含 能 材 料
CHINESE JOURNAL OF ENERGETIC MATERIALS


文章编号:1006-9941(2007)02-0158-04

# Effect of Different Vacuum Pressure on the Expanding Velocity of the Smoke Cloud

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**Abstract**: Based on the pyrotechnic and powder smoke cloud, the effect of vacuum pressure on the expanding velocity during the smoke cloud forming was studied experimentally with the method of the expansive velocity obtained by testing the increases of the cloud edge size. Results show that the expanding velocity increases with the increases of vacuum from 0.10 MPa to 0.04 MPa, and the velocity increases about 0.03 times when the pressure decreases 0.02 MPa.

**Key words**: military chemistry and pyrotechnics; smoke cloud; vacuum; expanding

**CLC number**: TJ413; TQ567 **Document code**: A

## 1 Introduction

The smoke shield performance is straight affected by the extinction performance of smoke particles and the mass concentration of the smoke cloud, higher available mass concentration of smoke cloud make the smoke shield performance good when the extinction performance of smoke materials is constant[1]. According as the area size of the protected targets infrared radiant point and the performance of the coming raid infrared guidance head or detector, the smoke cloud must have enough effective shield area and time. Applying smoke in outer space[2], the problem is whether the smoke particles, dispersed in the rarefied air can form the suspended cloud, that possesses enough available mass concentration, shield area and shield time. For a definite quantity smoke agent in a definite time the above properties of smoke cloud is straight affected by the smoke cloud expanding characteristics. So, the smoke cloud expanding characteristics have attracted many people's attention[3-6], but the study in vacuum is still lack[7]. On this basis, this paper presents the effect of vacuum pressure on the expanding characteristics of the pyrotechnic and powder smoke cloud, expecting to establish technology basis for the smoke applying in outer space.

## 2 Experimental

### 2.1 Preparation of samples

Pyrotechnic sample: the experimental agent is based on the excogitated pyrotechnic anti-IR smoke agent[8], modulating the agent oxygen equilibrium appropriately to combust successfully at different vacuum pressures. The basic compositions of the smoke agent are $KClO_4$, Mg powder and PTFE, etc. Charging 1 gram of anti-IR smoke agent, transition agent and amorce to a ten-millimeter-diameter columned die, being pressed 5 seconds lastly by 25-ton-pressure oil pressure machinery under the 0.3 MPa pressure of the meter reading, then discharging the columned agent, and charging it to a combustion vessel and mooring a electric igniter on top. In this way the sample is prepared.

Powder sample: choosing squama graphite as the powder smoke interferential materials[9] with about 8.7 μm median diameter. Charging an electric igniter and propellant to a combustion vessel orderly, then placing 1 gram of graphite on top, then the sample is prepared.

### 2.2 Experimental set-up and method

The experimental set-up is made up of the vacuum simulation system and image collection system. The vacuum simulation system is the same as the reference [10]. Image collection system is composed of SIJ-High-speed camera and computer. To note the expanding circumstances of the smoke cloud, that was necessary to place a gauge side by the vacuum jar. The gauge precision is millimeter; the gauge graduation is in the direction of the camera lens, the sketch of experimental set-up vides Fig. 1.

**Received Date**: 2006-04-06 **Revised Date**: 2006-07-06
**Foundation Item**: The National Science Foundation of China (No. 90305008)
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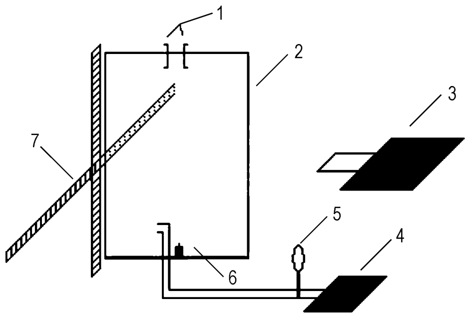


Fig. 1　Sketch of experimental set-up

1—connection pole, 2—vacuum jar, 3—image collection system, 4—vacuum pump, 5—vacuum meter, 6—sample and igniter, 7—gauge

The electric ignition mode was adopted in experiment. Placing the samples at the bottom of the vacuum jar respectively, connecting the electric igniter to the connection pole, covering and vacuumizing the vacuum jar, then the experiments were performed.

