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# Reaction Degree and Selecting Sensitive Geological Factors for Coal and Gas Outburst Forecast

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**Abstract:** To accurately carry out coal and gas outburst forecast, the concept and calculation method of reaction degree were put forward base on the third theory of quantification which have extended the applying range and scientificalness of the primary reaction. Taking the Zhongmacun mine as an example, the geological factors affecting coal and gas outburst were researched. Eight sensitive factors for the outburst of coal and gas were screened out from 11 geological factors using the method of unit classification and the third theory of quantification. The results show that it is feasible to apply the third theory of quantification to gas geology, which offers a new thought to select the sensitive geological factors of gas outburst forecast.

**Key words:** Third theory of quantification, reaction degree, sensitive geological factors, coal and gas outburst forecast, Zhongmacum mine

## INTRODUCTION

Experts has carried out regarding the influencing factors of coal and gas outburst, such as gas content, gas pressure, coal structure, buried depth, lithology of roof and floor, geological structure, etc., (Zhang, 2009). However, coal and gas outburst is an extremely complex system which is determined by a variety of factors with complex nonlinear relationships (Gas Geology Lab of Jiaozuo Institute of Technology, 1990). The third theory of quantification can truly describe the nonlinear relationships between input and output variables, therefore, is widely used in geological fields (Zhang and Yuan, 1999; Wang *et al.*, 2006; Guo and Hao, 2008; Shi *et al.*, 2011; Shi and Yang, 2013).

In this study, the Zhongmacun mine of Jiaozuo was selected as an example, applying the third theory of quantification to select sensitive geological factors of coal and gas outburst to improve the accuracy and reliability of the outburst forecasting work.

## REACTION DEGREE

The quantification theory is a multi analysis method which can deal with qualitative variable and quantitative variable at the same time. In the theory, qualitative variable is entitled item and all different values of quantitative variable are entitled species (Dong and Xia, 1979).

Suppose there are n samples, $\delta_i$ (j, k)denotes the reaction of k species of j item in No. i sample and $\sum \delta_i$ (j, k). When all the qualitative data of j item in No.i sample is k species, $\delta_i$ (j, k) = 1 or else $\delta_i$ (j, k) = 0. But in gas geology, the reactions of species of many qualitative variables are difficult to be selected by this simple means otherwise the researching results may warp awfully (Zhang *et al.*, 2001; Shi *et al.*, 2011; Shi and Yang, 2013). So, a new method of valuing reactions is brought forward: $\delta_i$ (j, k), $\alpha$,$\alpha$ is the ratio of the reaction of k species in j item of No. i sample, 0 $\le\alpha\le$, 1 here, $\delta_i$ (j, k) is entitled the reaction degree (Guo and Hao, 2008) of k species of j item in No. i sample, its coverage is (0, 1). For example, suppose the variable, lithology of coal seam top, is the third item of samples (j = 3), including three species, mudstone, sandstone and limestone, mudstone accounts for 60% in No. i statistical unit and limestone is 40%, so, $\delta_i$ (3, 1) = 0.6, $\delta_i$ (3, 2) = 0, $\delta_i$ (3, 3) = 0.4. Adopting reaction degree to value qualitative variable extends the range of primary reaction value and has more extensive practicability (Zhang and Zhang, 2001).

## SELECT SENSITIVE GEOLOGICAL FACTORS

After going in-depth analyzing the geological factors affecting coal and gas outburst in Zhongmacun mine, 11 parameters are selected as the variables for the third theory of quantification, such as Jiulishan fault, Lizhuang fault, the degree of coal destruction, the

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Table 1: Basic data of all statistical units of exploited region of Zhangmacun mine

