samples of reservoir rock physical phase, reduce the influence of human factors, and it is easy to establish the discriminated model of reservoir rock physical phase under the different sedimentary environment. This method also has good applicability for some problems, such as solving the automatic recognition for the sedimentary facials of small layer [10], flooded discriminated [11].

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