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Research on suppressing premixed fuel-air explosion by ultra-fine cold aerosol

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Abstract

The problem of prevention and suppression of gas-and air explosions is extremely important because such explosions represent serious threat to firemen life. It is significant that ultra-fine cold aerosol with typical characteristics of compressibility, flow ability and good dispersion attributed, can suppress the deflagration and detonation of leaking of flammable oil gases. In this paper, some series of the explosion suppression experiments were carried out in the laboratory 20-liter apparatus with three gas routes and two igniters of chemical and high-voltage pulse which provide a reliable, multiple-point ignition source. The main series were about the suppressing the developed explosion process of oil gas premixed air and ultra-fine cold aerosol, or 1301 fire extinguishing agent. The results are shown that in case of suppressing the developed explosion, the increase of the concentration of ultra-fine powder and 1301 both causes the decrease of the maximum explosion pressure and maximum rate of pressure rise of oil gases. Moreover, 1301 fire extinguishing agent has distinctly threshold nature and the induced time of oil explosion is delayed. Furthermore, it is shown that the explosion suppression effect is associated to inherent property and concentration of suppressing agent and ignition condition. And the rank of suppressing capability of ultra-fine aerosol or gas suppressing agent for oil gas atmosphere was proposed, and the maximum suppressed explosion pressure may be used as the criterion to estimate explosion-suppression efficiency of oil gas. This research helps optimize explosion suppression condition of oil gas, and have important reference values for further application on explosion suppression technology in large oil rank farm and other danger sites.

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Keywords: oil gas; explosion suppression; ultra-fine cold aerosol / super fine powder; explosion pressure

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Nomenclature

C_g	concentration of oil gas, %(vol)
C_a	concentration of ultra-fine cold aerosol, g/l
C_{1301}	concentration of 1301 fire extinguishing agent, %(vol)
p_{red}	reduced (suppressed) explosion pressure
$p_{red,max}$	maximum reduced (suppressed) explosion pressure
p_{max}	maximum explosion pressure
K_{max}	maximum explosion index
$(dp/dt)_{max}$	maximum rate of pressure rise
t_d	ignition delay time
t_{ld}	long ignition delay time

1. Introduction

The problem of prevention and suppression of premixed Fuel-air is extremely important because such explosions are the major source of frequent human deaths and financial damage at oil tank farm, gas station or tunnel. Super fine powder has some typical characteristics of compressibility, flow ability, and good dispersion, and when they are discharged with big flux, ultra-fine cold aerosol is came into being and might suppress oil gas to explosion with physical and chemic suppression effect[1−3]. Suppressing premixed fuel-air explosion by ultra-fine cold Aerosol is an environmental, safe and valid method of prevention and suppression oil gas. And it has important signification to preventing deflagration or detonation in big oil rank area, gas station, tunnel and other confine space.

The study on fire extinguish technology of ultra-fine cold aerosol mainly focuses on new aerosol extinguishing agent, improved cold aerosol and compound aerosol, and at present, the latter including improved and compound type are developed trend[1, 2, 4]. Explosion mitigation technology of oil gas includes explosion isolation, explosion suppression and venting of explosions, and presently, initiative explosion isolation and suppression are research hot spots. Jiang X.S et.al have researched and produced a complex explosion suppression experimental system for the explosion of the combustible gas in the long - confined space based on the suppression technology of the super - fine cool aerosol [5, 6]. Chen S.W. et.al has founded a simulation experimental system of oil gas mixture explosion in the tank, and made a profound analysis of the influential trends of the pressure and the distribution of the likely-to-be exploded product [7]. Ren C.X. et al studied the explosion suppression of ultra-fine powder and halo-hydrocarbons gas by 20-L sphere apparatus [8]. Mikhail Krasnyansky has developed and tested a very effective powder "powder for suppression of explosions" for the suppression of explosions [9].

In this paper, it was tested and simulated about the explosion-suppression process of oil gas premixed air and ultra-fine cold aerosol, by a 20-liter apparatus with three gas routes and two igniters of chemical and pulse which provide a reliable, multiple-point ignition source. Moreover, some impact factors and of explosion suppression by experimental research were discussed, and the maximum suppressed explosion pressure and explosion index may be used as the criterion to estimate explosion-suppression efficiency of oil gas by ultra-fine cold aerosol. The researches help optimize explosion suppression condition of oil gas, and have important reference values for further application on explosion suppression technology in large oil rank farm.