| Unit | Jiulishan fault (m) | | Lizhuang fault (m) | | Degree of coal destruction | | Thickness and its change coal seam (m) | | | Splitting and mergence of coal seam | | Sediment charge of of coal seam top | | | Lithology of seam top | | Condition of ground water | | Distance from unit to the bursting points | | | Volatile component (V%) | Buried depth of coal sceam (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | >250 m | <250 m | >250 m | <250 m | Common | Bad | <4 | 4~6 | >6 | Mergence | Splitting | >0.6 | 0.4~0.6 | <0.4 | Sandstone | Mudstone | Activity | Iactivity | Close | Middle | Far | | |
| 1 | 1 | 0 | 1 | 0 | 0 | 1 | 0.00 | 0.05 | 0.95 | 1 | 0 | 0.00 | 1.00 | 0.00 | 0.00 | 1.00 | 0 | 1 | 0 | 1 | 0 | 14 | -54.60 |
| 2 | 1 | 0 | 1 | 0 | 0 | 1 | 0.00 | 0.95 | 0.05 | 1 | 0 | 0.00 | 1.00 | 0.00 | 0.00 | 1.00 | 0 | 1 | 0 | 1 | 0 | 13 | -115.56 |
| 3 | 0 | 1 | 1 | 0 | 0 | 1 | 0.00 | 1.00 | 0.00 | 1 | 0 | 0.24 | 0.76 | 0.00 | 0.00 | 1.00 | 1 | 0 | 1 | 0 | 0 | 10 | -160.00 |
| 4 | 1 | 0 | 1 | 0 | 1 | 0 | 0.00 | 0.35 | 0.65 | 1 | 0 | 0.00 | 1.00 | 0.00 | 0.00 | 1.00 | 0 | 1 | 1 | 0 | 0 | 13 | -80.00 |
| 5 | 1 | 0 | 1 | 0 | 0 | 1 | 0.00 | 0.95 | 0.05 | 1 | 0 | 0.00 | 1.00 | 0.00 | 0.00 | 1.00 | 1 | 0 | 1 | 0 | 0 | 11 | -127.62 |
| 6 | 0 | 1 | 1 | 0 | 0 | 1 | 0.00 | 0.75 | 0.25 | 1 | 0 | 0.00 | 1.00 | 0.00 | 0.07 | 0.93 | 1 | 0 | 1 | 0 | 0 | 9 | -180.68 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 58 | 1 | 0 | 1 | 0 | 0 | 1 | 0.48 | 0.15 | 0.37 | 0 | 1 | 1.00 | 0.00 | 0.00 | 1.00 | 0.00 | 0 | 1 | 0 | 0 | 1 | 8 | -125.00 |
| 59 | 1 | 0 | 1 | 0 | 0 | 1 | 0.02 | 0.20 | 0.78 | 1 | 0 | 0.30 | 0.70 | 0.00 | 0.55 | 0.45 | 0 | 1 | 0 | 0 | 1 | 7 | -185.00 |
| 60 | 1 | 0 | 1 | 0 | 0 | 1 | 0.36 | 0.60 | 0.04 | 1 | 0 | 0.00 | 0.88 | 0.12 | 0.00 | 1.00 | 0 | 1 | 0 | 1 | 0 | 8 | -245.00 |

thickness and its change of coal seam, the splitting and mergence of coal seam, the sediment charge of coal seam top, the lithology of roof, the condition of groundwater, the distance from unit to the bursting points, the volatile component, the buried depth of coal seam and so, on. The volatile component and the buried depth of coal seam are quantitative variables and the rest are qualitative variables. The method of valuing variables are shown in Table 1.

The self-programming software of the third theory of quantification is adopted to select the sensitive geological factors, the selected variables are as follows: Quantitative ones are 2, qualitative ones are 9, the total amount of species is 21 and the number of samples is 60. As running the software the scores of variables, the eigenvalue of equation and the cumulative percentage were shown in Table 2, The scores of 8 max-eigenvalues $\lambda_1$-$\lambda_8$ are selected as the 8 principal factors $F_1$, $F_2$, $F_3$, $F_4$, $F_5$, $F_6$, $F_7$, $F_8$, which account for 90.80% of the total contribution of variance and almost delegate the full initial information. Here the distance from unit to the bursting points reflects the criticality of coal and gas outburst, the changing trend of this variable and the connections between the rest and it can be used to screen out the sensitive geological factors. Due to Table 2 the optimum factor reflecting the changing trend of gas is the first factor $F_1$ whose contribution of variance is 31.13%, so, it is the leading factor axis in all data. On this factor axis the scores of far species, middle species and close species in the item, the distance from unit to bursting points are 0.0241-0.0132,-0.0162, which shows the negative correlation between the criticality of gas outburst and the scores of variable. Integrating factual complexions and taking 0.01 and -0.01 as limits, we can receive follow results: The variables whose scores are <-0.01 are the sensitive factors of coal and gas outburst and whose scores are >0.01 are the leading factors of little fatalness of gas outburst and the ones whose scores are -0.01~0.01 are no obvious connections with the fatalness of gas outburst.

According to Table 2, the relationship were shown in Fig. 1 between each variables and the fatalness of gas outburst. Three points (19, 20 and 21) denote, respectively the little bursting fatalness, the middling one and the great one. So, the results can be received.

F (The distance from unit to Jiulishan Fault >250 m) = -0.0053 and F (The distance from unit to Jiulishan Fault <250 m) = 0.0400. Jiulishan Fault is an open normal fault, it provides a dissipation channel for the gas. Nearby the open fault, the density of cleats and fractures was increased, it's beneficial for the migration of the gas. Then, it shows the less fatalness of gas outburst near Jiulishan fault.

