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Research on the Explosive Characteristics of Oil and Gas Mixture in Urban Drainage Pipeline

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To test explosive characteristics of the oil and gas mixture in urban drainage pipeline, we select six groups of the mixtures with different proportions of gasoline, methane and water, use 20L explosive ball experimental device in testing explosion rules of the oil and gas mixtures with different concentrations, and give research on explosive characteristics of oil and gas mixture systematically. Moreover, we give discussions on explosive characteristics of the mixed gases with different contents of gasoline, effect of water on explosion suppression of oil and gas mixture, and influence of methane with different concentrations on the explosive characteristics of oil and gas mixture from the two aspects of explosion pressure and explosion pressure rate of the mixed gas. The results indicate that: during pure gasoline explosion, the explosion pressure shall reach to the peak firstly and then reduce gradually, and explosion pressure shall increase obviously and explosion pressure rising rate shall rise apparently along with rising of gasoline concentration; when gasoline concentration remains unchanged, explosion pressure shall drop and explosion pressure rising rate shall increase obviously along with increment of water humidity; following rising of methane concentration, explosion pressure of the mixed gas of gasoline and water show the trend of rising before damping.

1. Introduction

Along with increasingly large-scale development of the cities, the use of flammable liquid and gas increases day by day, and the oil and gas pipelines are mostly buried underground and connected with urban sewage pipelines staggered. Once oil and gas leakage happens, explosion shall occur by mixing with the flammable and combustible gases in drainage duct, which could bring huge threat to the safety of urban residents and the cities. In recent years, there are many reports on the explosion accidents for oil and gas leakage, e.g. the "11•22" particularly serious accident of Dong-Huang oil pipeline leakage explosion of the Sinopec in Qingdao, Shandong in 2013, which had caused 62 persons died and 136 persons injure. To ensure life and property safety of the human and sustainable and healthy development of society, we shall give research on and attach importance to the combustion explosion rules of flammable liquid and gas and the accident prevention and control.

Researches of the domestic and overseas scholars on the gas explosion in drainage duct mainly concentrate on the monitoring of toxic and hazardous gases in underground drainage duct of cities and the risk assessment on gas explosion (Benhorma et al., 2017; Caruso and Nobili, 2017; Sakhrieh et al., 2017; Yang et al., 2016; Zaidi et al., 2017). Li (2007) gives research on characteristics and reasons of the explosion in urban sewers, Mi (2010) gives research on the risk assessment on gas explosion in urban sewers, and build the semi-quantitative risk assessment model for the gas explosion in urban sewers, Fang (2012) gives research on detection and distribution rules of the harmful gas in sewage pipelines in mountainous cities, and Chen (2011) gives research on explosion experiments of the oil and gas in long and narrow confined space. As there are fewer explosion accidents occurred in the overseas sewage pipelines, the corresponding researches are lesser. Sayers (1997) believes that composition of the gas in sewer is very complex and the gas distribution is affected by many factors. From the view of existing researches, there are lesser systematic researches on explosive characteristics of the oil and gas mixture in drainage duct. However, according to the existing literatures, the theoretical and experimental researches on explosive characteristics of flammable gas are relatively mature, e.g. Qu et al., (2013) give experimental research according to influence of the methane

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concentration on combustion explosion characteristics of methane, Hu et al., (2009) give application research on the explosive characteristics of methanol-ammonia-air polynary explosive mixture, and (Wu, 2004)gives research on the explosion pressure of polynary explosive mixture and the explosion suppression technology. In the aspect of mixed gas explosion suppression, Lu et al., (1998) gives research on suppression mechanism of water to gas explosion, and Mikhail (2006) gives research on preventing and suppressing explosion of gas-air and dust-air mixtures with powder aerosol.
In this background, we test explosive characteristics of the mixture with different proportions of $92^{\#}$ motor gasoline, water and methane by adopting 20L explosion test device, and research on explosive characteristics of the mixtures with different gasoline contents, explosion suppression function of water to mixed gas and influence rules of methane with different concentration on explosive characteristics of mixed gas.

2. Explosion experiment and the principle

As most of the urban sewage pipelines are buried underground, experimental device of the oil and gas mixture explosion of this experiment adopts 20L spherical explosion can to simulate the underground confined space environment. Pressure change in explosion can is measured by sensor and forms electrical signal, and external computer is used in controlling explosion and recording explosion parameters, as shown in Figure 1.

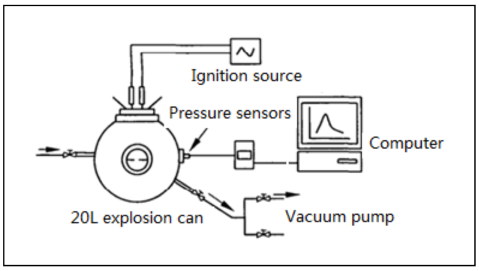

Figure 1: 20L Explosion Test Device

2.1 Experimental samples

The samples used in this experiment are $92^{\#}$ motor gasoline, methane and water. To ensure purity and dosage accuracy of the samples, medical injector is used in the experiment for sampling. For better comparison of the experimental results, the experimental samples are divided into six groups, with concrete parameters as shown in Table 1.