2. Experiment

The explosion suppression experiment of oil gas usually is classified into initial explosion control and suppression, and explosion isolation. For the former, suppression reagents are jet quickly with some pressure and spread all over explosion shell before the flammable gas and air is ignited, such as 20-liter sphere apparatus and 1m^3 cylinders. For the latter, according to the fire spread condition, suppression reagents are jet quickly with some pressure and contact with flame spread face after the flammable gas and air is ignited, such as slightness tube suppress apparatus [5, 9] and 70-liter column reaction vessel [10].

For oil gas atmosphere, maximum explosion pressure (p_{max}), maximum explosion index (K_{max}) and burning rate is the most token parameters of the fire and explosion accidents consequence. The test and simulation experimental system of oil gas mixture explosion is usually used in assessing the validity of suppress process. In this paper, the following equipment was upgraded with three gas routes, pressure range from 0 to 2.0 MPa (absolute pressure), precision of 0.1% FS. And it was equipped with chemical fire with 10 KJ and high-voltage pulse fire, sampling and recording interval with 0.2 ms. The experiment oil gas was gasoline no.93 and the following Table 1 shows some technology indexes of suppression reagents.

Table 1. Ultra-fine powder parameters.

Test parameters	Result and value
Bulk desnsity, g/mL	0.32
Moisture content, %	0.24
hygroscopic rate, %	1.02
moisture repulsing property	Unabsorbing water， no agglomeration
anticaking capacity, mm	34.9
90% granularity, *u*m	7
electrical insulation, kV	No breakdown with 4kv and 5min
Extinguishing efficiency of A、B、C, g/m3	50

3. Result and discussion

3.1. Mode of ignition

From a large number of test results obtained in the 20-l-apparatus for the maximum explosion pressure, it appears the influence of the mode of ignition on the explosion pressure is relatively little. Mode of chemical igniters with 10 kJ and high-voltage pulse discharge leaded to the some change of maximum explosion pressure for oil gas atmosphere, with the same experiment token condition, which was shown by Fig.1. In the test, time difference between the activation of the ignition and the electrically activating the valve was 60 ms, and the concentration of oil gas was from 3.4 percent to 3.6 percent (vol%).

As can be seen on Fig. 2 the mode of ignition whit criterion ignition energy has some little impact on the maximum explosion pressure, because the ignition energy of oil gas usually is less than combustible dust. Moreover, due to the influence of time-delay of the outlet valve, ignition delay time and other impact factors, the oil gas concentration has some difference in the 20-liter apparatus, but the maximum rate of pressure rise $(dp/dt)_{max}$ has more distinction to a large number of test course.

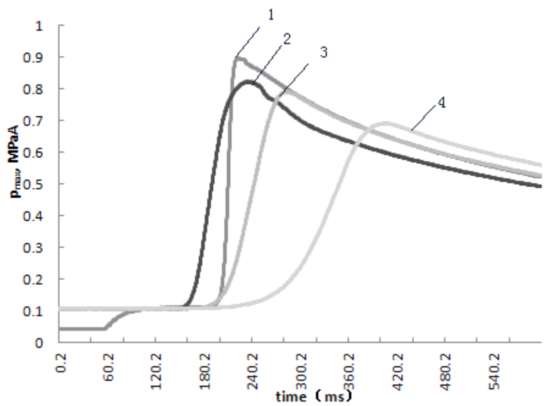

Fig. 1. The influence of long ignition delay on the p_{max} of gas oil:1-C_g=2.89%,t_{ld}=0s; 2-C_g=3.0%,t_{ld}=30s; 3-C_g=2.89%,t_{ld}=60s; 4-C_g=3.08%,t_{ld}=90s.

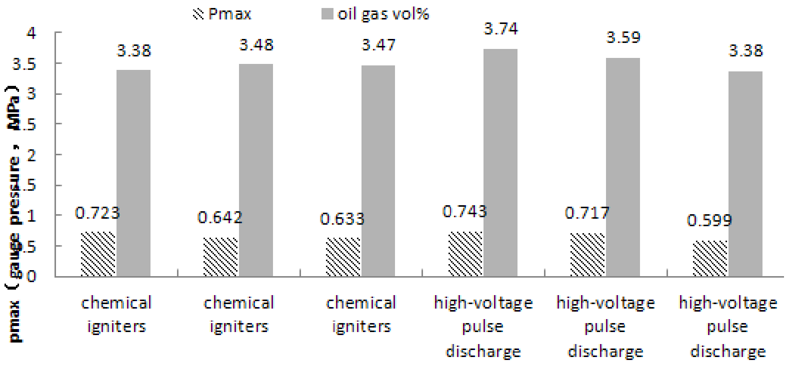

Fig. 2. The influence of the mode of ignition on the maximum explosion pressure.