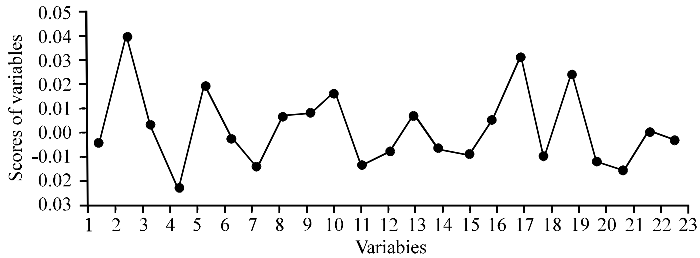


Fig. 1: Relation of all variables and the fatalness of gas outburst

Table 2: Result of running the third theory of quantification of exploited region

| Variables | $F_1$ | $F_2$ | $F_3$ | $F_4$ | $F_5$ | $F_6$ | $F_7$ | $F_8$ |
|---|---|---|---|---|---|---|---|---|
| Distance from unit to Jiulishan Fault >250 m | -0.0053 | -0.0020 | 0.0051 | 0.0011 | -0.0043 | -0.0065 | -0.0024 | -0.0072 |
| Distance from unit to Jiulishan Fault <250 m | 0.0400 | 0.0152 | -0.0390 | -0.0082 | 0.0328 | 0.0492 | 0.0180 | 0.0541 |
| Distance from unit to Lizhuang Fault >250 m | 0.0026 | -0.0076 | -0.0024 | 0.0070 | -0.0014 | -0.0003 | 0.0000 | -0.0013 |
| Distance from unit to Lizhuang Fault <250 m | -0.0234 | 0.0685 | 0.0213 | -0.0630 | 0.0125 | 0.0031 | 0.0005 | 0.0115 |
| Common destruction of coal seam | 0.0201 | -0.0328 | 0.0672 | -0.0162 | 0.0373 | 0.0154 | 0.0314 | 0.0137 |
| Bad destruction of coal seam | -0.0027 | 0.0043 | -0.0089 | 0.0021 | -0.0049 | -0.0020 | -0.0041 | -0.0018 |
| The thickness of coal seam <4 m | -0.0160 | 0.0190 | -0.0063 | -0.0053 | 0.0215 | 0.0103 | 0.0029 | -0.0196 |
| The thickness of coal seam 4~6 m | 0.0069 | -0.0036 | -0.0077 | 0.0029 | -0.0169 | -0.0012 | 0.0090 | 0.0066 |
| The thickness of coal seam >6 m | 0.0066 | -0.0141 | 0.0164 | 0.0012 | 0.0012 | -0.0085 | -0.0147 | 0.0104 |
| The mergence of coal seam | 0.0170 | 0.0160 | 0.0008 | -0.0014 | -0.0013 | -0.0226 | 0.0099 | 0.0001 |
| The splitting of coal seam | -0.0139 | -0.0131 | -0.0007 | 0.0011 | 0.0011 | 0.0185 | -0.0081 | -0.0001 |
| Sediment charge of coal seam top >0.6 | -0.0094 | -0.0316 | -0.0409 | -0.0181 | 0.0770 | -0.1008 | -0.0886 | 0.0908 |
| Sediment charge of coal seam top 0.4~0.6 | 0.0067 | 0.0019 | -0.0003 | 0.0091 | 0.0133 | -0.0090 | 0.0180 | -0.0151 |
| Sediment charge of coal seam top <0.4 | -0.0069 | 0.0003 | 0.0036 | -0.0090 | -0.0214 | 0.0186 | -0.0136 | 0.0099 |
| The mudstone seam top | -0.0120 | -0.0103 | -0.0162 | 0.0023 | 0.0293 | 0.0085 | -0.0076 | -0.0194 |
| The sandstone seam top | 0.0049 | 0.0042 | 0.0067 | -0.0010 | -0.0121 | -0.0035 | 0.0032 | 0.0079 |
| Groundwater activity | 0.0313 | 0.0084 | -0.0140 | -0.0075 | -0.0049 | 0.0036 | -0.0210 | -0.0202 |
| Groundwater inactivity | -0.0114 | -0.0031 | 0.0051 | 0.0027 | 0.0018 | -0.0013 | 0.0076 | 0.0073 |
| Far from bursting points | 0.0241 | -0.0051 | 0.0092 | -0.0085 | 0.0031 | 0.0082 | -0.0175 | -0.0136 |
| Middle off bursting points | -0.0132 | 0.0298 | 0.0126 | 0.0490 | 0.0063 | 0.0041 | -0.0066 | 0.0170 |
| Close to bursting points | -0.0162 | -0.0151 | -0.0183 | -0.0246 | -0.0076 | -0.0113 | 0.0228 | 0.0025 |
| The volatile component | -0.0001 | 0.0003 | 0.0005 | -0.0004 | 0.0002 | -0.0002 | -0.0004 | -0.0003 |
| The buried depth of coal seam | -0.0043 | 0.0040 | 0.0105 | -0.0074 | 0.0029 | -0.0039 | -0.0111 | -0.0040 |
| Eigenvalue | 0.2887 | 0.1299 | 0.1201 | 0.0859 | 0.0763 | 0.0571 | 0.0485 | 0.0356 |
| The cumulate percentage (%) | 31.1300 | 45.1400 | 58.0800 | 67.3500 | 75.5800 | 81.7300 | 86.9600 | 90.8000 |

