

# Comparison and Application of Two types of Filling Gel to Prevent Spontaneous Combustion at the Region where Top-Coal Caves above Entry

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**Abstract.** Two types of gel were developed, by taking fly ash and foaming cement as aggregate, which is usually used as filling material at the region where top-coal caves above coal entry in the Jinggezhuang coal mine, and adding high molecular polymer and bio-gel as additive. Sweating rates of the two types of gel under various matching ratio and temperature were tested. And then sweating ratio and water retention ratio of the two gels were calculated, based on which, the optimized matching ratios, were determined. Viscosity indexes of the two-type gel under different ratios were tested. The optimized filling ratios of the two types of gel were determined according to the two indexes, water retention rate and the viscosity. The filling experiments were implemented and evaluated in site, the Jinggezhuang coal mine. The results show that the fly ash gel has a good achievement on preventing spontaneous combustion at the Region where Top-Coal Caves above entries. It is promising, economically and environmental friendly, and valuable in popularization in coal mines.

**Keywords:** top-coal caving region; gel; sweating rate; water retention rate; viscosity

## 1 Introduction

The Jinggezhuang coal mine is mining out, and start to excavate the bound coal and pillar in recent years. The main working face is located at 9# coal seam, which is classified as a prone to spontaneous combusting seam, average 7.5m thick in thickness. Because of a lot of faults, old chambers and gob areas in the coal seam, the top-coal broke and fell during development and many cavities formed. Therefore, potential hazard of spontaneous combustion in the entries during retreat mining emerged. In order to prevent the potential hazard in the coal seam, method of filling with fly ash and foamed cement were applied in the top-coal caving region of the entries in the Jinggezhuang coal mine. The problems were those: 1) the result of filling is not acceptable satisfied, and 2) cost is high. Therefore, it is necessary to develop a

new filling material to prevent the spontaneous combustion in the top-coal caving region, with good filling achievement and low cost.

## 2 Selection of the Gel

The technologies currently used for prevention coal spontaneous combustion include water injection, grouting, plugging, inerting, gel injection, etc [1]. The filling-gel technology to extinguish fire is one of the most important techniques to prevent coal spontaneous combustion [2-3]. The gel suitable for coal mine using should coincide with the following requirements: non-poisonous, harmless, no peculiar smell, no pollution, good in permeability and high temperature resistance to prevent the material from gasifying rapidly, good in heat absorption performance so as to cool the coal rapidly, good in the abilities of plugging, and inhibiting coal oxidation, convenient to construct, and low in cost [3-5].

### Selection of the Aggregates

A popular additive material for making gel is polyacrylamide (PAM). The PAM is a strong flocculate, good in adhesion and thickening [6]. The function of flocculation can make the suspending material bridging adsorpted through electric neutralization [7].

It was found, in the experiments, that the water solution of PAM was close to a transparent viscous liquid, and the viscosity is low. For this reason, settlement happened after mixing with the fly ash or foaming cement so uniform gel can't form. The experiment shows that the mixture of bio-gel (PX) and PAM at a certain mixing ratio can increase the viscosity, and enhance the stability of gel. Therefore, the PX and PAM were selected as the additive materials of the gels.

## 3 Testing of the Properties of the Gels

### The Sweating Rate, Sweating Ratio and Water Retention Ratio

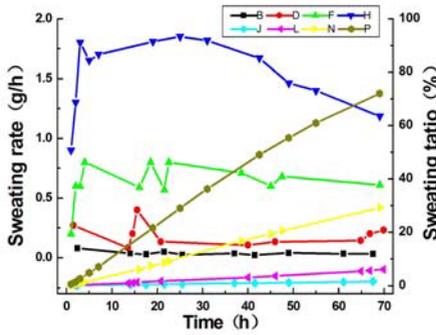
For each group of experiments, the aggregate weight was 90g, and the water 150ml, based on previous investigation experiments. The PAM and PX were added at various ratio and then mixed with the aggregate and water together. The sweating rates of the two gels were tested at temperature 20°C, 30°C, 50°C, 70°C, etc. The gels were kept in a thermostat at constant temperature for a certain time. Then they were taken out for testing and analyzing the changes of sweating rate in different condition. The sweating ratio were obtained through dividing the quantity of extracted water by the total quantity of water in the get. The water retention ratio of gel can be obtained through the sweating ratio of gel, as shown in:

$$\beta = 100\% - \alpha. \quad (1)$$

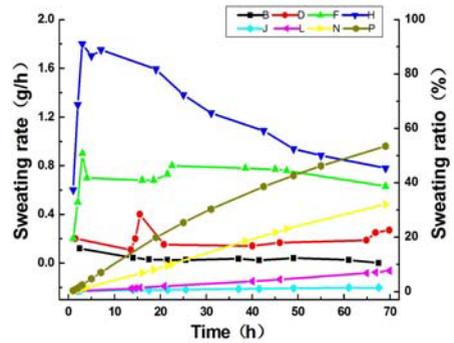
Where:  $\beta$  is water retention ratio, and  $\alpha$  is sweating ratio.

### Testing and Analyzing of Sweating Rate and Sweating Ratio of the Fly Ash Gel Testing Data

16 groups of experiments, in which the fly ash was used as the aggregate material, in various temperatures and mixing ratios, were carry out, to test the sweating rate and ratio. Four distinct groups of which are shown in the Fig.1 to Fig.4.

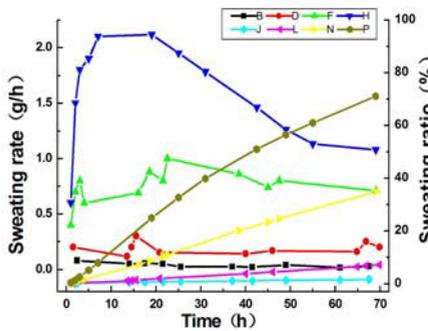


**Fig.1** The sweating rate and sweating ratio of the fly ash gel at various temperature at a constant PX and PAM ratio of 0.75% and 0.5%, respectively

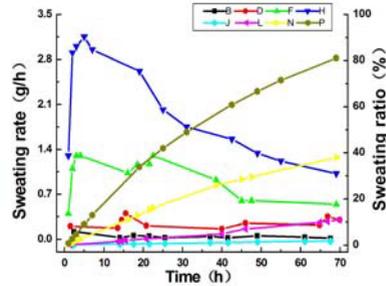


**Fig.2** The sweating rate and sweating ratio of the fly ash gel at various temperature at a constant PX and PAM ratio of 0.875% and 0.75%, respectively

(Where B is sweating rate at 20°C, D is sweating rate at 30°C, F is sweating rate at 50°C, H is sweating rate at 70°C, J is sweating ratio at 20°C, L is sweating ratio at 30°C, N is sweating ratio at 50°C, P is sweating ratio at 70°C, same pattern is used in the following figures)



**Fig.3** The sweating rate and sweating ratio of the fly ash gel at various temperature at a constant PX and PAM ratio of 1% and 0.625%, respectively



**Fig.4** The sweating rate and sweating ratio of the fly ash gel at various temperature at a constant PX and PAM ratio of 1.125% and 0.375%, respectively

### 3.1 Analysis of the Testing Result

As showing in the Fig.1 to Fig.4, the sweating rate of fly ash gel exhibited various change trend with time under different temperature. And the sweating ratio increased gradually with time. The sweating rate at temperature 20°C and 30°C changed slightly with time, and the corresponding ratio after 72 hours were no more than 5% and 10%, respectively. The sweating rate at 50°C increased in an increase-decrease-increase-decrease mode. The change of sweating rate under 70°C was the most distinct, increased at first then decreased.

