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## Journal of Chemical and Pharmaceutical Research, 2014, 6(6):2191-2197

**Research Article**

**ISSN : 0975-7384**
**CODEN(USA) : JCPRC5**

# Characteristics and formation mechanism of water abundance of the upper limestone of Taiyuan formation in the Huaibei coalfield

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**ABSTRACT**

*This paper, based on hydrogeological conditions of Zhahe river and Linhuan mining areas in Huaibei coalfield, analyzes the effects of recharge conditions to the upper limestone water abundance, and studies the law that the upper limestone aquifer increases and water abundance is gradually weakened as buried depth changes. The results turn out that with the increase in buried depth, limestone aquifer permeability coefficient will decrease with negative exponential trend. The decrease of aquifer permeability coefficient leads to the slowdown of karst fracture development. The research provides frame of reference for risk assessment of water inrush from seam floor during mining of limestone aquifer of Huaibei coalfield.*

**Key words:** the upper limestone of Taiyuan Formation; buried depth; permeability coefficient; water abundance

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## INTRODUCTION

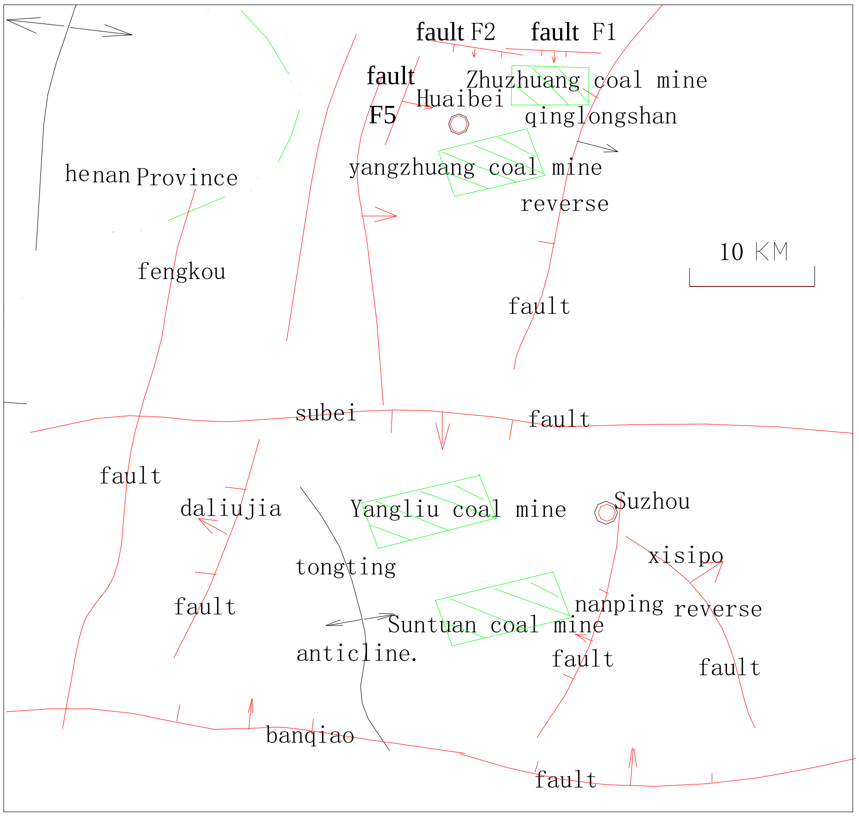
Mining in North China type coalfields' limestone confined aquifer is always plagued by water inrush in pit floors. Among them, the coal floor of the upper limestone of Taiyuan Formation aquifer is one of the key points of prevention of water inrush from coal floor in North China type coalfields. With the increase in mining depth, water pressure of limestone aquifer in coal floor increase more and more, making chances of water inrush from seam floor even larger. At present the theories and approaches of risks assessment of water inrush from coal floor have positive effects on prevention of water inrush in coal floor. The emphases of these theories and approaches are on the mathematical description on mechanism of water inrush. Hydrogeological conditions must be the prerequisites of the application of those results. However, not penetrating law researches on karst confined aquifer water abundance severely affect the popularization and application of prediction theories and methods. The size, quantity and connectivity degree of aquifer fracture control permeability of rock mass, namely, the density of the fracture development and fracture aperture have correlativity with aquifer water abundance and permeability coefficient [5]。It is showed form the results that [6-8]as aquifer buried depth inceases, confining pressure increases too, while intensity of karst fracture development and fracture aperture sharply decrease, and permeability of karst fracture aquifer decreases. As a result, the research into the change of permeability of karst fracture aquifer according to aquifer buried depth offers effective way for the change law of limestone aquifer water abundance.

