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The feasibility study of extinguishing oil tank fire by using compressed air foam system

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Abstract

Because of the complex characteristics of oil liquid, oil tank fire is more complex, and we need to consider the performance of fire extinguishing agent and environmental factorin the process of fighting, so fire suppression of oil tank fire is hard. This page analyzed the combustion characteristic of oil tank fires and themechanism of foam loss. Based on the previous studies, this paper provides guide ides of oil tank fire by discussing the feasibility and applicability of suppressing oil tank fire by using compressed air foam system (CAFS) with different fire extinction agents and analyzing the effectiveness of different agents.

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Keywords: compressed air foam system, drainage time, foam extinction agent, oil

1. Introduction

With the development of the industry, the demand of oil is growing in factory. Due to the oil's instability of flammable and explosive and problems about fire protection, the oil tank fire occurs frequently and repeatedly. The time of suppressing oil tank fire is long and it has many problems since the oil tank fire has chain reaction and large-scale. So, the key points are how to suppress fire and what agents should be used.

According to the experience of the previous experimental research and fire extinguishing experience, foam system usually is the first choice because of its good properties of heat insulation, liquidity and permeability. Traditional foam system products foam by forming negative pressure at the exit of foam maker and inhaling air to mix air and foam solution. As a new technologyof foam, CAFS has improved on the basis of foam system and products prefer foam which have better performance. The detailed discuss as follow.

2. Analysis of oil tank fire

2.1. Theory of oil combustion

According to the studies by Zhi-Xin W et al. the burning area of oil tank usually can be divided into three layers, i.e. fire layer, mixture layer of air and flammable vapor and oil liquid layer [1]. In oil combustion, the negative pressure will occur at certain area because of consumption of oxygen and it inhales surrounding clod air into this area, which will mix with flammable vapor and form mixture layer. The existence of mixed layer makes the flame wave and its combustion rate gradually tends to a constant value. The mixed layer is influenced by diffusion velocity of surface vapor, in other words that the diffusion velocity of surface vapor determines the process of combustion.

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In the process of combustion, part of heat diffuses to the outside through the thermal radiation and heat convection when others feedbacks to the surface of oil throughheat conduction of tank wall, heat convection of hot smoke and thermal radiation of flame. It keeps flammable vapor producing steadily from surface and propels combustion. Combustion of vapor, heat feedback and evaporation are three related and circulatory links and only intervene this loop and slow its process, the combustion could be stopped.

2.2. Analysis of difficulty in suppressing oil tank fire

(1) The strong airflow will occur in oil tank fire. The characteristics of the flame are closely related to diameter of the tank, the nature of the liquid and liquid level. When the liquid level is high, the flame is torch-like shape and cold air enters combustion area from sides (as shown in Fig 1). With the combustion, the cold air will rise as well as mix with vapor through the centre of liquid surface when the liquid level decreases to 80% (as shown in Fig 1). By this time, the rising airflow blows part of lightweight foam and it causes the foam is hard to adhere to the surface.

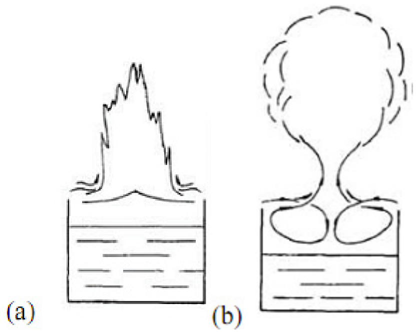

Fig. 1.The torch-like flame (a) and ball-like flame (b) in theory

In addition to the airflow, the bad wind weather could also form resistance to jet foam and will blows the foam adhered to surface, which causes loss of effective foam. In order to solve the above problems, heavyweight and high-injection pressure foam is needed. At the same time, producing more foam can has effect under certain provided condition.

(2) In oil tank fire, there are high temperature and long suppressing time. The flame temperature is above 1000℃in continuous oil tank fire[2]. When the foam doesn't completely cover the oil surface, the gas inside foam will break the foam because of thermalexpand. The high temperature will reduce viscosity of liquid which distribute between foam films and promote the liquid withdrawal rate. When the foam doesn't completely cover the oil surface, the oil tank is still in state of high temperature which could promote the evaporation. A channel will be formed when vapor rises through foam layer. It will break the airtightness of foam layer and induces the oil rekindle. These problems both can weaken the performance of foam. Based on the above analysis, the efficiency of suppressing fire can be increased by using the foam which has good burn resistance and long drainage time. In addition, if the foam covered on the surface is thick, this problem also can be relieved.

