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A penetrative addictive for water infusion in coal seams

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Abstract: The manufacturing process, characteristics, and application results of a rod-like penetrative additive (the penetrative rod) were discussed. The components and functions of the penetrative rod were studied carefully. A large number of orthogonal combined tests were carried out and over 100 sample molds were made. Ultimately the components were decided after careful selection among these molds, mainly including hygroscopic major components and auxiliary material. The results of on-site practical application show that such an addictive can increase the water penetrative ability effectively and has a remarkable effect on preventing dust production during coal seam excavation. The penetrating radius, the infusing velocity and the dust-preventive effect were systematically studied.

Key words: coal seam water infusion; penetrative; penetrative rod; additive

1 Introduction

The earliest study of using additive in infusion water to prevent dust was made by some German researchers. A test of increasing glutinosity by adding material, such as Retatin 819, Retatin FS62, *etc.*, into the infusion water was carried out successfully in Ruhr Mine of German in 1968 [1]. The results were good and the effects were evident. However, the commercial application was not achieved due to its inconvenient process of adding into the water and its over sensitivity to the characteristics of coal seams. Some further researches were carried out in Poland [2], German [1], Former Soviet Union [3] and France [4]. Some good results were also reported. In the 1990s the technology of dust prevention by glutinosity was quickly developed. Good results of dust prevention were achieved by adding glutinosity into the infusion water during coal seam excavation in Germany, USA, France and other countries.

The studies of adding some surfactants into the infusion water were carried out in some research institutes of China in 1990's. Some industrial experiments were done in Datun Mine, Yinggangling Mine, Zhenzhou Mine, *etc.* Some desirable results were reported [3].

Even though good experimental results of dust prevention were achieved, many of these techniques didn't reach a commercial level of application due to their complicated process of use and inconvenient operation. To overcome these shortages, this study is to produce a high efficient penetrative addictive with a rod-like shape. To enable the technology to be commercially practical in the large-scale application, detailed researches have been done to simplify the operational progress for use.

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2 Composition of the penetrative rod

2.1 Components and functions

Besides determining reasonable infusion parameters, decreasing the water surface tension and preventing it from being evaporated are considered as two primary ways to further increase the efficiency of dust prevention when the technology of coal seam water infusion is used [5].

Researches and analyses have conclusively established that appending hygroscopic material can prevent infusion water from being evaporated, while adding surfactant material can decrease the water surface tension. A large number of orthogonal combined tests between more than 40 kinds of organic monomers and hygroscopic material were carried out. Over 100 sample molds were made. Ultimately the components were decided after careful selection among these molds, mainly including hygroscopic major components and functionary surfactant combined substance (also called auxiliary material), which can lower the water surface tension, dispersing, mitigating corrosion and so on. For the convenient on-site application, the additive was made into solid rod-like material as shown in **figure 1**, here shortly named as "penetrative

rod". It can slow deliquescence, keep on caking dust, decrease the water surface tension and prevent infusion water from being evaporated.

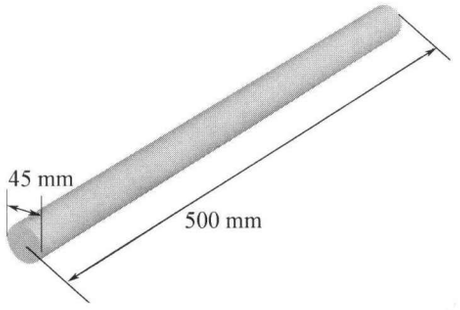

Figure 1 penetrative rod sketch.

The components and functions of the penetrative rod are presented in **figure 2**.

2.2 Selection of major components

In view of the function, the hygroscopic (preventing evaporation) character should be firstly considered when selecting major components. The hygroscopic materials are generally divided into two types: adsorptive hygroscopic material and chemical hygroscopic material. The former mainly includes silica gel ($mSiO_2 \cdot nH_2O$), molecular sieve ($Me_x/[(AlO_2)_x \cdot (SiO_2)_y] \cdot mH_2O$), alumina gel ($Al_2O_3$), activated carbon, bone glue, floridin ($Al_2O_3 \cdot 4SiO_2 \cdot nH_2O$), *etc.*, while the latter mainly includes calcium chloride ($CaCl_2 \cdot nH_2O$), magnesium chloride ($MgCl_2 \cdot nH_2O$), calcium oxide (CaO), phosphorus pentoxide (P_2O_5), glycerin ($C_3H_5(OH)_3$), caprolactam ($NH(CH_2)OH$), and diglycol ($CH_2OHCH_2OCH_2OH$) [6].