Table 1: Parameters of experimental samples

No.	$92^{\#}$ Gasoline Content/ml	Methane Content/%	Water Content/ml
A	2	0	0
B	3	0	0
C	2	0	2/4/6/8
D	3	0	2/4/6/8/12/15/20
E	2	1	2/4/6/8
F	2	1/2/4/6/8/10/12/14	2

2.2 Experimental principle

10KJ chemical ignition is adopted in the experiment, vacuum pressure is 33.7KPa, atomized spraying time is 300ms, atomized spraying pressure is 2MPa, ignition delay time is 100ms, and data collection time is 1000ms. During the experiment, the fact whether the pressure in can is greater than 0.1MPa is considered as the basis for explosion.
The peak pressure, caused at the time when system is in complete heat insulation and the flammable gas in limited closed container is fully ignited in an instant in ideal state, is considered as explosion pressure.
(1) The maximum explosion pressure P_{max}
The maximum explosion pressure P_{max} can be recorded automatically in experiment, and explosion pressure rising rate K_m is defined as:

$$K_m = \left(\frac{d_p}{d_t}\right) K_m = \left(\frac{d_p}{d_t}\right)_m \cdot V^{\frac{1}{3}} \tag{1}$$

In the formula, V refers to volume of the test device.

(2) The maximum explosion pressure rising rate $(d_p/d_t)_m$

The maximum pressure rising rate of a test is recorded as $(d_p/d_t)_m$, the explosion pressure rising rate obtained in the experiment within dust concentration range is $(d_p/d_t)_m$, and the maximum value is the maximum pressure rising rate of this dust and recorded as $(d_p/d_t)_{max}$

3. Results and analysis

3.1 Gasoline explosion pressure distribution

When testing explosion pressures of 2ml gasoline and 3ml gasoline respectively by not increasing water humidity in normal conditions, the explosion pressure distributions are as shown in Figures 2 and 3.

During pure gasoline explosion, the explosion pressure shall reach to the peak firstly and then reduce gradually along with increment of time; along with rising of gasoline concentration, the explosion pressure increases obviously; simultaneously, the peak pressure shall occur in advance. During combustion explosion, explosion pressure rising rate rises obviously along with rising of gasoline concentration.

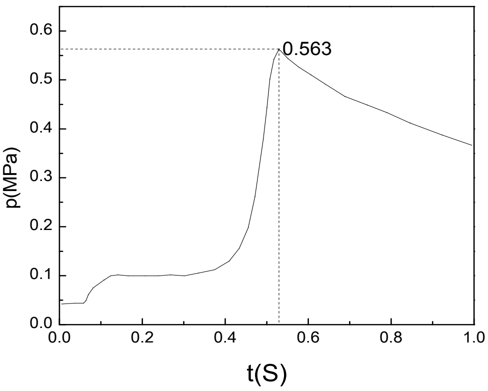

Figure 2: Curve of the Explosion Pressure Distribution of 2ml Gasoline

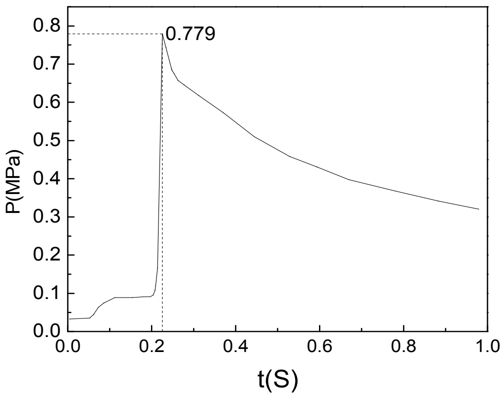

Figure 3: Curve of the Explosion Pressure Distribution of 3ml Gasoline

Table 2: Explosion Pressure and Explosion Pressure Rising rate of the Oil and Gas Mixture

Gasoline/ml	Oil and Gas Volume/(V/V)%	Explosion Pressure/MPa	Explosion Pressure/MPas^{-1}	Pressure Rising /%
2	0.01	0.5630	80.58	-
3	0.015	0.7792	119.50	38.37

From the view of peak explosion pressure, the explosion pressure generated increases along with increment of gasoline content. Concentration of the 2ml gasoline in 20L explosion can is 0.01%, and the peak explosion pressure is 0.563MPa. When concentration reaches 0.015%, the peak explosion pressure could reach 0.779MPa, and the pressure shall rise by 38.37%.