3. The performance of compressed air foam (CAF)

Aiming at the difficulties discussed above, a more advanced system is needed since the traditional foam system is difficult to achieve the ideal state. Foam expansion and 25% drainage time are two important indicators for assessing foam system. Both of them influence two important indexes of foam stability, i.e. burn-back time and fire-extinguishing time. The research studied by Lattimer B Y et al shows that maintaining the stability of foam is an important factor which foam can have good effect of covering and barring fire. These parameters should be considered when choosing the suitable foam system. CAFS can do better effect than traditional foam system and the detail analysis which combined with the characteristics of CAF and practical problems is followed.

(1) For the problem of strong airflow, an effective solution is to use moderate quality foam in fire extinguishment. The foam quality is determined by foam expansion. According to the studies by Magribe S A et al. reducing the foam expansion can decreases the superficial area of foam and increases the fluid content which cause the foam film become thick and produces heavyweight foam. But under the condition of the same foam volume,thick liquid film will strengthen the plateau effect between bubbles which accelerates the movement speed of liquid between bubbles and shortens the drainage time (as shown in Fig 2). So we need to take moderate foam expansion under the consideration of different conditions. Compared

with traditional foam which has fixed foam expansion, CAFS can change the foam expansion in a large scale and can effectively copes with different situations since it is used under positive pressure.

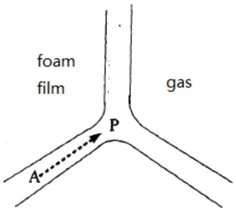

Fig. 2. The plateau effect: liquid at Apoint always trends to move to point P.

At the same, using positive pressure can more effective saves water. The water consumption and foam compound consumption oftraditional foam system is twice than CAFS. It means that CAFS can produces more foam for extinguishing fire. On the one hand it can effectively cope with the airflow problem, on the other hand it also can prevents rekindle of oil.

(2) In view of the problems of high temperature and long combustion time, an effective solution is enhancing the drainage time and burn-back time. According to studies by Zhi-Ming Bao et al. whatever the foam expansion is big or small, 25% drainage time influences little to fire-extinguishing time [3]. But it influences burn-back time because it can reflect the foam stability which can influence the burn back resistance. According to the temperature curve of foam which studied by Cheristopher F, this conclusion also can be proved. So, for this problem, the main consideration is extending the drainage time.

From macro perspectives, the fracture of the bubbles causes the drainage. The research studied by Yan Yang shows that there are two ways causes fracture of foam, one is the gas in foam diffuse to outside through film and the other is drainage of film. The action of gravity and Plateau effect causes the drainage. In order to restrain the fracture, the pressure inside can't be big, namely, the size of foam need to be uniform. Compared with the foam produced by traditional foam system, CAF has been fully foaming in the process of transportation and it can mix further. So CAFS can get uniform-sized foam (as shown in Fig 3 and Fig 4).

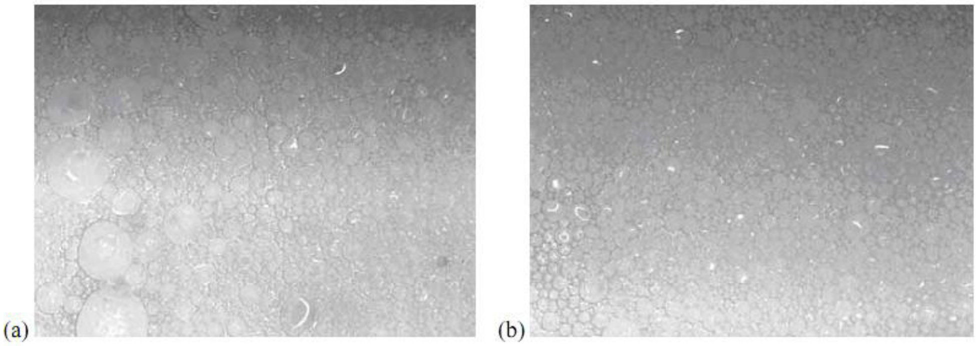

Fig. 3.The different images of foams produced from traditional foam system (a) and CAFS (b) using stereoscopic microscope.