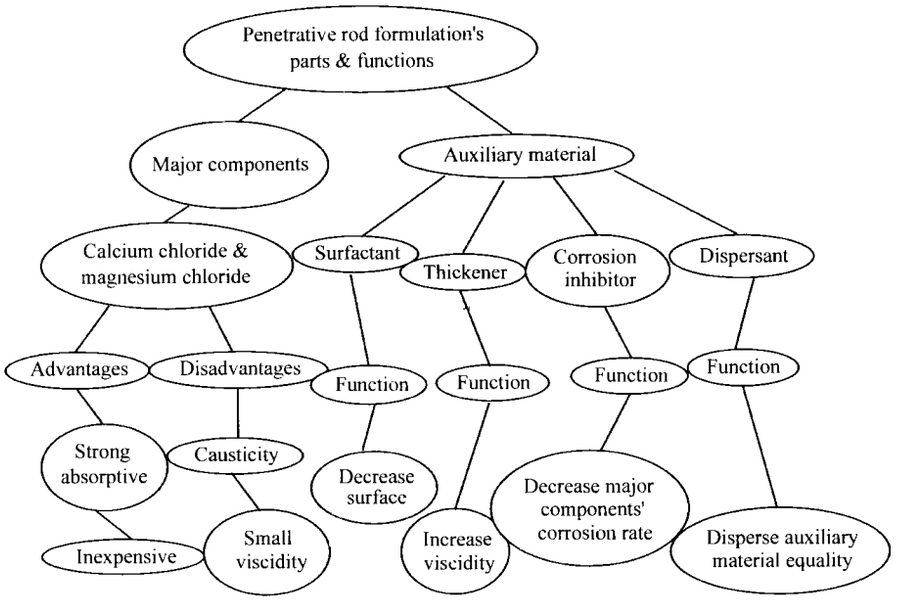

Figure 2 The parts and functions of penetrative rod.

According to the above materials' chemical affinity with water, source, price and other factors, the author believes that calcium chloride and magnesium chloride are more suitable for Chinese mining industry.

Both calcium chloride and magnesium chloride not only have good hygroscopic characteristic, but also can meet the application conditions of chemical productions under the mine. That is (a) they have no poison, no bad smell, and no pollution to environment; (b) they can easily be dissolved in any well water with high solubility; (c) they are never capable of burning, explosion; and (d) they never erode metal obviously.

As 90% of the penetrative rod is the major components, their price directly influence the total cost of penetrative rod. Therefore the inexpensive calcium chloride and magnesium chloride should have a bright prospect of commercial application. And their disadvantages, such as large surface tension of water solution and others, can be remedied by adding auxiliary material.

2.3 Selection of the auxiliary material

As discussed above, the selection of the major components is mainly based on the hygroscopic character (evaporation protection) of the penetrative rod. But the surface tension of inorganic salt solution is larger than that of pure water (72.75 mN/m at 20℃ in pure water, measured in laboratory). However, as a combined substance of multi-function surfactants, auxiliary material plays important roles in decreasing the surface tension of major components solution, and enhancing the functions of moistening, dispersing, thickening, and mitigating corrosion. So selecting the surfactant, which has good compatibility with calcium chloride and magnesium chloride, is the key technique

for wetting coal seam by using the penetrative rod aqua more effectively.

The inorganic salts have little influence on nonionic surfactant, sometimes they may even be dissolved in thick salt solution or base solution, and easy to separate ionic surfactant salt from solution. Therefore not only should we consider its absorptive quantity from inorganic salt solution, but also we ought to solve the problem of compatibility between surfactant and inorganic salt solution in the course of selecting surfactant.

Table 1 lists some surfactants' surface tension in pure aqueous solution and inorganic salt solution, which were tested in laboratory.

Table 1 Surfactant adsorption in pure aqueous solution and inorganic salt solution (20℃)

Goods	Content of the added agent / ‰	Surface tension / (mN·m^{-1})		Surfactant manufacturer
		Pure aqueous solution	30% inorganic salts solution	
Fatty alcohol amide 704	1.0	38.63	65.21	Beijing
Oπ—10	0.5	31.65	35.55	Tianjin
Oπ—15	0.5	33.86	36.05	Tianjin
Dispersant calcium soap	0.1	41.65	36.75	Xingtai
Penetrative agent JFC	0.5	29.75	34.54	Xingtai
Triton X-100	0.1	29.43	32.32	Hong Kong
Span 60	0.5	34.36	76.87	Beijing
Triethanolamine oleate	1.0	46.07	75.62	Tianjin
Detergent AN	0.5	36.78	48.59	Tianjin
Alkyl quaternary ammonium salts	3.0	40.32	83.43	Victory oil-field
SR— I	3.0	32.76	77.61	Taiyuan
P_1	0.1	31.23	33.26	Combined
P_2	0.1	38.97	41.07	Combined
P_3	0.1	29.65	28.43	Combined

As adding surfactant not only decreases the surface tension of inorganic salt solution, but also enhances the functions of wetting, dispersing, thickening, and mitigating corrosion, *etc.*, one more kinds of surfactant need to be combined. The optimized compounding was decided through orthogonal combined tests. **Table 2** lists the orthogonal combined test of the class of fatty alcohol polyoxyethylene ether surfactant.