From the view of explosion pressure rising rate, the explosion pressure rising rate of 2ml gasoline in 20L explosion can is 80.58 MPas^{-1}. Along with increment of concentration, the explosion pressure rising rate can reach 119.50 MPas^{-1} when gasoline content is 3ml, as shown in Table 2.

Table 2: Explosion Pressure and Explosion Pressure Rising rate of the Oil and Gas Mixture

Gasoline/ml	Oil and Gas Volume/(V/V)%	Explosion Pressure/MPa	Explosion Pressure/MPas^{-1}	Pressure Rising /%
2	0.01	0.5630	80.58	-
3	0.015	0.7792	119.50	38.37

3.2 Analysis on influence of water humidity on explosive characteristics of the oil and gas mixture

(1) Explosive characteristics of the mixed gas of 2ml gasoline with different water contents

During the experiment, keep the initial pressure constant, gasoline content keeps at 2ml, and water content shows change, namely 2ml, 4ml, 6ml and 8ml respectively. The explosion parameters of the oil and gas mixture are as shown in Figure 4.

From the view of experimental results, explosion pressure reduces most obviously when water humidity changes and water content reaches 8ml. When mixing 2ml gasoline with equivalent water uniformly, the peak pressure generated shall be 0.5423MPa, and the pressure shall reduce by 3.68%; when water content reaches 4ml, peak pressure could reach 0.5994MPa, and the pressure shall rise by 10.52%; when water content reaches 6ml, peak pressure shall be 0.5314MPa, and pressure shall reduce by 11.342%; when water content reaches 8ml, peak pressure shall be 0.12MPa, and pressure shall reduce by 77.41%. This shows that explosion can be fully suppressed when gasoline concentration is too low and water humidity increases to a certain degree.

From the view of explosion pressure rising rate, the explosion pressure rising rate shall increase along with increment of water humidity. When water content is 2ml, the explosion pressure rising rate of the oil and gas mixture shall have an obvious promotion and reach 270.35 $MPas^{-1}$, and the pressure rising rate shall be 235.07%; when water content reaches 4ml, the explosion pressure rising rate shall be 323.90 $MPas^{-1}$, and explosion pressure rate shall rise by 19.80%; when water content reaches 6ml, the explosion pressure rising rate shall be 361.64$MPas^{-1}$, and the explosion pressure rate shall rise by 11.96%; when the water content reaches 8ml, the explosion pressure rising rate shall be 650$MPas^{-1}$, and explosion pressure rate shall rise by 79.74%.

(2) Explosive characteristics of the mixed gas of 3ml gasoline with different water contents

Gasoline content keeps at 3ml, and water content shows change, namely 2ml, 4ml, 6ml, 8ml, 12ml, 15ml and 20ml respectively.

When mixing gasoline with water, the maximum explosion pressure really reduces to some extent. However, along with continuous increment of water humidity interval, pressure peak does not show obvious fluctuation. Till to the time when water humidity increases to 0.1%, the maximum explosion pressure shall reduce to 0.5582MPa, and the pressure shall show relatively obvious reduction and reduces by 16.2%. During the whole explosion experiment, the explosion pressure rising rate shows drastic increment. The maximum explosion pressure rising rate is 679.25$MPas^{-1}$, and it increases by 208.33%. When water humidity increases obviously, the explosion pressure rising rate shall reduce gradually along with reduction of peak pressure. Explosion parameters are as shown in Figure 5.

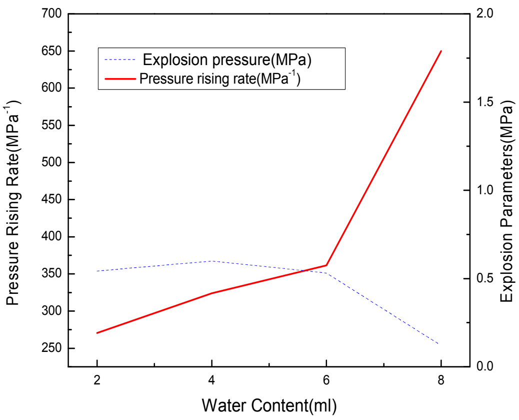

Figure 4: Explosion Parameters of 2ml Gasoline with Different Water Humidity

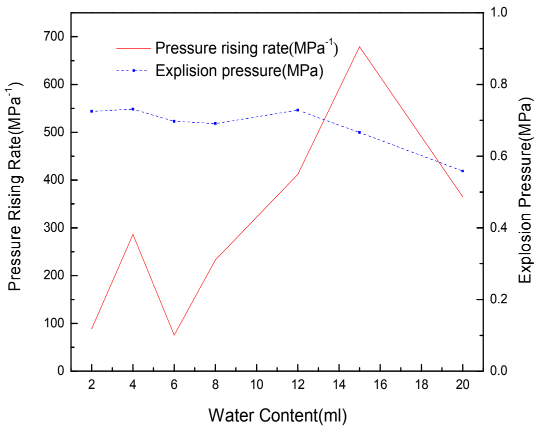

Figure 5: Explosion Parameters of 3ml Gasoline with Different Water Humidity

3.3 Influence of methane concentration on the explosion effect of mixed gas

(1) Explosive characteristics of the mixed gas of 1% methane with different water contents