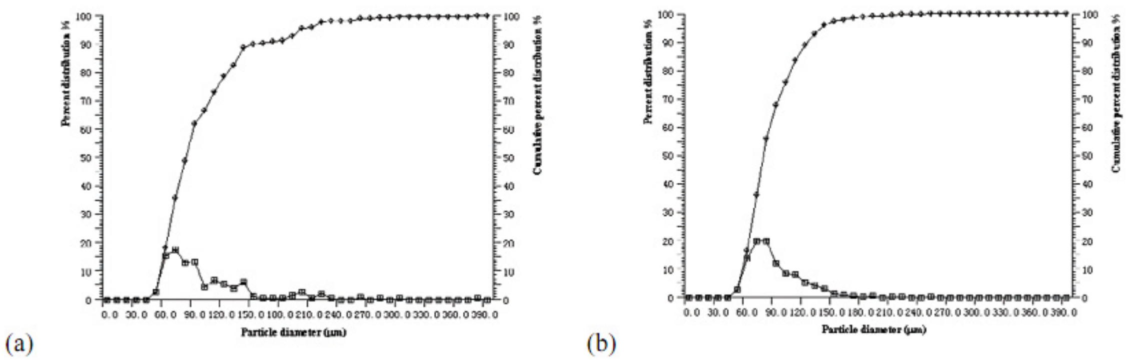

Fig. 4. The different size distributions of foams from traditional foam system (a) and CAFS (b).

From the Angle of thermodynamics, the production of foam is a thermodynamic instability system since it produced by including energy through negative or positive pressure. According to the basic principles of thermodynamics, the free energy *G* has a decreasing trend which causes the fracture of foam. According to the formula:

$$G = \gamma A \tag{1}$$

In there, γ is the surface tension of foam, *A* is increased surface area and it is positive value. Both of them is influenced by foam expansion. Because the foam expansion of CAFS is adjustable, so *G* can be controlledto some extent, thus drainage time can increase. The followed shows the relationship between drainage time and foam expansion.

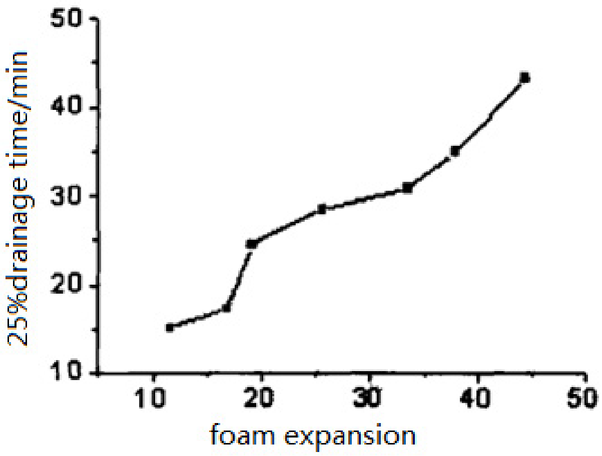

Fig. 5. The relationship between drainage time and foam expansion

From the above, CAFS can better solve the problems in oil tank fire. Considering the different foam extinction agentsare differenton the fire extinguishing performance, in order to choose the most effective agent, we need to compare the performance of different agents.

4. Assessment of foam extinction agents

Foam extinction agent is a very important part for fire extinction. The main agents are used in the market are protein foam extinction agent (P), Aqueous film forming foam extinction agent (AFFF), Alcohol resistant foam extinction agent (AR) and Class A foam extinction agent, and both of them is tested by CAFS [4]. Tao Chen et al. tested the performance of protein foam extinction agent in CAFS and the results shows that the fire-extinguishing time of them is similar, but for the burn-back time, CAFS is better than traditional foam system [5].   For Class A foam extinction agent, Zhi-Ming Bao et al. have taken the experiment which uses three Class A agents produced by different manufacturers, and the results shows that Class A foam agent has little effect on fire-extinguishing time but burn-back time. This agent can be well used in oil fire, but the effect of fire extinguishment is different between the agents produced by different manufacturers (as shown in Fig 6) [6]. In addition, Qing-Lin Zhang et al. put forward applying heptafluoropropanegas as injected gas. Its density is six times than air and it is liquid in pipes, so that it can mix well with foam liquid. This kind of foam not only has effect of physical cover, but also has effect of chemical fire extinguishment. But this technology isn't mature enough, so the advanced studies need to be taken.