Table 2 Fatty alcohol polyoxyethylene ether class surfactant combined tests table

Test No.	Combined surfactants					Inorganic salts solution surface tension / (mN·m^{-1})	Inorganic salts solution soakage speed / (mg·s^{-1})
	$C_{11\text{-}13}E_m$	$C_{12}E_m$	$C_{14}E_m$	$C_{16}E_m$	$C_{18}E_m$		
1	7	5	7	7	5	45.93	0.87
2	7	7	9	9	7	46.11	0.84
3	7	9	11	11	9	47.68	0.96
4	7	11	13	13	11	49.42	1.58
5	7	13	15	15	13	58.64	1.77
6	9	5	9	11	11	46.77	0.86
7	9	7	11	13	13	51.73	0.74
8	9	9	13	15	5	54.87	0.82
9	9	11	15	7	7	52.33	0.63
10	9	13	7	9	9	46.98	0.58
...	...	...	...	...	...	...	...

Note: C—alkyl chain; E—Epoxy ethane; *m*—the number of epoxy ethane adduct.

The thermal compound craft is required during the manufacturing the penetrative rod, thermal decomposition of the surfactant must be considered. Therefor the decomposition under different temperatures was tested. **Table 3** shows the decomposition of four kinds of fatty alcohol polyoxyethylene ether surfactant.

Table 3 shows that different surfactants have completely different thermal characters. So only by adding the particular surfactant at different temperatures can remain the native chemical character. During the proc-

ess of purifying, water was evaporated and the solution became the crystal of pure inorganic salt. Furthermore the surfactant decomposed at low temperature must be added in solvent spray way.

According to the experiments of orthogonal combined and thermal decomposition, the P_3 shown in table 2 is selected as the penetrative rod's auxiliary material. The P_3 combined substance, made up of many surfactants, can decrease the surface tension of all kinds of inorganic salt solutions in a great range, as well as play a part role in wetting, dispersing, thickening and mitigating corrosion, *etc.* P_3 is stable material at both low and high temperatures.

Table 3 The thermal decomposition characters of the surfactants

t /℃	Peregal O	Peregal OS-15	Penetrative agent JFC	Dispersant calcium soap
50	Begin dissolve	No dissolve	Delaminate	No change
80	Full dissolve	Begin dissolve	Begin vaporize and bubble up	Delaminate
100	Begin bubble up	No change	More bubble up	Begin dissolve
150	More bubble up	Begin bubble up	Begin dissolve	—
180	Begin bubble up	More bubble up	—	—
200	Begin dissolve	Begin bubble down	—	—
250	—	Begin dissolve	—	—

3 Properties of the penetrative rod

The penetrative rod is the off-white and rod-like crystal configuration. According to the measurement, its basic characteristics are as follows: it tastes slightly salty, it has no bad smell, the pH value is 6.9-7.3, the viscosity of the solution including 30% water (at 25℃) is 6.49 mPa·s, the melting point is over 650℃, the solubility in water is 816 g/L, the dissolving heat is −9.8 kJ/mol, the amount of solid is from 68% to 71%, the corrosion rate to carbon steel at normal temperature is below 0.2 mm per year. There is no thermal decomposition phenomenon under normal temperature and no harmful gas when it is heated. It can corrode leather to some degree [5].

The absorbing moisture equilibrium is one of the most important characters of the penetrative rod. Researches indicate that when the absorption speed trends toward zero at certain humidity, both comparative absorption quantity and the solid content of the penetrative rod tend to be constant. The mechanical measurement of the penetrative rod with different concentration shows that the surface tension of the penetrative rod's solution can be reduced by 1.86-2.57 times, the viscosity can increase by 2.45-32.75 times, and the soakage velocity to coal dust reaches 0.19-2.57 mg/s while that to pure water nearly reaching zero. The contrastive experiment of coal body native seepage indicates that adding the penetrative rod to water can improve the effect of soaking coal body obviously, the humidity of coal can increase by 15 times, the losing water rate of coal can be reduced by 2.8 times, and the losing water velocity can decrease by 7.7 times. The contrastive experiment of the influence on coal body which produce the dust from pure water and the penetrative rod solution points out that the amount of breathing power produced in breaking coal decreases by 25% with the increasing water content of coal. But the decreasing trend will be little when the water content increases to 3.2%. The larger the water content, the bigger all kinds of equivalent diameter of the broken granule. Compared with pure water, the penetrative rod solution can prevent the dust produced during coal excavation effectively, and the breathing power can fall by 35.3% on average [7].

The applied experiments were carried out in Yaoqiao coalmine and Taoyuan coalmine. After adding the penetrative rod in the coal seam infusion craft, the wetting radius could reach 32 m while that of the general water infusion only reached 15 m, the water content could increase by 75.7% compared with the general method. According to the pertinent experiments, adding 2% to 16% dosages of the penetrative rod can decrease the evaporation by 20%-82% [8].

4 Conclusions

(1) After adding the penetrative rod, the wetting radius and humidity increase obviously, and the prevention of being evaporated becomes effective.

(2) Using the same infusion parameters, the infusion velocity after adding the penetrative rod can increase by 1.57 times. The new craft achieves the same result in short time, which can be got by using the traditional pure water craft in long time.

(3) Compared with the traditional infusion craft, the dust production ratio of every working procedure can reduce by 0.3-5.4 mg/m^3, the amplitude of reduction can reach 1%-39%, and the decreasing rate of dust can

increase by 26.2% in working face, of which the traditional infusion and the adding the penetrative rod infusion are respectively 54.4% and 80.6%.

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