Fire Retardant Mechanisms of Polymer Fire-retardant and Extinguishing Gels

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Abstract This study evaluates the performance of polymer fire-retardant and extinguishing gels through experimental comparisons with traditional foam extinguishing agents and water. The findings indicate that polymer fire-retardant and extinguishing gels exhibit significant advantages over conventional water and foam in terms of fire suppression and prevention of re-ignition. Based on these results, the fire retardant mechanisms of the polymer gel are hypothesized.

Key words Polymer fire-retardant and extinguishing gel; Fire retardant mechanism; Comparison experiment

1 Introduction

Currently, water is the primary extinguishing agent employed in combating forest fires. However, the high mobility of water results in a reduced duration of contact with the burning material, leading to inefficiencies in resource utilization and a significant wastage of water resources during fire suppression efforts. The advancement of new materials has garnered significant attention for polymer fire-retardant and extinguishing gels in the domain of forest fire prevention, both domestically and internationally. Several studies have been conducted in this area[1-6]. The polymer fire-retardant and extinguishing gel is a gel-like substance produced by super absorbent polymer (SAP) following its absorption of water. Due to its ability to rapidly absorb water equivalent to hundreds or even thousands of times its own weight, this material offers several significant advantages, including a large water-absorbing capacity, a rapid absorption rate, strong water-retention capabilities, as well as non-toxicity and odorlessness. Consequently, it is regarded as one of the most promising fire-retardant and extinguishing materials in the domain of forest fire prevention[7-11]. Quantitative conclusions were derived from the analysis of the properties of polymer gels and their comparison with conventional water and foam extinguishing agents in fire suppression experiments. This analysis aims to elucidate the underlying mechanisms of fire retardance.

2 Methods

2.1 Determination of water absorbency of polymer fire-retardant and extinguishing gel 1 g dry sample of polymer gel was accurately weighed and placed in a beaker. Distilled water with a mass denoted as M_1 was added, and the mixture was allowed to stand for 15 min. Subsequently, the mixture was filtered through a 100-mesh sieve, allowing the high-absorbent resin to remain on the sieve for a period of time until no water was further filtered out of the resin. The mass of the filtered water, referred to as M_2, was then measured. The water absorbency was calculated using the formula (1).

$$\text{Water absorbency } Q = (M_1 - M_2)/1 \times 100\% \quad (1)$$

2.2 Determination of water absorption rate of polymer fire retardant gel A precise mass of 1 g of dry polymer gel was measured and placed in a beaker. A specific mass of distilled water was then added, and the mixture was allowed to stand for 15 min. Subsequently, the mixture was filtered through a 100-mesh sieve. The water absorption rate was determined according to the established methodology. The water absorption rate of the water-absorbing resin can be derived by plotting the water absorbency against the duration of water absorption[12-16].

2.3 Fire extinguishing experiment

2.3.1 Formulation of polymer fire-retardant and extinguishing gel. 0.2% polymer gel was initially formulated using the following method. The dry polymer fire-retardant and extinguishing gel was combined with water in a weight ratio of 1 : 500, while simultaneously undergoing rapid stirring to ensure complete absorption of water and subsequent swelling. The resulting swollen polymer fire-retardant and extinguishing gel was then transferred into the fire extinguisher.

2.3.2 Simulation of burning wood stack building. According to the national standard GB 17835-2008, three identical simulations of burning wood stacks were constructed. Each stack was assembled using 50 red pine wood strips, each measuring 12 mm × 12 mm × 210 mm, with a moisture content ranging from 8% to 12%. The configuration consisted of five strips per layer, resulting in a total of 10 layers arranged in a 90° cross-linking pattern within a pre-prepared iron frame. Additionally, a metal pallet measuring 250 mm × 250 mm × 60 mm was positioned beneath each wood stack.

2.3.3 Fire extinguishing experiment. Under the experimental conditions of 20 ℃ and a wind speed of 1 m/sec, an equal volume of No. 92 automotive unleaded petrol was poured into three metal pallets. Simultaneously, three wooden stacks were ignited, and the timer was initiated at the moment of ignition. After 3 min of combustion, water, a foam extinguishing agent, and a polymer fire-retardant gel were employed to extinguish the flames of the three burning stacks, respectively.

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Data were collected in the following manner: the maximum temperature recorded at the center of each stack after a burn duration of 3 min; the time required to lower the temperature at the center of the stack to 300 ℃ utilizing each of the three fire extinguishing methods; the duration taken to extinguish an open fire in a stack employing each of the three fire extinguishing methods; and the observation of any rekindling of the extinguished stacks after 20 min.