Observing the change trend at temperature 50°C in particular: the sweating rate reached top at 0.9g/h, the sweating ratio was 32.9% after 72h, if the mixing ratio was: the PX 0.75%

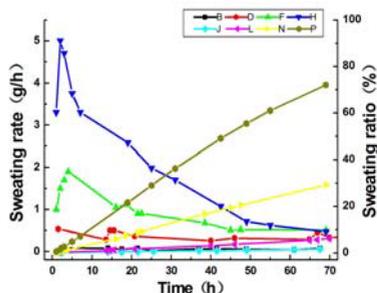
and the PAM 0.5%; the sweating rate reached top at 0.8g/h, the sweating ratio was 32.0% after 72h, if the mixing ratio was: the PX 0.875% and the PAM 0.75%; the sweating rate reached top at 1.0g/h, the sweating ratio was 34.8% after 72h, if the mixing ratio was: the PX 1% and the PAM 0.625%; the sweating rate reached top at 1.3g/h, the sweating ratio was 37.9% after 72h, if the mixing ratio was: the PX 1.125% and the PAM 0.375%.

At temperature 70 °C : the sweating rate reached top at 1.9g/h, the sweating ratio was 72.0% after 72h, if the mixing ratio was: the PX 0.75% and the PAM 0.5%; the sweating rate reached top at 1.8g/h, the sweating ratio was 53.4% after 72h, if the mixing ratio was: the PX 0.875% and the PAM 0.75%; the sweating rate reached top at 2.1g/h, the sweating ratio was 71.0% after 72h, if the mixing ratio was: the PX 1% and the PAM 0.625%; the sweating rate reached top at 3.1g/h, the sweating ratio was 81.0% after 72h, if the mixing ratio was: the PX 1.125% and the PAM 0.375%.

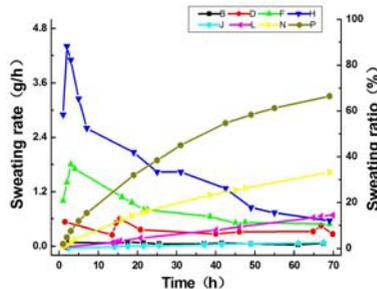
The test results showed that, keeping the sample of fly ash gel at temperature 70 °C for 72 hours, the water retention rate was basically around 30%, the highest value was 46.6%. At temperature 50 °C, and incubated for 72 hours the water retention rate was basically around 65%, the highest values was 68.0%. At temperature 30 °C, the water retention rate and the highest value were more than 90%, and 95%, respectively. At temperature 20 °C, they were more than 95%, and 98.5%, respectively. It is suggested that, the optimized mixing ratio was the PX at 0.875% and the PAM at 0.75%, in which the sweating ratio of fly ash gel as the lowest and the water retention ratio was the highest.

#### Testing and Analysis of the Sweating Rate and Ratio of the Foamed Cement Gel Data of the Test

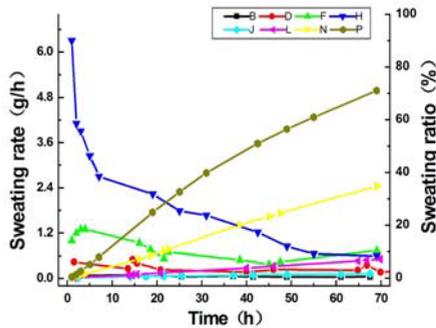
16 groups of experiments, in which the foamed cement was used as the aggregate material, in various temperatures and mixing ratios, were carry out, to test the sweating rate and ratio. Four distinct groups of which are shown in the Fig.5 to Fig.8.