3.2. Ignition delay time

When ultra-fine cold aerosol was sprayed into the 20-liter apparatus, the concentration of ultra-fine powder was asymmetry distribution and kept a little time at the original moment. At the same time, the concentration of powder trended to uniformity and stabilization because of turbulence. The degree of turbulence is mainly a function of the ignition delay time, which is between the onset of dust dispersion and the activation of the ignition of the dust/air mixture. In order to probe into the influence of the ignition delay time (t_d) on the explosion pressure, the long ignition delay time (t_{ld}) is presumed. In other word, it means the time between the onset of dust dispersion and the activation of the ignition of the dust/air mixture was delayed from 0s to 90s.

As can be seen on Fig.1 the increase of the long ignition delay time evidently causes the decrease of the maximum explosion pressure of oil gas with the concentration of 3.0% (v/v). And it is shown that the maximum explosion pressure of oil gas decreases by 15.8 percent. Moreover, this means that as the turbulence fails in for some time, the mixture of oil gas and air becomes homogeneous.

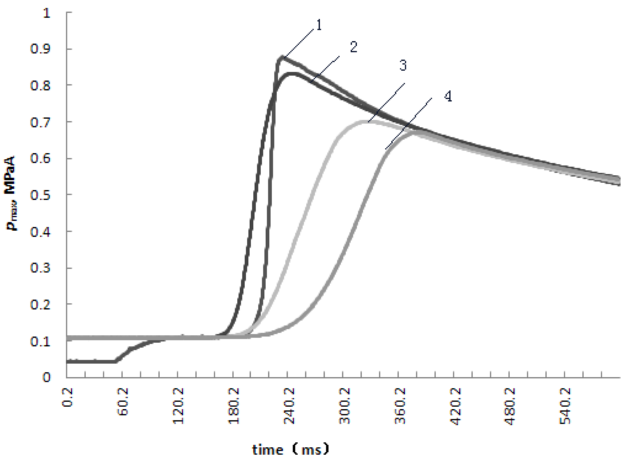

Fig. 3. The influence of long ignition delay on the p_{max} of the mixture of gas oil and ultra-fine cold aerosol(C_a=0.25g/l): 1-C_g=2.99%, t_{ld}=0s; 2-C_g=3.08%, t_{ld}=30s; 3-C_g=2.99%,t_{ld}=60 s; 4-C_g=2.99%,t_{ld}=90 s.

At the same time, the concentration of test oil gas and ultra-fine powder was fixed with 3.0%(vol%) and 0.25g/L, a series of experiments were done. Fig. 3 shows that as the long ignition delay time increases, the maximum explosion pressure of the mixture oil gas and powder decreases and arrives for some delay time. It can be seen that, the maximum explosion pressure of the mixture decreased with 19.33%, and the coming time of maximum explosion pressure has about 700ms delay. Therefore, it is obvious that the suppressing effect of ultra-fine cold aerosol for oil gas atmosphere is not distinctness in the spraying beginning of powder, and has a good effect when the mixture of oil gas and powder is mixed equably and uniformly.

3.3. Suppressing reagent

Two series of the explosion-suppression experiments were carried out in the laboratory 20-liter apparatus. In the first series the prevention and suppression process was simulated and the ultra-fine cold powder was added to the about 3.0% (v/v) concentration of oil gas simultaneously with the chemical igniters (Fig. 4). In the second series to simulate the suppression of a spreading explosion, 1301 fire extinguishing agent was added to the about 3.0% (v/v) concentration of oil gas (Fig. 5).

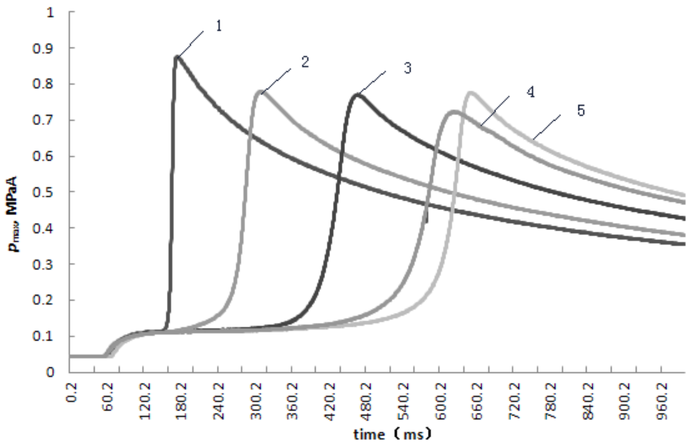

Fig. 4. The explosion suppression experimental curve of oil gas and ultra-fine cold aerosol: 1-C_g=3.08%, C_a=0.05g/l;. 2- C_g =3.09%, C_a =0.15g/l; 3- C_g =3.09%, C_a =0.25g/l; 4- C_g =2.9%, C_a =0.35g/l; 5- C_g =2.99%, C_a =0.40g/l.