The radial size increases of the smoke cloud in a unit time, is namely, the expanding velocity of smoke cloud. To analyze the collected image when experiments finished, according to the gauge graduation of the cloud edge and the time interval of two sequential images of the smoke cloud, the expanding velocity of smoke cloud is solved by the following Equation (1):

$$u = \frac{\overline{\Delta l_{\text{upright}}} + \overline{\Delta l_{\text{level}}}}{2 \cdot \Delta t} \quad (1)$$

Where $u$ denotes the expanding velocity of smoke cloud. $\overline{\Delta l_{\text{upright}}}$ and $\overline{\Delta l_{\text{level}}}$ denote the upright and level size increases of the cloud edge in two sequential images of the smoke cloud, respectively. $\Delta t$ represents the time interval of two sequential images of the smoke cloud.

## 3　Experimental results and discussion

### 3.1　Expanding characteristics of pyrotechnic smoke cloud

Igniting the pyrotechnic samples in different vacuum pressures; turning on the image collection system to note the expanding process of smoke cloud, simultaneously. The combustion time of all samples lasted about 6.7 s in each vacuum pressure, and the spending time of smoke clouds expanding to the wall of the vacuum jar are presented in Table 1.

**Table 1　The spending time of pyrotechnic smoke clouds expanding to the wall under different vacuum pressure**

| $p$/MPa | 0.1 | 0.08 | 0.06 | 0.04 |
|---|---|---|---|---|
| $t$/s | 6.7 | 6.5 | 6.3 | 5.8 |

Results in Table 1 show that the expanding velocity at the pressure of 0.04 MPa is better than that at other pressures, and the spending time is 5.8 s. The 1 s, 2 s, 3 s, 4 s, 5 s images of the smoke cloud were analyzed, respectively, the upright and level cloud edge size change in average two sequential images was observed, and the size increases of several different positions were obtained through the comparison of the gauge graduation, then $\overline{\Delta l_{\text{upright}}}$ and $\overline{\Delta l_{\text{level}}}$ in different vacuum degrees were deduced from the average of size increases, which listed in Table 2.

From the analysis of average data in Table 2, it shows that the size increases in upright is a little bigger than that in level. The reason is that the smoke cloud volume in upright increased by the pneumatic acceleration effect caused by the combustion event of smoke agent . Using the data in Table 2, the expanding velocity of the smoke cloud during the combustion event have been calculated according to Equation (1), which given in Table 3, Fig. 2.

Fig. 2 shows that the expanding velocity of pyrotechnic smoke cloud is increasing with the decreases of the pressure, and the increase amplitude of the average is equal approximately, the expanding velocity increases 0.03 times when the pressure decreases 0.02 MPa; moreover , the expanding velocity of pyrotechnic smoke

**Table 2　Size increases of pyrotechnic smoke cloud edge at each interval under different vacuum pressure**

| $t$/s | $\overline{\Delta l_{\text{upright}}}$/cm | | | | $\overline{\Delta l_{\text{level}}}$/cm | | | |
|---|---|---|---|---|---|---|---|---|
| | 0.1 MPa | 0.08 MPa | 0.06 MPa | 0.04 MPa | 0.1 MPa | 0.08 MPa | 0.06 MPa | 0.04 MPa |
| 1 ~ 2 | 6.76 | 6.92 | 7.03 | 7.25 | 6.23 | 6.32 | 6.66 | 6.67 |
| 2 ~ 3 | 6.42 | 6.11 | 6.77 | 6.76 | 6.50 | 6.98 | 6.82 | 7.31 |
| 3 ~ 4 | 5.87 | 6.23 | 6.89 | 7.51 | 6.69 | 6.91 | 6.74 | 6.40 |
| 4 ~ 5 | 6.57 | 6.66 | 6.72 | 6.41 | 5.88 | 6.42 | 6.53 | 7.32 |
| average | 6.405 | 6.48 | 6.853 | 6.983 | 6.325 | 6.658 | 6.688 | 6.925 |