Gasoline content keeps at 2ml, 1% methane is added, and water content shows change, namely 2ml, 4ml, 6ml and 8ml respectively. Gasoline concentration in explosion can is kept at 0.01%, 1% methane is added, and peak explosion pressure shows the trend of diminishing gradually along with increment of water humidity. Methane belongs to flammable and explosive gas, the peak explosion pressure can reach 0.648MPa when adding in 1% methane, and the pressure rises by 106.04%. During the whole experimental process, the explosion pressure rising rate increases obviously along with increment of water humidity. When water content reaches 8ml, the explosion pressure rising rate shall reach 685.53 $MPas^{-1}$, and it shall rise by 518.42%. Explosion suppression parameters of the mixed gas of 1% methane with different water contents are as shown in Figure 6.

(2) Explosive characteristics of the mixed gas of methane with different concentrations

Gasoline content and water content keep at 2ml, and methane with different concentrations is added, namely 1%, 2%, 4%, 6%, 8%, 10%, 12% and 14% respectively. Along with increment of methane concentration, explosion pressure and explosion pressure rising rate all show the rising trend firstly, and the rising rate increases gradually. Along with continuous rising of the methane concentration, explosion pressure and explosion pressure rising rate all show damping trend. When methane concentration reaches 8%-10%, explosion pressure and explosion pressure rising rate shall reach the maximum values, which might indicate more sufficient combustion of mixed gas and the relatively stable detonation. The explosion characteristics are as shown in Figure 7.

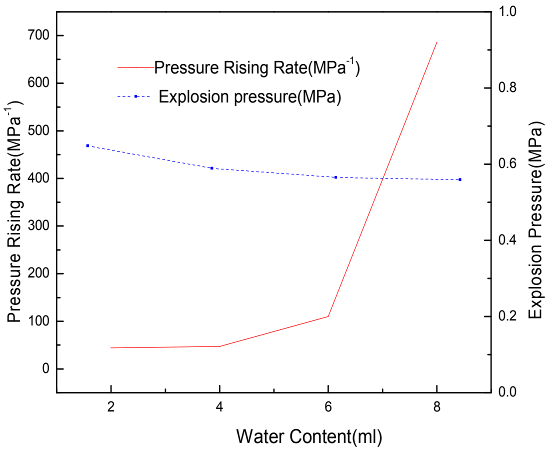

Figure 6: Explosion Parameters of 1% Methane with Different Water Humidity

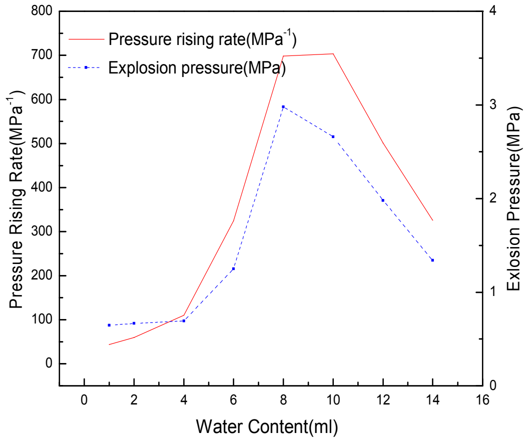

Figure 7: Explosion Parameters of the Mixture of 2ml Gasoline, 2ml Water and Methane with Different Concentrations

4. Conclusions

(1) Along with increment of gasoline concentration, the maximum explosion pressure of the mixed gas increases obviously; when gasoline concentration maintains unchanged, the maximum explosion pressure generated by mixed gas shall show gradually diminishing trend on the whole along with water humidity increment.

(2) From the view of explosion pressure rising rate, the explosion pressure rising rate shows rising trend on the whole along with increment of gasoline concentration, and the rising amplitude is greater; when gasoline concentration remains unchanged, pressure rising rate shall increase obviously along with increment of water humidity. When the humidity of water increases obviously, the increase rate of explosion pressure decreases with the decrease of the peak pressure.

(3) When gasoline concentration and water humidity remain unchanged, the peak pressure caused by explosion shall increase along with methane concentration increment, the pressure rising rate shall show increasing trend on the whole, and trends of explosion pressure and explosion pressure rising rate shall stay

the same basically; in the condition that gasoline concentration remains unchanged, and when methane concentration is 1%, the explosion peak caused shall show downtrend on the whole along with water humidity increment.

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