The Taiyuan formation in Huaibei coalfield is an ocean-continent intersection mutual sedimentary, consisting of limestone and clastic rocks, with 14 layers of limestone. It is divided into the upper, the middle and the lower aquifer. The first to the fourth aquifer in the upper limestone (shortly named as the upper limestone) is the main water-filling aquifer posing dangers to 6 (10) coal mining. In October 24th, 1988, there was a serious floor water invasion in Huaibei coalfield Yangzhuang coal mine, with maximum instantaneous water flow speed topping at 3153m3/h, drowning the two level and suffering heavy losses. In recent years, along with the increase in mining depth in mining area in Huaibei coalfield, water pressure gradually increases too. By applying the calculation formula of coefficient of water bursting to assess risks of water bursting from coal seam floor, the coefficient of water bursting is beyond the critical values, making large amount of coals in the limestone aquifer unable to be exploited. However, mining practices demonstrate that as increases in buried depth and decrease in water abundance, the upper limestone aquifer shows apparent characteristics of high pressure-bearing and weak rich water. Therefore, probing into the water abundance laws of coal floor aquifer and its causes has reference significance.

## 1. THE HYDROGEOGRAPHICAL CONDITIONS OF ZHAHE MINING AREA AND LIHUAN MINING AREA IN THE HUAIBEI COALFIELD

Zhahe mining area of the Huaibei coalfield includes two coal mines—Yangzhuang coal mine and Zhuzhuang coal mine, which mainly excavates the coal seam 6 of the Shanxi Formation, with a mining depth of 200m-600m. The two coal mines belong to the same hydrogeological unit. The major aquifers affecting the excavation of coal seam 6 are the Taiyuan limestone aquifer and the Ordovician limestone aquifer of the seam floor. The upper limestone of Taiyuan Formation falls into the covered type regarding the mode of occurrence, with an unstable aquiclude at the bottom of the Quaternary water, which may cause the Quaternary water in the shallow-buried area recharging the Taiyuan limestone. Affected by the fault, the Ordovician limestone may have an end-to-end joint with the upper limestone of Taiyuan Formation, which serves as the recharge water for the upper limestone of Taiyuan Formation aquifer.

The northeastern part of the Zhahe mining area is the confining boundary (see Map 1). The Zhuzhuang graben serves as the north boundary of this area, with a falling head of 60m-250m between the fault F1 and F2 which forms the graben structure, measuring about 10km in length. In 1995, Zhuzhuang coal mine and Yangzhuang coal mine altogether launched a draining test with a water yield of 3200 m3 per hour. The water level outside this area witnessed no change, proving that the fault between F1 and F2 is a stable confining boundary in the north part of Zhahe mining area.




**Map 1 An outline map of the Zhahe mining area and Linhuan mining area in the Huaibei coalfield**

The northwestern part of Zhahe mining area is another confining boundary. The boundary is composed by 1-4 blind apex and fault F5. The limestone apex is covered by the clay aquiclude at the bottom of the fourth strata, blocking the recharge from the atmospheric precipitation and the Quaternary water. The F5 fault has a falling head of 100m, which underlies the Zhuzhuang mine field. The upper limestone connects with the coal-bearing series directly, which can be regarded as a confining boundary.