3 Results and analysis

3.1 Water absorbency of polymer fire-retardant and extinguishing gel According to the experimental method outlined in Section **2.1**, the experiment was conducted five times. Subsequently, the water absorbency for each trial was calculated using formula (1), and the average value was determined to be 615 g/g for the polymer fire-retardant and extinguishing gel. This result indicated that the dry polymer fire-retardant and extinguishing gel exhibited excellent water absorbency.

3.2 Water absorption rate of polymer fire-retardant and extinguishing gel According to the experimental method outlined in Section **2.2**, the experiment was conducted five times. The average water absorption rate was calculated to be 78 g/min, indicating a rapid water absorption rate. In practical applications for fire extinguishing, the dry polymer fire-retardant and extinguishing gel can be combined with water and fully absorbed to form an absorbent gel in less than 10 min.

3.3 Fire extinguishing experiment The data obtained from fire extinguishing experiments utilizing water, foam extinguishing agents, and polymer fire-retardant and extinguishing gel are presented in Table 1.

Table 1 Experimental results of extinguishing wooden stacks with different extinguishing agents

Type of fire extinguishing agent	Maximum temperature at the center of stack // ℃	Time required to lower the temperature at the center of stack to 300 ℃ // sec	Duration taken to extinguish open fire in stack // sec	Rekindling of extinguished stacks
Water	746	181	225	Present
Foam extinguishing agent	742	115	146	Absent
Polymer fire-retardant and extinguishing gel	745	58	70	Absent

As illustrated in Table 1, when the maximum temperature at the center of the wood stack reached approximately 745 ℃, the durations required for the three extinguishing agents to lower the temperature at the center of the wood stack from 745 ℃ to 300 ℃ were 181, 115, and 58 sec, respectively. The time required to extinguish an open fire using the three extinguishing agents was 225, 146, and 70 sec, respectively. Re-ignition was observed when the fire was extinguished with water; however, this phenomenon was not noted with the other two extinguishing agents.

It is evident that, in comparison to water and foam extinguishing agents, the polymer fire-retardant and extinguishing gel demonstrated a significantly faster rate of reduction in flame center temperature and a more rapid extinguishing capability. This enhanced fire suppression effectiveness can be attributed to their unique structural properties.

4 Mechanisms of fire protection

The polymer fire-retardant and extinguishing gel possesses a three-dimensional mesh structure that enables it to absorb water in quantities ranging from hundreds to thousands of times its own weight. Furthermore, this gel is capable of retaining the absorbed water for extended periods, even when subjected to high temperatures and pressures, resulting in minimal water loss. Based on these properties, it can be inferred that the fire retardant mechanism possesses the following characteristics.

(i) The polymer fire-retardant and extinguishing gel contains a significant amount of water, which is applied to the surfaces of combustible materials. When exposed to a fire source, the evaporation of water absorbs substantial heat, thereby lowering the temperature of the surface of the combustible materials.

(ii) The polymer fire-retardant and extinguishing gel possesses specific gel strength, enabling it to create a gel layer with certain thickness on the surfaces of combustible materials. This gel layer acts as an insulating barrier between the fire source and the combustible materials, effectively depriving oxygen, which is one of the three essential elements of fire. Consequently, this mechanism serves to achieve the objective of fire retardation.

(iii) The polymer fire-retardant and extinguishing gel exhibits adhesive properties, allowing it to adhere not only to flat surfaces but also to vertical surfaces at angles of up to 90° for extended periods. Consequently, when utilized in forest fires, it not only obstructs surface fires but also demonstrates an effective fire-stopping capability against crown fires.

(iv) The polymer fire-retardant and extinguishing gel, which is water-rich, has the capacity to create numerous miniature reservoirs within the soil beneath the forest. This gel exhibits effective blocking properties against subterranean fires that are often difficult to detect, thereby preventing the escalation of forest fires at an early stage.

5 Conclusions

The assessment of the performance of polymer fire-retardant and extinguishing gel indicates that it possesses exceptional water absorbency and a rapid water absorption rate. A comparative analysis of fire extinguishing experiments utilizing traditional foam and water reveals that the polymer fire-retardant and extinguishing gel exhibits significant advantages over conventional water and foam. These advantages are evident in their effectiveness in reducing the flame center temperature and enhancing extinguishing speed.

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Based on these findings, a speculative discussion regarding the fire retardant mechanism is presented.

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