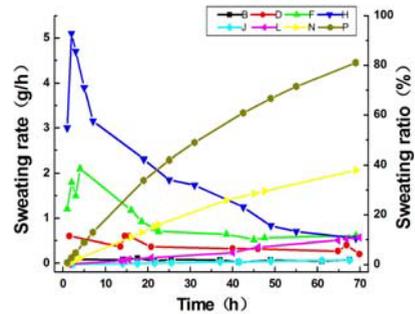
**Fig.5** The sweating rate and sweating ratio of the foamed cement gel at various temperature at a constant PX and PAM ratio of 0.75% and 0.5%, respectively



**Fig.6** The sweating rate and sweating ratio of the foamed cement gel at various temperature at a constant PX and PAM ratio of 0.875% and 0.75%, respectively



**Fig.7** The sweating rate and sweating ratio of the foamed cement gel at various temperature at a constant PX and PAM ratio of 1% and 0.625%, respectively



**Fig.8** The sweating rate and sweating ratio of the foamed cement gel at various temperature at a constant PX and PAM ratio of 1.125% and 0.375%, respectively

### 3.2 The Analysis of Test Results

As showing in the Fig.1 to Fig.4, the sweating rate of the foamed cement gel showed an increase-decrease trend. And the sweating ratio increased fast with time at first and then slowed down. The sweating rate at temperature 20°C and 30°C changed slightly with time, and the corresponding ratio after 72 hours were no more than 5% and 15%, respectively. The sweating rate at 50°C and 70°C were distinct and showed the trend that increase at first then decrease.

Observing the change trend at temperature 50°C in particular: the sweating rate reached top at 1.9g/h, the sweating ratio was 34.3% after 72h, if the mixing ratio was: the PX 0.75% and the PAM 0.5%; the sweating rate reached top at 1.8g/h, the sweating ratio was 33.2% after 72h, if the mixing ratio was: the PX 0.875% and the PAM 0.75%; the sweating rate reached top at 1.3g/h, the sweating ratio was 33.2% after 72h, if the mixing ratio was: the PX 1% and the PAM 0.625%; the sweating rate reached top at 2.1g/h, the sweating ratio was 31.6% after 72h, if the mixing ratio was: the PX 1.125% and the PAM 0.375%.

At temperature 70°C: the sweating rate reached top at 4.7g/h, the sweating ratio was 71.5% after 72h, if the mixing ratio was: the PX 0.75% and the PAM 0.5%; the sweating rate reached top at 4.5g/h, the sweating ratio was 66.5% after 72h, if the mixing ratio was: the PX 0.875% and the PAM 0.75%; the sweating rate reached top at 6.3g/h, the sweating ratio was 70.2% after 72h, if the mixing ratio was: the PX 1% and the PAM 0.625%; the sweating rate reached top at 5.1g/h, the sweating ratio was 71.7% after 72h, if the mixing ratio was: the PX 1.125% and the PAM 0.375%.

The test results show that, keeping the sample of foamed cement gel at temperature 70°C for 72 hours, the water retention rate is basically around 30%, the highest value was 35.5%. At temperature 50°C, and incubated for 72 hours the water retention rate is basically around 60%, the highest values is 69.60%. At temperature 30°C, the corresponding water retention rate and the highest values were more than 85% and 87%, respectively. At temperature of 20°C, the corresponding water retention rate and the highest values were more than 95% and 97.8%, respectively.

Comparing with the fly ash gel, the foamed cement gel has a higher sweating rate at first, then decreased with time. On the other hand, the water retention rate of the foamed cement gel at different ratio showed different regularity. After comprehensive comparison, the optimal mixing patten with the best water retention ratio was determined in descending order

as following: ①PX0.875%, PAM0.75%; ②PX0.75%, PAM0.5%; ③PX1%, PAM0.625%; ④PX1.125%, PAM0.375%.

## 4 Determining the Optimum Filling Ratios of the Gel Materials

According to laboratory tests, the appropriate viscosity of gel material for filling was 25~30 pa·s. In this range the gel material has good fluidity, and could flow adequately in the broken coal of top-coal caving region and cover the broken coal, at the same time it won't lead to large amount gel flowing out or blocking the equipment.