The southeastern part of Zhahe mining area is a recharge boundary. The Qinglong Mountain reverse fault lies along the southeastern boundary, which links the Taiyuan limestone with the Ordovician limestone, providing favorable conditions to form a recharge boundary.

Suntuan coal mine and Yangliu coal mine of the Linhuan mining area sit in the middle of the Huaibei coalfield, east of the Tongting anticline. They mainly excavates the coal seam 10 of the Shanxi Formation, with a mining depth of 550m-850m. The major aquifer affecting the excavation of coal seam 10 is the Taiyuan limestone aquifer which belongs to the covered type. There is a stable aquiclude at the bottom of the Quaternary water, blocking the connection between the Quaternary water and the Taiyuan limestone. These two coal mines are surrounded by four faults—Subei fault in the north, Banqiao fault in the South, Fengkou fault in the west, and Nanping fault in the east, making the Linhuan mining area a secluded area. The secondary structure within this area is mainly confined by the surrounding faults, and loses the hydraulic connection with outsides due to the impediment of the faults.

## THE LAW OF THE UPPER LIMESTONE AQUIFER WATER ABUNDANCE IN THE HUAIBEI COALFIELD

*3.1The Law of Water Abundance in the Zhahe Mining Area*

A mixed-layer pumping test has been carried out on the upper limestone of Taiyuan Formation aquifer in the Zhahe mining area (see Chart 1). Among the 16 drilling holes, 3 of them have their units-inflow (q) between 1.15-1.63L/s•m, including Zhuzhuang D62 and Yang90-Guan7. According to Rule of Mine Prevention and Cure Water Disaster, if q meet with 1.0L/s•m<q≤5L/s•m, that indicates a strong water abundance aquifer, which means that the upper limestone shows strong features of the water abundance. In this test, the minimum of units-inflow (q) is 0.050L/s•m, the maximum of q is 1.63L/s•m, and the units-inflow of some drilling holes are lower than 0.1L/s•m, all of which shows that it is a weak aquifer with the typical inhomogeneity of water abundance. Besides, it also presents a tendency that the q tested in the upper limestone of Taiyuan Formation decreases with the increase in the buried depth. Upper limestone of Taiyuan Formation with a buried depth over 200m has the figure q of 1.15-1.63L/s•m; that with a buried depth of 250m-492m, 0.102-0.685L/s•m; that with a buried depth lower than 500m, 0.050-0.084L/s•m. This group of figure shows that the aquifer water abundance becomes weaker with the increase in the buried depth.

**Chart 1 The results of the mixed-layer pumping test carried out on theupper limestone of Zhahe mining area in the Huaibei coalfield**

| No. | Drilling number | Buried Depth H(m) | Water pressure (MPa) | units-inflow q (L/s.m) | Premeability Coefficient k(m/d) |
|---|---|---|---|---|---|
| 1 | Yang 90 Guan 7 | 201 | 1.9 | 1.63 | 2.43 |
| 2 | ZhuzhuangD62 | 210 | 1.96 | 1.33 | 1.63 |
| 3 | Yang 90 Guan5 | 231 | 2.18 | 1.15 | 1.78 |
| 4 | Zhuzhuang D93 | 250 | 2.39 | 0.685 | 1.33 |
| 5 | Yang 90 Guan 1 | 290 | 2.75 | 0.585 | 0.68 |
| 6 | Zhuzhaung 90-Guan 1 | 322 | 3.19 | 0.382 | 0.97 |
| 7 | Yang 90 Guan 8 | 357 | 3.40 | 0.363 | 0.51 |
| 8 | Zhuzhuang $C_{38}$ | 387 | 3.69 | 0.212 | 0.69 |
| 9 | Yang B64 | 434 | 418 | 0.204 | 0.36 |
| 10 | Yang 92 Guan 1 | 473 | 457 | 0.125 | 0.47 |
| 11 | Zhuzhuang 89-1 | 492 | 4.71 | 0.102 | 0.20 |
| 12 | Yang 90 Guan2 | 523 | 4.88 | 0.084 | 0.26 |
| 13 | Yang 97 Guan 1 | 547 | 5.17 | 0.066 | 0.142 |
| 14 | Zhuzhuang Guan 02-2 | 570 | 5.46 | 0.061 | 0.21 |
| 15 | Zhuzhuang Guan 03-1 | 593 | 5.57 | 0.053 | 0.128 |
| 16 | Zhuzhuang Guan 04-1 | 601 | 5.81 | 0.050 | 0.085 |

