Influence of dosage and size on radiation performance of MTV and AP/HTPB agents

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Abstract. The limited effort in this paper is focused on studying the infrared radiation performance of Ammonium perchlorate/ hydroxy-terminated polybutadiene(AP/HTPB) and Magnesium/ Teflon(MTV) agents, in order to compare the differences in the spectral distribution of the two agents at different doses and tube shell sizes. A FTIR remote-sensing spectrometer was used to characterize combustion flame radiation products and a Spectraline SC7000 imaging spectrometer was used to test the radiation performance of each band. The test results show that the radiation energy of AP/HTPB agents is 5-8 times smaller than that of MTV agents under the same conditions. In addition, as the mass is small (5g), the spectral distribution of AP/HTPB agent θα/β/λ is 0.6:1:0.15, which is better than MTV agent whose θα/β/λ is 2.3:1:0.15. But as the mass increased to 40g and the diameter of the tube shell increased to 40mm, the mass burning rate of the MTV agent increased from 0.287g/s to 4.167g/s, and the mass burning rate of AP/HTPB agent increased from 0.258g/s to 2.920g/s. At this time, the MTV spectral distribution did not change much, but the radiation energy of AP/HTPB agents is changed more concentrated in the near-infrared band, and the spectral distribution θα/β/λ becomes 1.4:1:0.3.

1. Introduction

With the development of optoelectronic countermeasures technology, the identification of target trajectories is an important issue in the development of flare[1-3]. In order not to be captured by the infrared searcher, the decoy agent not only needs to generate a stable thrust to drive the steering device to match the trajectory [4-7], but also obtain a suitable infrared spectrum radiation to match spectrum of the target[8-9]. Among them, for the target, the infrared spectrum produced is mainly concentrated in the mid-infrared band, while the infrared spectrum of the traditional magnesium/Teflon(Mg/PTFE) bait is opposite concentrated in the near-infrared band, which has become an urgent problem to be solved.[10-11] A lot of efforts have been made by researchers on how to change the infrared spectrum of MTV agents, but the effect is limited.[12-13] In recent years, with the advancement of propulsion bait, the decoy agents based on AP/HTPB have received a lot of attention[14-15]. AP/HTPB agent is widely used as high-energy propellant for large specific impulse, stable combustion and mature technology, then it can produce a stable thrust and attain a high radiation by adding high-energy combustible[16]. Nielson[17] tried to add magnesium (Mg) to partly replace Ammonium Perchlorate(AP) in the AP/HTPB system and obtained a better near-to-mid infrared ratio(θα/β) close to that of aircraft when the mg content was 22%.

The purpose of this article is to compare the radiation spectrum distribution of the MTV system and AP/HTPB system under different dosages and different shell diameters.Changes in the amount and size of the agents are expected to change the burning temperature and burning rate, which will inevitably affect the heat radiation energy, thereby changing the spectral distribution of the agents.
2. Experimental Section

2.1. Preparation of pyrotechnic powder

Table 1 lists the formulation of each component and corresponding mass and shell size used in experiment. The test content The materials used for preparation including: AP(Nanjing Jiaoziteng Chemical Company, 100mesh, 99%purity), HTPB(Tianyuan Chemical Group, mass fraction \(\geq 97.5\%\)), sulfuric acid intercalation expandable graphite (particle size 80 mesh, carbon content \(\geq 95\%\), expansion multiple \((ml/g) \geq 200\), Aladdin), TPG (Shanghai Jiujiang Group, 100 mesh, 99% purity), TDI (Shanghai Jiujiang Group, 100-120 mesh, 99% purity), DOS (Beijing Sinopharm Group, 100-120 mesh, 99% purity), Mg (Beijing Sinopharm Group, 200-300 mesh, 99% purity), PTFE (Beijing Sinopharm Group, 80-120 mesh, 99% purity), Viton (Beijing Sinopharm Group, F23-11, the ratio of vinylidene fluoride and chlorotrifluoroethylene is 1:1). In the preparation process of the pyrotechnics, For AP/HTPB compositions, the components of the pyrotechnic powder were mechanically stirred uniformly, and then be weighed into an iron shell as required for compaction. Subsequently, 12h was demanded for curing in a 60°C oven and stand 4h in air for experimental test[18]. For MTV compositions, viton was weighed in advance and dissolved in acetone as glue, then each component was mixed in the glue. After mechanical mixing, the mixture were granulated into 40 mesh and dried by a 40°C oven for 4h. Then A YQ32-400T hydraulic press was used to press the mixture and the same compression density of 1.51g*cm\(^3\) could be obtained[19]. The ignition surface was weighed with 0.5g of boron/barium chromate (B/Ba(CrO\(_4\))\(_2\)) agents tape and used for ignition test.

