Original Research Article

Binary Mixture Based on Epoxy for Spectrally Adapted Decoy Flare

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ARTICLE INFO

ABSTRACT

Pyrotechnic decoy flares are the most widely used passive countermeasures for heat-seeking missiles. The development of (photoconductive) InSb-detectors with cut-off wavelength>6 μm has allowed two-color detectors working in both short (α) (1.8-2.5 μm) and mid-wave (β) (3.5-4.8 μm) bands. Thus, it is possible to determine the sensitivity ratio and to discriminate against fake targets. An attempt was made to change the spectral distribution of MTV (Magnesium-Teflon-Viton) decoy flare compositions by adding another composition to modify spectral emission based on aluminum, hexamine, potassium nitrate and ammonium perchlorate. Aluminum emission at 1.5 μm due to Al_2O_3. Hexamine used as flame expanders due and to provide cooling of the flame to transform radiation from a spot location to a burning zone. In this study, theoretical and experimental comparisons were made between various spectrally adapted flame compositions based on epoxy as a binder and the MTE flare which represented by sample (4). The first composition was Mg/Teflon/Epoxy (MTE) with percentage (60-80)% and the second adapted compositions with percentage (20-40)%. The temperature of the flame and the time of burning were measured using an inframetric radiometer. The radiant emission was determined using a computer program. The results show that sample (1) which contains 20% of the adapted compositions produces high flame temperature (1300 °C) and the highest radiant emittance 6.6 $W/cm^2/\mu m$.

GRAPHICAL ABSTRACT
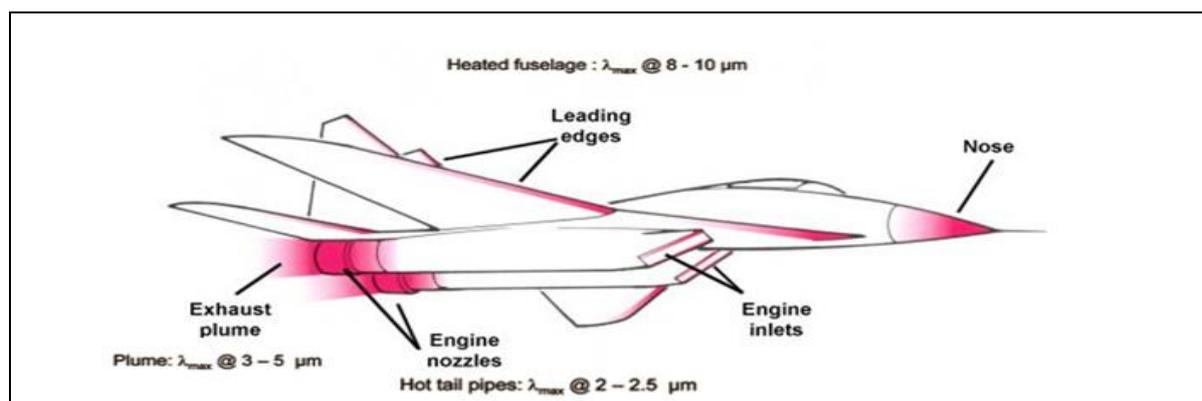
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Introduction

The Spectral Intensity distribution of the true target greatly deviates from the 3000 K black body. This is due to the plume emission in the 3-5 μm band and radiation in the 8-10 μm band due to the thermal radiation of the heated fuselage [1]. Figure 1 shows the main sources of radiation on fighter aircraft. Therefore, true targets are selective emitters with peak intensities in the 3-5 μm band. The intensity ratio Iθ (2-3) μm (3-5) μm for a true target equals values≤0.7, on the contrary, the intensity ratio for a 3000 K black body equals values≥1.3.

The advance of (photoconductive) InSb-Detectors with cut off wavelength>6 μm has enabled two-color detectors working in both short α (1.8-2.5) μm and mid-wave β (3.5-4.8) μm band. Accordingly, the determination of the intensity ratio and the discrimination of false targets are possible. Figure (2) displays the relative radiant intensity for classical MTV flares and a target signature. It can be seen that the Radiant Intensity distribution is different for MTV compared to the actual target signature. Whereas MTV yields ratios Iθ (2- 3) μm/ (3-5) μm =1.33, true targets exhibit ratios between 0.5≤Iθ 2-3 μm/3-5 μm≤0.8 depending on the type of engine. As this problem had been identified numerous attempts have been made to modify the spectral distribution of MTV based flares.