*3.2 The Characteristics of The Upper Limestone Water Abundance in Linhuan Mining Areas*

According to the data collected respectively in the mixed-layer pumping tests from six drilling holes of Suntuan well (Fig.2), including the Borehole 22-231, the units-inflow of the upper limestone of Taiyuan Formation aquifer reaches q=0.011~0.078 l/s •m, k=0.0152~0.0920m/d. As for the data from five boreholes of Yangliu coal mine, including the Hole 04-24, the units-inflow of the upper limestone of Taiyuan Formation aquifer reaches q=0.010~0.042 l/s·m, k=0.0081~0.1170 m/d. These figures indicate that the upper limestone of Linhuan mining areas is moderately-productive aquifer. In addition, it can be learnt from Figure 2 that the permeability and the water abundance decrease along with the increase of the buried depth. During the preparation, totally five drilling holes were bored at Taiyuan limestone layer in the return-air rise roadway and the No.2 Middle District Station of Mining District 102 (Fig.3). According to the data collected from the water discharge record, among the five drilling holes, the water discharge speed of three are less than 2 m3/h, and the largest one reaches merely 7m3/h. In summary, the upper limestone water abundance in Linhuan mining areas is low, and with poor connectivity the system of karst fracture has not developed well.

**Figure 2 The Result of the Mixed-layer Pumping Tests of Linhuan mining areas in the Huaibei Coalfield**

| No. | Drilling number | Buried Depth H(m) | Water pressure (MPa) | units-inflow q (L/s.m) | Permeability Coefficient k(m/d) |
|---|---|---|---|---|---|
| 1 | Suntuan coal mine 22-231 | 620 | 5.9 | 0.078 | 0.0920 |
| 2 | Suntuan coal mine 22-35 | 640 | 6.12 | 0.067 | 0.1560 |
| 3 | Suntuan coal mine24 | 670 | 6.48 | 0.019 | 0.0350 |
| 4 | Suntuan coal mine4 | 750 | 7.24 | 0.016 | 0.0540 |
| 5 | Suntuan coal mine271 | 780 | 7.49 | 0.013 | 0.0440 |
| 6 | Suntuan coal mine291 | 830 | 8.01 | 0.011 | 0.0152 |
| 7 | Yangliu coal mine 04-24 | 650 | 6.18 | 0.042 | 0.1170 |
| 8 | Yangliu coal mine04-37 | 710 | 6.89 | 0.023 | 0.06711 |
| 9 | Yangliu coal mine07-1 | 760 | 7.21 | 0.011 | 0.0460 |
| 10 | Yangliu coal mine09-3 | 800 | 7.58 | 0.010 | 0.0342 |
| 11 | Yangliu coal mine 10-1 | 860 | 8.49 | 0.010 | 0.0081 |

**Figure 3 The Record of Water Discharge Speed at the upper limestone of Mining District 102 in Suntuan Well**

| Drilling Number | | Location of the | Buried Depth | Water Discharge Record($m^3/h$) |
|---|---|---|---|---|
| Hole group 1 | 1 | Return-air rise roadway A4 in Mining District 102 | 750 | 5 |
| | 2 | Return-air rise roadway A4 in Mining District 102 | 750 | 1.7 |
| Hole group 2 | 1 | Middle District Station | 810 | 6 |
| | 2 | Middle District Station | 810 | 7 |
| | 3 | Middle District Station | 810 | 1.8 |