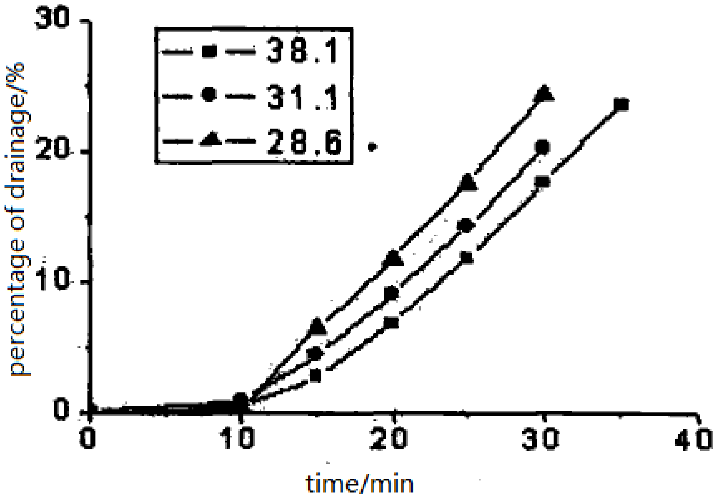

Fig. 6. The different performance of percentage of drainage among three agents produced by different manufacturers

The study shows that it is inefficient to use two or more agents at the same time since that will start the chemicalreaction in mutual. So the best possible way is choosing one agent for a certain fire.

The extinguishing theory is complicated and contains both physical reaction and chemical reaction with both cooling effect and oxygen isolation effect [7]. These made the process of liquid combustion and foam extinguishing theory is more complex. We need to use a simplified formula to calculate the related parameters since a single formula can't describe this process.

According to the model established by H.Z.Yu:

$$\dot{Q} = \dot{Q}_0 e^{-k(t-t_0)} \tag{2}$$

$\dot{Q}_0$ is the total heat release rate before extinguishing, the unit is kW. t_0 is the start moment of extinguishing, t is time, k is constant related to the fuel, its unit is s^{-1}. The variation relation between the heat release rate and time is established. k is expressed as follows:

$$k = a\dot{m}_w^{"} - b \tag{3}$$

Where a and b are constants related to fuel and extinction agent type, they should be determined by experiments. $\dot{m}_w^{"}$ is the effective flux which is directly acted on fuel surface byfoam extinction agent, i.e. extinguishing effective intensity, the unit is $kg/(m^2 \cdot s)$. Based on these formulas, the fire extinguishing time can be defined as follow:

$$t = \frac{\ln \frac{\dot{Q}}{\dot{Q}_0}}{-k} = \frac{\ln \frac{\dot{Q}}{\dot{Q}_0}}{b - a\dot{m}_w^{"}} \tag{4}$$

According to the data from experiment, we can get the constants a and b, then we can get the value of k. k is a value that can be used to determine the difficulty of fire extinction and the effectiveness of foam extinction agent. The great the value of k, the smaller the difficulty of fire extinction and the better the effectiveness of foam extinction agent.

Lin Su et al. in view of the applicability and accuracy of this model, have tested by using different agents and fuel [9]. The result shows that k is related to effective flux at unit area. The constants should be determined by test and they are related to the type of fuel and foam extinction agent. This test proved that this model can be applied to calculation of complex fuel and agents and also can be used to research the performance of foam extinction agent. So, this model can combine with test of agents to find out the most ideal foam extinction agent.

5. Conclusion

Through the above analysis, we get the followed conclusions. According to the combustion characteristics of oil tank fire, the relevant experimental study shows thatCAFS has better performance than traditional foam system and it is more applicable to put out oil tank fire. The effect of fire- extinguishment is different between different foam extinction agents. We need to choose the most adaptive agent for the certain condition by taking experiment which combines with the H.Z.Yu's model.

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