**Table 3 Expanding velocity of pyrotechnic smoke cloud at each interval under different vacuum pressure**

| t/s | u / cm · s$^{-1}$ | | | |
|---|---|---|---|---|
| | 0.1 MPa | 0.08 MPa | 0.06 MPa | 0.04 MPa |
| 1 ~ 2 | 6.495 | 6.62 | 6.845 | 6.96 |
| 2 ~ 3 | 6.46 | 6.545 | 6.795 | 7.035 |
| 3 ~ 4 | 6.28 | 6.57 | 6.815 | 6.955 |
| 4 ~ 5 | 6.225 | 6.54 | 6.625 | 6.865 |
| average | 6.361 | 6.569 | 6.77 | 6.953 |

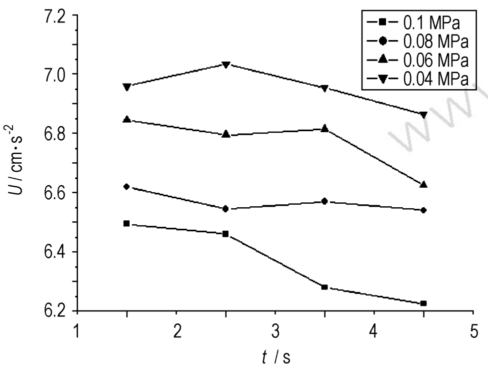


Fig. 2 Relation between expanding velocity of pyrotechnic smoke cloud ($u$) and times ($t$) under different vacuum pressure

cloud is decreasing with the process of time in a same vacuum pressure. In the vacuum jar the gas density was continually changing. With the increases of the vacuum pressure, the decreasing gas density make the gas resistance to the expanding smoke cloud reduced[11], and the expanding velocity increases. The decreasing curve of 0.08 MPa in Fig. 2 is more flat, which resulted from the measure error. In vacuum pressure 0.08 MPa, the smoke cloud figure is irregular induced by the incidental unstable combustion of the sample, so the error exists in the collected data due to the uncertainty of the measure standard. On the other hand, with the process of time, the smoke agent is combusting continuously, the gas in combustion production offsets the decreasing of gas density which deduced by the increases of the vacuum pressure, which make the gas resistance increase, and the expanding velocity decrease. The needed explanatory is that although the smoke particles number is increasing during the smoke agent combusting, the smoke particles concentration is indefinitely increase due to the increase of the cloud volume, and the cloud expanding velocity is mostly directed by the producing smoke velocity of the smoke agent when the environment conditions is constant, so, the effect of the variety of the particles concentration on pyrotechnic smoke cloud expanding velocity is ignored in present study.

## 3.2 Expanding characteristics of powder smoke cloud

Igniting the powder samples in different vacuum pressures, turning on the image collection system simultaneously. On the action of high pressure gas produced by propellant combustion, the graphite smoke cloud was formed quickly and expanded to around, and the spending time of smoke clouds expanding to the wall of the vacuum jar are presented in Table 4. It shows that the expanding velocity at 0.04 MPa is comparable to other pressures, and the spending time is 2.9 s.