| Table 1  | The formulation of each component and corresponding mass and shell size |
|----------|--------------------------------------------------------------------------|
|          | AP /mass % | HTPB /mass % | DOS /mass % | TDI /mass % | TPG /mass % | Mass /g | Shell diameter /mm | Density /g*cm\(^{-3}\) |
| AP/HTPB-5g | 80        | 13          | 5           | 2           | 1           | 5      | 22                  | 1.64                  |
| AP/HTPB-40g | 80        | 13          | 5           | 2           | 1           | 40     | 40                  | 1.64                  |
| Mg        | 47.5       | 47.5        | 5           | 5           | 22          |        |                     |                       |
| MTV-5g    | 47.5       | 47.5        | 5           | 5           | 22          | 40     | 40                  | 1.5                   |
| MTV-40g   | 47.5       | 47.5        | 5           | 40          | 40          | 40     |                     |                       |

2.2. Experimental test

Figure 1 is the schematic diagram of combustion test. The Fourier infrared spectrometer and spectral radiometer were used to test the radiation performance in the combustion tower. The combustion tower has a horizontal diameter of 0.6m and a height of 1m. After the pellets were completely burned, the exhaust fan was turned on to smoke out to prevent the effect of the instrument's test. The response band range of the spectral radiometer (Spectraline SC7000 imaging spectrometer) is 1.28μm-13.88μm and the field angle is 4.7°. The test distance was set 50m for 40g agents and 14m for 5g agents and the test frequency was 25hz. DY-HT4 high temperature black body (800-1600°C) was used to calibrate the spectrometer and radiant intensity in different bands. The calibration temperature is 1000°C, the light source is full of the instrument's field of view calibration, and the calibration curve has stable fluctuations. The Fourier infrared spectrometer(OPAG33, Bruker CoSloration, Germany) was used to characterize gas-phase combustion products during the combustion of pyrotechnics. The instrument also uses blackbody calibration. The spectral test range of the FTIR remote sensing spectrometer is 4000-400cm\(^{-1}\), the resolution is 4cm\(^{-1}\), the test distance is 5.2m, and the test frequency is 1HZ [20].
3. Result and Discussion

3.1. Flame combustion products tested by Fourier infrared spectrometer

Using FTIR remote-sensing spectrometer to test the infrared radiation spectrum of AP/HTPB and MTV compositions, results are expressed as relative spectral illuminance, with no unit because of the existence of the instrument response function. Results are presented in Fig. 2.

As for AP/HTPB-5g compositions, it can be seen that the maximum peak at 2281 cm\(^{-1}\) is the peak of hot CO\(_2\), close to which is symmetrical stretching peak of CO\(_2\) at 2390 cm\(^{-1}\) for cold CO\(_2\) absorption in air. The wave band of 2400-3150 cm\(^{-1}\) is the R and P branched spectrum of HCl, that of 3230-3800 cm\(^{-1}\) is the R and P branched spectrum of H\(_2\)O and wave band of 1800-2000 cm\(^{-1}\) is the branched spectrum of CO [21-22]. Further, it can be seen that the intensity of the CO\(_2\) selective radiation peak is much higher than the heat radiation energy brought by the combustion temperature.
As for MTV agents, the main solid residues from MTV composition are MgF\textsubscript{2} (standard peak at 3286 cm\textsuperscript{-1}) and MgO (501 cm\textsuperscript{-1}), including the H\textsubscript{2}O (3365 cm\textsuperscript{-1}) adsorbed in the air. What’s more, little CO\textsubscript{2}
peak from air at 2390cm$^{-1}$ and CO peak can be observed. As shown from the figure 2, the main radiation energy of MTV agents depends on heat radiation rather than characteristic radiation. The heat radiation follows Planck's law, which makes the MTV agent's radiation energy of near-infrared much higher than the mid-to-far infrared band.

By comparing the combustion infrared spectra of AP/HTPB agent and MTV agent, it can be found that when the quality of the agent is low, the main radiation energy of AP/HTPB is provided by selective radiation such as CO$_2$, and the heat radiation energy is small. The opposite is true for MTV agents, whose radiation energy mainly depends on heat radiation. In view of this, AP/HTPB can be expected to improve the spectral distribution of traditional MTV agents when the mass is only 5g.

3.2. The radiation performance of AP/HTPB and MTV agents in each band against different mass and shell size

The infrared radiation spectrum of AP/HTPB and MTV agents in each band against different mass and shell size were shown in Fig.3. The curves of radiation intensity versus time of MTV and AP/HTPB compositions with a little amount were shown in Fig.4. The summary of the radiation intensity of compositions at each band and the mass burning rate are listed in Table 2.