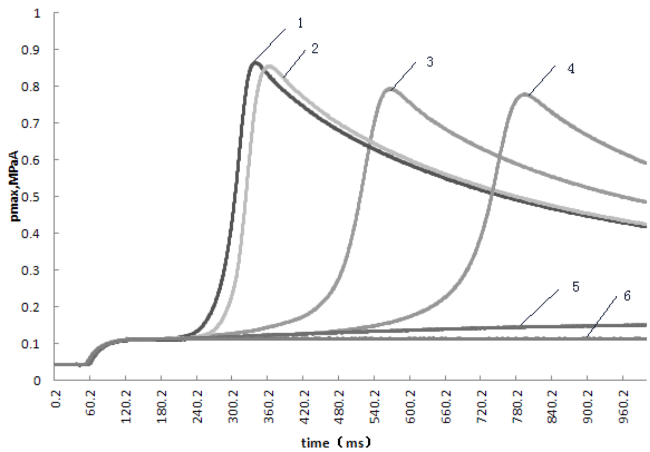

Fig. 5. Explosion suppression of the mixture of oil gas, 1301 fire extinguishing agent and air: 1-Cg=3.0%, C_{1301}=4.1%;. 2-Cg=2.9%, C_{1301}=4.2%; 3-Cg=3.0%, C_{1301}=5.1%; 4-Cg=3.1%, C_{1301}=5.9%; 5-Cg=3.0%, C_{1301}=6.1%;6-Cg=3.0%, C_{1301}=8.2%.

As can be seen on Fig. 4, induction period of oil gas explosion was delayed as the concentration of ultra-fine cold aerosol from 50 g/m^3 to 400 g/m^3, but the suppressing effect hadn't distinctly threshold nature. As a result, it is shown that the suppressing efficiency of test powder was very little, and the suppressing concentration and spray condition of ultra-fine cold aerosol should be optimized in depth.

In order to compare super fine powder fire extinguishing agent and gas suppressing agent, 1301 gas was added to 20-liter apparatus with some concentration, but it is not environment friendly gas. As can be seen on Fig.5, the process of prevention of the explosion has distinctly threshold nature, and it is obvious that the range from 5.9%(v/v) to 6.1(v/v) of a concentration of the 1301 gas for the suppression of explosion is present inside the 20-l sphere, the effect of the explosion prevention is eliminated. In case of suppressing the developed explosion, the increase of the 1301gas concentration of the vessel evidently causes the decrease of a maximum explosion pressure from 0.86 MPaG for down to 0.11 MPaG.

4. Rank of suppressing capability of ultra-fine cold aerosol for oil gas atmosphere

The above described laboratory investigations and discussion allow us to make the following rank of suppressing capability of ultra-fine aerosol for oil gas atmosphere (Table 2.). In order to determine to the rank of suppressing capability for oil gas atmosphere, the particle size distribution, suppressing concentration of super fine powder and maximum explosion pressure of oil gas are tested and determined by 20-liter apparatus or 1 m^3 cylinder. Because of many impact factors of explosion pressure,it is very difficult to research the optimal suppressing condition.

Table 2. The rank of suppressing capability of ultra-fine aerosol for oil gas atmosphere.

Suppressing agent	One class	Two class	Three class
Ultra-fine cold aerosol or supper-fine powder, gas suppressing agent. Test equipment: 20-l apparatus or 1m^3 cylinders.	$p_{red,max} < 10\% \, p_{max}$	$10\% \, p_{max} \leq p_{red,max} < 30\% \, p_{max}$	$30\% \, p_{max} \leq p_{red,max} < 60\% \, p_{max}$

5. Conclusions and recommendations

The above described laboratory investigations allow us to make the following conclusions:

(1) The ignition delay time (t_d) and long ignition delay time (t_{ld}) has an important influence on the explosion pressure of oil gas, or the mixture oil gas and ultra-fine cold aerosol. With the increase of the long ignition delay time, the maximum explosion pressure of oil gas decreases.

(2) According to suppression agent, the threshold character for the suppression of explosions should be searched and determined. In this paper, the tested super-fine powder hasn't obvious threshold, but the 1301 fire extinguishing agent has distinctly threshold nature.

(3) The rank index of suppressing capability of ultra-fine cold aerosol for oil gas atmosphere include particle size distribution, suppressing concentration, maximum explosion pressure and maximum reduced (suppressed) explosion pressure, and the rank criterion is proposed .

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