## 2. THE REASONS OF CHANGES OF THE THE UPPER LIMESTONE AQUIFER WATER ABUNDANCE IN THE HUAIBEI COALFIELD

*4.1 Aquifer Supply Diversity*

Yangzhuang coal mine and Zhuzhuang coal mine are situated at reverse fault of Qinglong Mountain, which makes the Ordovician limestone and Taiyuan limestone meet each other, then the supply section is formed. The outcrop area of the Ordovician limestone is supplied by rain then the Taiyuan limestone can be supplied through the Ordovician limestone. Consequently, the water qualities of the Ordovician limestone and the Taiyuan limestone are similar, or close to be identical (Fig.4). From the supply area to the discharge area, the aquifer in this area attains comparatively good runoff condition and the underground water is well blended. The existence of NH4 ion in the underground water indicates that the aquiclude distribution at the bottom of the quaternary system in this area is unstable, because it is during the process of surface water infiltration that NH4 can be brought underground. Logically, the Taiyuan limestone aquifer in Zhahe river mining area is supplied by rain. That NH4 ion appears in the Taiyuan limestone water and the Ordovician limestone water demonstrates that the underground water in this area has been polluted. Therefore, the reason why the upper limestone water abundance in Zhahe river mining area is high is that the Taiyuan limestone aquifer in this area is supplied both by the Ordovician limestone and the rain directly.

**Figure 4 The Correlation Table of water quality of the Taiyuan Limestone aquifer and the Ordovician limestone aquifer in the Huaibei Coalfield**

| Aquifer / The content of ion | The Taiyuan limestone aquifer | the Ordovician limestone aquifer |
|---|---|---|
| $[HCO_3^-]$% | 64~81 | 78~84 |
| $[Cl^-]$% | 6.3 | 4.8~5.36 |
| $[SO_4^{2-}]$% | 9.4 | 12.66~16.16 |
| $[CO_3^{2-}]mg/L$ | 2.9 | 3.0 |
| $[NO_3^-]mg/L$ | 5.0 | 7.0 |
| $[NO_2^-]m/L$ | 0.07 | 0.07 |
| $[Na^+/K^+]$% | 7.4 | 6.87 |
| $[Ca^{2+}]$% | 54.8 | 59.03 |
| $[Mg^{2+}]$% | 37.74 | 34.03 |
| $[NH_4^+]mg/L$ | 0.2(#90-Guan4) | 0.2(90-Guan3) |
| Total hardness | 12.47~20.3 | 18.17~22.95 |
| PH | 7.2~8 | 7.3~8.4 |

Suntuan coal mine and Yangliu coal mine in Linhuan mining areas are influenced by the aquicludes in Subei, Fengkou and Nanping areas, which makes the whole mining area an isolate plate, cut off from the outside water supply. The result of water quality analysis shows (Fig.5) that the mineralization degree of the Taiyuan limestone water increases with the salinity content. Thus, it can be inferred that Suntuan coal mine and Yangliu coal mine are located above the discharge area of the Taiyuan limestone water. Moreover, the aquifer is not only buried deep but also has a slow flow rate without good runoff condition as well as adequate water supply. Prominent differences has been showed about water quality of the Taiyuan limestone aquifer and the Quaternary system aquifer, showing that the aquiclude distribution at the bottom of the quaternary system is stable and directly on the bed rock. This kind of structure prevents the connection between the aquifer and the aquiclude. Therefore the aquifer has few water supplies and the water circulation is rare. Ultimately, the upper limestone aquifer water abundance of Suntuan coal mine and Yangliu coal mine in Linhuan mining areas is deficient.