The viscosity of the two gels with different ratios was tested. The test results are shown in Table 1 and Table 2.

**TABLE 1 VISCOSITY OF FLY ASH GEL AT DIFFERENT RATIOS**

	PX/%	PAM/%	Fly ash/g	Water /g	Viscosity/pa·s
Test 1	0.75	0.5	90	150	14
Test 2	0.875	0.75	90	150	28
Test 3	1	0.625	90	150	26
Test 4	1.125	0.375	90	150	21

**TABLE 2 VISCOSITY OF FOAMED CEMENT GEL AT DIFFERENT RATIOS**

	PX/%	PAM/%	Foamed cement/g	Water /g	Viscosity/pa·s
Test 1	0.75	0.5	90	150	21
Test 2	0.875	0.75	90	150	20
Test 3	1	0.625	90	150	24
Test 4	1.125	0.375	90	150	36

Fortunately, fly ash gel with the best water retention ratio coinciding with the requirement, and the best filling ratio is 0.875% of PX and 0.75% of PAM, which has a viscosity of 28 pa·s.

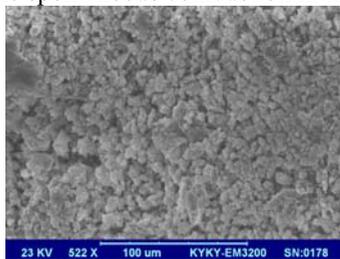
## 5 Structure Analysis of the Gels

The samples of two types of gels were analyzed by SEM. Particles of foamed cement gel are finer and the gap is less than the fly ash gel. Pore of the fly ash gel is very clear, which can be very effective to confine water and reduce sweating of water. The crystal structure of the fly ash doesn't change. The fly ash not only absorbs water by capillary pore between particles, but also stores water in cave of broken particles and honeycomb porosity. So the ability of water retention of fly ash gel is better than the foamed cement gel.

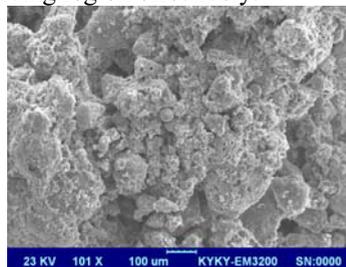
## 6 The Application of Filling Gel in Site

The pilot experiments of filling two types of gel were implemented at top-coal caving region of the coal entry in the Jinggezhuang coal mine. A 50kg fly ash gel was injected by pneumatic-pump into the bore located at 36m in the intake entry of 0090 work face of the No.9 coal seam. Another 50kg foamed cement gel was injected into a bore located at 73m in the same entry. The temperature in the filled entry was tested after injection, showing in the table 3. The fly ash gel is better than the foamed cement gel in the aspect of filling and

cooling according to the temperature tested in the entry. The fly ash gel could fill the top-coal caving region and cool the surrounding coal effectively at the same time. Therefore, it can prevent the spontaneous combustion in the top-coal caving region effectively.



**Fig.9** SEM image of foamed cement gel amplified 500 times



**Fig.10** SEM image of fly ash gel amplified 100 times

**TABLE 3** TEMPERATURE OF FILLED DRILL HOLES IN INTAKE ENTRY OF 0090 WORK FACE

observation date	The fly ash gel injected into the bore located at 36m	the foamed cement gel into the bore located at 73m
10.17	24	27
10.18	21	29
10.19	21	28
10.24	22	28
10.31	24	27
11.01	24	29

## 7 Conclusion

By studying the sweating rate, water retention and viscosity of the two types of gel, the best ratios of the two types of gel were obtained. The field filling test showed that the fly ash gel material has the advantage of low sweating rate, good water retention and appropriate viscosity, suitable for application in shaft coal mines as they are easy and fast to inject and can cool the the surrounding coal to prevent spontaneous combustion in the top-coal caving region effectively. It is promising, economically and environmental friendly, and valuable in popularization in coal mines.

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