**Table 4 The spending time of powder smoke clouds expanding to the wall under different vacuum pressure**

| p/MPa | 0.1 | 0.08 | 0.06 | 0.04 |
|---|---|---|---|---|
| t/s | 3.3 | 3.2 | 3.1 | 2.9 |

The relationship between expanding velocity of power smoke cloud and time at 0.04, 0.06, 0.08, 0.1 MPa vacuum pressure are shown in Table 5 and Fig. 3. From data in Table 5 and curves in Fig. 3, it shows that the expanding velocity of smoke cloud is increasing with the decreases of the pressure during the expanding process, and the expanding velocity increases about 0.03 times when the pressure decreases 0.02 MPa, which agreed with the expanding characteristics of pyrotechnic smoke cloud, the reasons are also the decreasing gas resistance to smoke cloud due to the decreasing of the gas density. Comparing Fig. 2 to Fig. 3, we can find that the powder smoke cloud expanding velocity is faster than the pyrotechnic. That is because the forming velocity of pyrotechnic cloud is slower, and that of the powder cloud is more quickly. It also shows that the expanding velocity of powder smoke cloud is decreasing with the process of time in a same vacuum pressure, and the decrease amplitude is higher than the pyrotechnic at same conditions, the reason is that the expanding energy is dying out during the powder cloud expanding, which made the expanding velocity reduced; however, the combustion event is continuous during the pyrotechnic cloud expanding process, in despite of the expanding velocity decreased by the increasing gas production resistance, the reducing amplitude of expanding velocity is still not much more, due to the expanding energy provided by the combustion event continuously.

**Table 5　Expanding velocity of powder smoke cloud at each interval under different vacuum pressure**

| t/s | $u$ / cm · s$^{-1}$ | | | |
|---|---|---|---|---|
| | 0.1 MPa | 0.08 MPa | 0.06 MPa | 0.04 MPa |
| 0.5 ~ 1.0 | 13.563 | 13.873 | 14.324 | 14.753 |
| 1.0 ~ 1.5 | 12.879 | 13.453 | 13.825 | 14.416 |
| 1.5 ~ 2.0 | 12.475 | 12.671 | 13.085 | 13.804 |
| 2.0 ~ 2.5 | 11.978 | 12.488 | 12.832 | 13.167 |
| average | 12.724 | 13.121 | 13.516 | 14.035 |

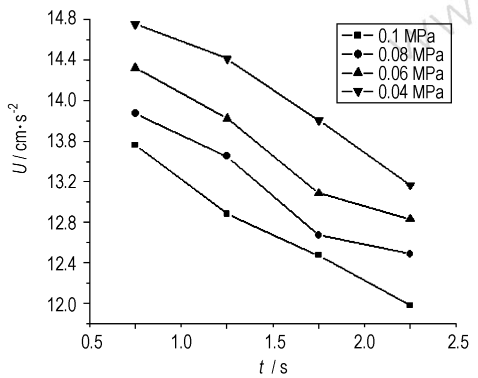


Fig. 3　Relation between expanding velocity of powder smoke cloud ($u$) and times ($t$) under different vacuum pressure

## 4　Conclusions

Through the expanding velocity testing of the pyrotechnic and powder smoke cloud, it is found expanding velocity of smoke cloud during the formation is increasing with the increases of the vacuum pressure, and the velocity increases about 0.03 times when pressure decreases 0.02 MPa in the allowable range of experiment condition. The expanding velocity increasing is because that the medium resistance to smoke cloud decreases gradually with the increases of the vacuum degrees of the medium.

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# 真空度对烟幕云团膨胀速率的影响

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**摘要:** 将烟幕应用于外层空间,研究烟幕云团的稳定性极为重要。针对外层空间高真空的特殊环境,基于燃烧型及粉末型烟幕云团,采用通过测试单位时间内云团边缘尺寸变化获取膨胀速率的方法,试验研究了真空度对烟幕云团形成时膨胀速率的影响。结果表明,烟幕云团的膨胀速率随着真空度由 0.1 MPa 升高到 0.04 MPa 而逐渐增大,并且压力每减小 0.02 MPa,膨胀速率约增大 0.03 倍左右。

**关键词:** 军事化学与烟火技术; 烟幕云团; 真空; 膨胀

**中图分类号:** TJ413; TQ567　　**文献标识码:** A