It can be seen from Fig.3 that when the mass of the agent is 5g and the caliber is 22mm, the main radiation band of AP/HTPB is concentrated in the mid-infrared band, while the radiation energy of MTV is concentrated in the near-infrared band. When the dosage is increased to 40g and the caliber is increased to 40mm, the spectrum of MTV does not change much, but the near-infrared radiation energy of AP/HTPB agent increases significantly, and the radiation energy is more concentrated in the near-infrared band. As shown in Fig.4, the combustion of AP/HTPB agent fluctuates greatly, but the whole is relatively stable, while the radiation energy of MTV agent increases steadily as the burning time increases. This is because the AP/HTPB combustion products are all gas products, which have limited heating of the tube shell, while the MTV agent has more solid products, and the tube shell heats up significantly, which reversely accelerates the combustion rate of the agent.

It can be seen from Table 3 that with the increase of the tube shell diameter, the mass burning rate of MTV agent increased from 0.287 to 4.167g/s, while the mass burning rate of AP/HTPB agent increased from 0.258 to 2.920g/s. The reason why the burning rate of MTV agent increases faster is that the increase of the tube shell diameter will significantly increase the burning temperature of the agent, while the thermal conductivity of MTV is better for more metal content, thus the heat conduction is faster. In addition, as for AP/HTPB agents, the increase in mass and size makes the spectral distribution $\theta_{\alpha/\beta/\lambda}$ changed from 0.6:1.0:0.15 to 1.4:1.0:3. This is because the increase in combustion temperature makes the heat radiation energy of the agent greatly increase. According to Planck's law, the heat radiation distribution shifts to the shortwave direction as the temperature rises, which makes the near-infrared radiation of AP/HTPB agents increase far higher than the mid-infrared band. Although the characteristic radiation energy of CO$_2$ also increases with combustion temperature, the increase is much smaller than that in heat radiation energy. This also makes AP/HTPB higher in near-infrared radiation than mid-infrared in the case of high dose and large size. As for MTV agents, the radiant energy mainly relies on heat radiation, so the increase in combustion temperature has little effect on the distribution of MTV radiant energy.

Last but not least, the radiation energy of AP/HTPB is much lower than that of MTV agents. This is because AP/HTPB combustion products are all gases, and the radiation emissivity is about 0.2 much lower than that of MTV agents. As required to make up for the gap in radiation energy, some high-energy metal additives or burning rate catalyst would be considered to added. Finally, the radiation energy distribution of high-dose AP/HTPB is far from satisfactory, and cannot have higher mid-infrared radiation as predicted.
Figure 3  Infrared radiation spectrum of each pyrotechnic agent, the unit is spectrum radiation intensity, W/Sr/μm
Figure 4: The curve of the radiation intensity of each band of pyrotechnic powder versus time.
Table 2 Summary of the radiation intensity of compositions at each band and the mass burning rate

| Composition | Radiation intensity obtained by imaging spectrometer | Burning time | Mass burning rate |
|-------------|-----------------------------------------------------|--------------|------------------|
|             | \( \alpha(1.28-3 \mu m) \) | \( \beta(3-5 \mu m) \) | \( \lambda(8-14 \mu m) \) | \( \theta\alpha/\beta/\lambda \) | T/s | g/s |
| AP/HTPB-5g  | 18 | 30 | 5 | 0.6:1:0.15 | 19.4 | 0.258 |
| AP/HTPB-40g | 780 | 570 | 200 | 1.4:1:0.3 | 13.7 | 2.920 |
| MTV-5g      | 226 | 102 | 15 | 2.3:1:0.15 | 17.4 | 0.287 |
| MTV-40g     | 4850 | 2415 | 775 | 2.0:1:0.3 | 9.6 | 4.167 |

4. Conclusion

(1) The radiation spectrum distribution of MTV and AP/HTPB in each band is compared. The test results show that the radiation energy of AP/HTPB is much smaller than MTV because of the lower emissivity. When the mass is 5g and the shell size is 22mm, the radiation energy of AP/HTPB is concentrated in the mid-infrared band, and the \( \theta\alpha/\beta/\lambda \) is 0.6:1:0.15. When the mass is 40g and the shell size is 40mm, the radiation energy is more concentrated in near infrared band, the ratio \( \theta\alpha/\beta/\lambda \) changes to 0.6:1:0.15 for higher combustion temperature bringing more heat radiation. While, as for MTV agents whose energy relied on heat radiation, the radiation distribution changes little.

(2) Experimental results show that it is not advisable to rely solely on AP/HTPB to change the infrared spectral distribution. On the one hand, because the characteristic radiation increase of CO\(_2\) is much smaller than the thermal radiation, on the other hand, the emissivity of AP/HTPB is too low, and higher combustion temperature and burning speed are needed to make up for the insufficient radiation energy, which will also make the radiation spectrum shift to the shortwave direction.

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