F (The distance from unit to Lizhuang Fault >250 m) = 0.0026 and F (The distance from unit to Lizhuang Fault <250 m) = -0.0234. Lizhuang Fault belongs to a closed normal fault, gas content is high, crustal stress is concentrated and the coal structure is damaged badly near the fault, gas outburst happens easily here. 8 outburst have happened near this fault. It shows the great fatalness of gas outburst near Lizhuang fault.

F (Common destruction of coal seam) = 0.0201 and F (Bad destruction of coal seam) = -0.0027. The coal seam of Zhongmacun mine suffered from destructions of different extent, according to the destroyable degrees the variable can be divided into bad destruction and common destruction two species. The coal seam near megefaults and in the place which minor faults and minor-scale folds growth or the thickness of coal seam changes suddenly is prescribed as bad destruction; the coal seam in the place which the structures are simple and the thickness of coal seam changes smoothly is prescribed as common destruction. In the area of common destruction, the coal structure is complete. While in the area of bad destruction, crustal stress is concentrated, permeability is poor, gas content is high and the coal is weak to resist externao force, it's easy to occur the coal and gas outburst (Zhang and Zhang, 2001; Xu *et al*., 2006). Then, it shows that the bursting fatalness is less in the area of common destruction of coal and great in the region of bad destruction.

F (The thickness of coal seam <4 m) = -0.0160, F (The thickness of coal seam 4~6 m) = 0.0069 and F (The thickness of coal seam >6 m) = 0.0066. It shows that most gas outbursts happen in the pinching belt of the thickness of coal seam, because of the splitting and layering of coal seams.

F (The splitting of coal seam) = -0.0139 and F (The mergence of coal seam) = 0.0170 how the positive correlation between the splitting of seam and gas outburst. When the coal seams are splitted, the coal structure was destoried, the tectonic coal is developed and the coal particles are more easy to roll in the coal seams which increases the probability of coal and gas outburst.

F (The sediment charge of coal seam top >0.6) = -0.0094, F (The sediment charge of coal seam top 0.4~0.6) = 0.0067 and F (The sediment charge of coal seam top <0.4) = -0.0069, their absolute value are <0.01, showing no obvious relations between the sediment charge of coal seam top and gas outburst.

F (The mudstone seam top) = -0.0120 and F (The sandstone seam top) = 0.0049 show the great bursting fatalness in the mudstone distributive belt of seam top. The mudstone seam top results in the gather of the gas, the gas pressure would increase and it provides power for the coal and gas outburst.

F (groundwater activity) = 0.0313 and F (groundwater inactivity) = -0.0114. The flow of groundwater can carry part of the gas to the stagnation area, the gas content in the inactivity area is higher than the activity area. So it shows the little bursting fatalness in the area of active groundwater.

F (Far from the bursting points) = 0.0241, F (Middle off the bursting points) = -0.0132 and F (Close to the bursting points) = -0.0162 show that the units more close to bursting points are more great bursting fatalness.

F (The volatile component) = -0.0001 and F (The buried depth of coal seam) = -0.0043, the absolute value of their variable scores are very small, showing their little influence to the uneven distribution of gas outburst. So the sensitive geological factors affecting the bursting fatalness of coal and gas outburst of Zhongmacun mine are Jiulishan fault, Lizhuang fault, the degree of coal destruction, the thickness of coal seam, the splitting and mergence of coal seam, the lithology of roof, the condition of groundwater, the distance from unit to bursting points.

## CONCLUSION

The third theory of quantification used to analyze the correlative factors of gas geology can carry though multivariant statistical analysis to the qualitative variables and the quantitative ones at the same time, which not only resolves the problem that the anfractuous relations between qualitative factors and quantitative ones but also develops the applied area of quantification theory and the results are fine.

The concept of reaction degree is brought forward, the calculation method is explained also, so, the former theory of valuing reactions in the quantification theory is developed which enhances the applicability and scientificalness of the quantification theory and establishes the foundation to deal with the fuzziness and complexity of qualitative geological factors of gas geology more becomingly. By analyzing and comparing the screened results and the scores of samples, the accuracy and reliability of coal and gas outburst forecast will be improved and the regionalism of gas geology of the researching area will be more scientific and effective.

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