**Fig.5 the correlation table of water quality of the Taiyuan limestone aquifer and the quaternary system aquifer at Linhuan mining areas in the Huaibei coalfield**

| Aquifer / The content of ions | Suntuan Taiyuan limestone aquifer | Yangliu Taiyuan limestone aquifer | The quaternary aquifer |
|---|---|---|---|
| $[Cl^-]\%$ | 217.90 | 182.46 | 18.33 |
| $[SO_4^{2-}]\%$ | 224.32 | 267.54 | 21.40 |
| $[HCO_3^-]mg/L$ | 427.14 | 349.36 | 373.01 |
| $[NO_3^-]mg/L$ | 0.60 | 0.490 | 1.33 |
| $[NO_2^-]m/L$ | 0.01 | 0.03 | 0.02 |
| $[Na^+/k^+]\%$ | 203.96 | 271.50 | 49.20 |
| $[Ca^{2+}]\%$ | 90.68 | 130.34 | 41.56 |
| $[Mg^{2+}]\%$ | 52.08 | 76.42 | 35.01 |
| $[NH_4^+]mg/L$ | 0 | 0 | 0.26 |
| Salinity g/L | 2.69 | 3.45 | 0.344 |
| PH | 7.2-7.3 | 7.15 | 7.7 |

*4.2 The influence of aquifer buried depth to water abundance*

The rock fracture aperture has relation of nonlinear function with normal stress. The main influence of stress field to fracture permeation field is to change the fracture aperture, causing changes in the permeability coefficient of fractures. Numerous research data, including BANDIS, propose that the Hyperbolic formula between the closing amount and normal stress of fracture face[9]:

$$\sigma_n = \frac{\nabla V_j}{a - b\nabla V_j}$$

In the formula, a and b are constants. Besides, a=1/Kni,b=b/Vm; Kni is initial normal stiffness, and Vm is joint maximum possible closure amount as well as hyperbolic asymptotic lines. SNOW holds that in the rock mass, fracture aperture has corresponding relations with buried depth under the self-weight stress, and thus causes corresponding relations between permeability and buried depth. [10]

Seen from Fig. 2 and Fig. 3, the upper limestone water abundance of Zhahe mining area and Linhuai mining area is weakened with the decrease of buried depth, and water pressure increases. The relations between quifer water pressure, water abundance and buried depth are shows in Fig. 2 and Fig. 3. The relations between limestone aquifer permeability coefficient and buried depth are shown in Fig. 4.

