Application of Three-phase Foam in Extinguishing Spontaneous Combustion of Coal

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Outline

- Background of Sponcom
- Components of Three-phase Foam (TPF)
- Characteristics of TPF
- Case Study of TPF
- Conclusions and Perspectives
Background

In the United States,

- **1978–1988**: ~15% of underground coal mine (UGCM) fires were caused by the sponcom of coal.

- **1990–1999**: UGCM fires caused by sponcom account for >17%.

- **2000–2006**: 10 UG sponcom of coal were reported.
Consequence of Sponcom

Sponcom may cause huge economic losses, temporary or permanent mine closures, significant environmental problems, even fatalities.

- Three of the reported mine fires resulted in subsequent methane explosions;

- In China, a coal mine explosion that happened in 2004 caused 166 fatalities. The most possible reason is the sponcom of coal.
# Prevention of Sponcom

## Table 1. Comparison among Different Fire Fighting Agents

<table>
<thead>
<tr>
<th>Agents</th>
<th>Components or Category</th>
<th>Main Pros</th>
<th>Main Cons</th>
<th>Cost ($/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>Tap Water</td>
<td>(1) Cool the temperature quickly; (2) Large amount of vapor produced can dilute the oxygen concentration in order to inert the fire zone; (3) Low cost</td>
<td>(1) Can only cover a small area because of its excessively good flowability; (2) Easily flow to the low area without reaching the higher fire zone; (3) May run out of the gob area and contaminate the working face and lower the coal quality.</td>
<td>Very low</td>
</tr>
<tr>
<td>Slurry</td>
<td>Fly Ash, Sand, Gypsum, Cement etc.</td>
<td>(1) Effectively cover the coal and isolate it from the oxygen; (2) Cool the temperature; (3) Simple technique; (4) Low cost</td>
<td>(1) Cannot uniformly cover the coal and can only cover a small area; (2) Flow to the low area without reaching the higher fire zone; (3) May run out of the gob area and contaminate the working face.</td>
<td>1.5-5</td>
</tr>
<tr>
<td>Inhibitor</td>
<td>Some surfactants such as MgCl₂, NaCl, Ca(OH)₂, Soluble Glass etc.</td>
<td>(1) Inert the surfactant structure of coal and prohibit the oxidation; (2) Cool down the coal and can keep the coal humid for a long time.</td>
<td>(1) Complex technique; (2) Difficult to uniformly sprinkle to the coal; (3) Corrode the equipment underground.</td>
<td>5-10</td>
</tr>
</tbody>
</table>
# Prevention of Sponcom

<table>
<thead>
<tr>
<th>Inert Gases</th>
<th>Nitrogen, CO&lt;sub&gt;2&lt;/sub&gt; etc.</th>
<th>(1) Dilute the oxygen concentration; (2) Dilute the explosive gases in the gob area; (3) does not corrode the equipment and does not harm people’s health;</th>
<th>(1) cannot stay in the gob area or fire zone for a long time due to the leakage; (2) The Nitrogen or CO&lt;sub&gt;2&lt;/sub&gt; generator needs maintenance frequently. (3) Cannot cool down the fire zone and may take a long time to extinguish the fire.</th>
<th>Relatively low</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gels</td>
<td>Ammonium-salt Gel</td>
<td>(1) Can cover the coal and block the leakage; (2) High temperature resistance; (3) Effective for small and local fire zone.</td>
<td>(1) Poor flowability; (2) Doesn’t work for large-area fire zone; (3) The gel will fracture in a certain time; (4) High cost</td>
<td>10-15</td>
</tr>
<tr>
<td></td>
<td>Macromolecular Gel</td>
<td></td>
<td></td>
<td>20-25</td>
</tr>
<tr>
<td>Leakage-blocking Material</td>
<td>Luokexiu; Malisan; Urethane Foam</td>
<td>(1) Has excellent crush resistance and leakage blockage; (2) Isolate the coal from oxygen.</td>
<td>(1) Complex technique; (2) Liberate harmful gases during pyrolysis; (3) some are combustible in high temperature; (4) High cost</td>
<td>15-170</td>
</tr>
<tr>
<td>Regular Two-phase Foam</td>
<td>Nitrogen/CO&lt;sub&gt;2&lt;/sub&gt;-water Foam</td>
<td>(1) Can reach the high part of the fire zone; (2) Uniformly spread in the gob area; (3) Suitable for combustion in gob/mined-out area or deep part in a coal pile.</td>
<td>Foam is easy to rapture in order not to cover the coal for a long time.</td>
<td>Relatively low</td>
</tr>
</tbody>
</table>
Three-phase Foam

• Three phases

(1) Gas: \(N_2\)
(2) Liquid: Water
(3) Solid: Fly ash or Earth
Each phase has its own purpose:

- **Water**: Cool down the fire and lower the temperature
- **Nitrogen**: Inert gas → Dilute the concentration of oxygen
- **Fly ash/earth**: Cover the coal to isolate the air
- **Capture the Free Radicals**
Parameters

- Expansion Ratio of Foam to Water: 30
- Mass Ratio of Fly ash to Water: 4:1
- Concentration of Foaming Agent: 0.2%
- Retention Time of Foam: ~10h
- Cost: $0.4/ft³ (0.2$/m³)
Three-phase Foam

Water

Earth/Fly Ash

Slurry

Slurry

Foaming Agent

Pump

Generation of three-phase foam

April 17, 2018
Bench Test of TPF

- Oven Temperature
- Unprocessed Coal Sample
- Coal Sample with 10% Three-phase Foam
- Coal Sample with 15% Three-phase Foam
Comparison between water and three-phase foam
Three-phase Foam

1.2m (4ft)

4m (13ft)
In October, 2003, a serious methane explosion happened in Baijigou Coal Mine in China, which caused a fire zone of more than 300 thousand m² (~3.2 M ft²).
Smoke run out of the shaft

A destroyed air door near a shaft

The destruction of a seal

The destruction of ventilation equipment room
In the gob

In the return airway

April 17, 2018
Conclusions and Perspectives

- TPF works very well in controlling the spontaneous combustion of coal

- TFP is not quite effective for the prevention of air leakage into the gob after the rupture of the foam.

- The combination of TPF and Gel may be a good solution
Thank You!