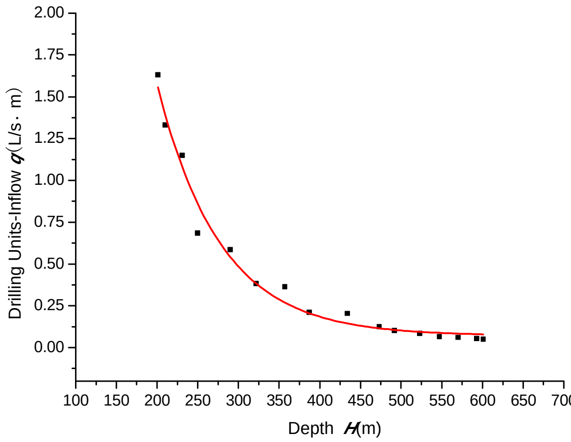



**Fig.2 Curve of units-inflow vs. deepness in Zhahe mining area**

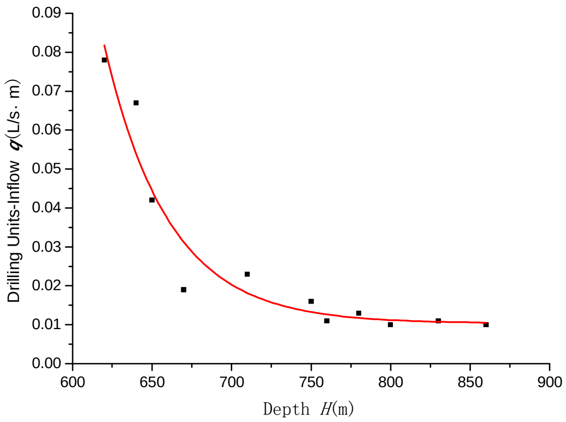



**Fig.3 Curve of units-inflow vs. deepness in Linhuan mining area**

After nonlinear fitting, relation formula between aquifer water abundance q(L/s·m)and buried depth H(m)can be attained. The relation formula between 闸河矿区 aquifer water abundance q(L/s·m)and buried depth H(m)in Zhahe mining area is shown below:

$$q = y_0 + Ae^{-H/t}$$

In the formula: y0=0.07105, A=19.89102, t=77.47277

The relation formula between aquifer water abundance q(L/s·m)and buried depth H(m)in Linhuai mining area is shown below:

$$q = y_0 + Ae^{-H/t}$$

In the formula: y0=0.01039, A=304800.93956, t=40.61029

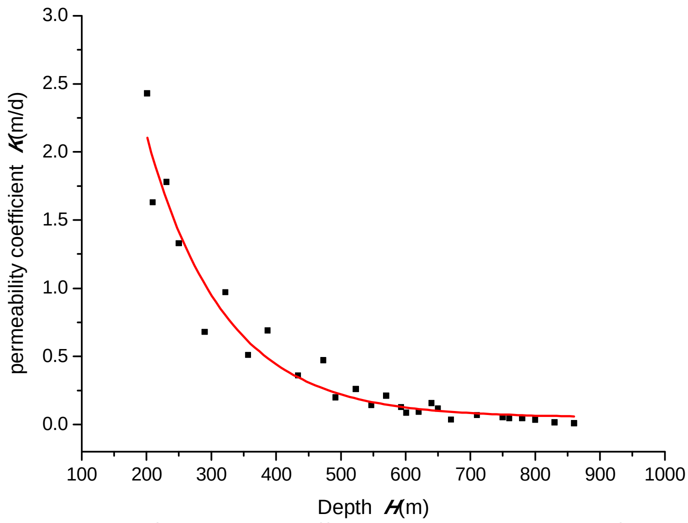



**Fig.4 Curve of permeability coefficient and depth in huaibei coalfield**

After nonlinear fitting, the relation formula between aquifer permeability coefficient K(m/d)and buried depth H(m):

$$K = y_0 + Ae^{-H/t}$$

In the formula: y0=0.05125, A=10.97702, t=119.92871

Concluding from the above results, the causes of weakening limestone aquifer water abundance lie in decreases of aquifer permeability coefficient, so there are apparent discrepancy of water abundance between shallow part and deep part of Zhahe mining area, while the fundamental cause to the decreases in limestone aquifer permeability coefficient is that with the increase of buried depth, fractures close and fracture development is weakened. The hydrodynamic condition of deep karst development deteriorates, which then affects the water abundance of deep karst fracture water-bearing media.

## CONCLUSION

1) The shallow layer of limestone aquifer in Zhahe River mining area in Huaibei coalfield has considerable water abundance. Supply condition is an important factor; the shadow layer is supplied by Ordovician limestone and the 4th aquifer, which results to higher water abundance.
2) Limestone aquifer water abundance in Zhahe River mining area in Huaibei coalfield decreases with the decrease of buried depth. The reason is that with the decrease in buried depth, limestone aquifer permeability coefficient decreases, which results in fracture closure and weakening fracture development, and thus affect the water abundance of the aquifer.
3) With negative exponential trend, the decline rule between aquifer permeability coefficient K(m/d)and buried depth H(m)can be expressed through the formula below:

$$K = y_0 + Ae^{-H/t}$$

This explains the causes of changes in aquifer water abundance according to buried depth, providing frame of references for risk assessment of water inrush from seam floor during mining of limestone aquifer of Huaibei coalfield.

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