Figure 1. Radiation sources on fighter plane [2]
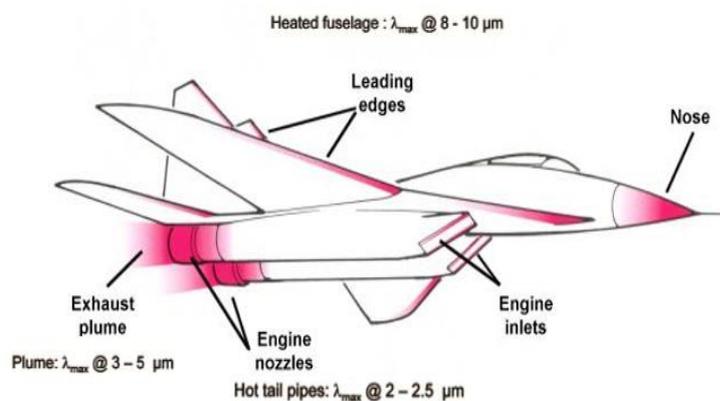
Figure 2. Relative radiant intensity for classical MTV flares and a target [3]
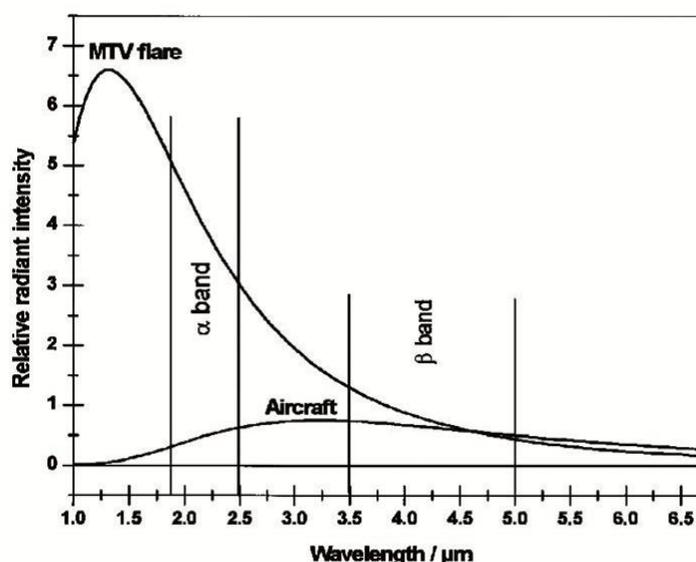
It has been stated that the black body behavior of burning magnesium/teflon flares derives from the formation of carbon black from combustion [3]. Since carbon black emissivity can be assumed to be close to unity, all attempts to render MTV's spectral distribution by adding modifiers must result in a decrease in total radiant intensity.

Main constituents of spectrally adapted decoy flares

Attempts to decoy two-color detectors operating in both short (α) (1.8-2.5) μm and mid-wave (β) (3.5-4.8) μm bands began with the use of partially oxidized carbonaceous fuels is combined with magnesium to prevent soot formation and generate large amounts of carbon dioxide that contribute to the radiant emission in the (β) band [4]. As an additional oxidizer, these compositions contain some Ammonium Perchlorate. The composition yield spectral ratio is Iθ 2-3 μm / 3-5 μm of ≈ 0.76-0.29. This is equal to the actual target signature. The main aim of this approach is the decrease of specific intensity due to the reduced heat of combustion since partially oxidized carbon materials will not yield the same heat output as the non-oxidized carbon backbone.

Another approach to adapt the spectral distribution of MTV compositions was made by the application of blending both MTV and a spectrally adapted composition containing (Boron, Aluminum, Hexamine, Potassium Nitrate and Ammonium Perchlorate). Both Aluminum and Boron upon combustion afford selective emitters such as BO, HBO_2 and Al_2O_3. Thus, a selective emission is obtained at 5μm due to HBO_2 and a band maximum at 1.5μm due to Al_2O_3 and 2.5μm due to BO, respectively [5]. The Intensity ratio Iθ (2-3 μm / 3-5 μm) is said to equal values ≈ 0.56. Application of Hexamine and its derivatives was known to function as flame expanders due to the evolution of Nitrogen gas [6]. Furthermore, cooling of the flame is provided to achieve an

appropriate spectral adaptation as well as a transition from a spot source to an area burning [7]. It was cited that spectral radiance of an MTV composition contains magnesium, PTFE, iron oxide, silicon and probably Viton. Radiometric measurements of the above composition have shown a superior Radiant Intensity in the α-band compared to classical MTV which gives rise to Iθ 2-3 μm/3-5 μm values beyond=1.5 μm [8]. In the present study, a theoretical and experimental comparison between different spectrally adapted flares based on epoxy as a binder instead of Viton was carried out. Radiant emittance has been controlled by manufacturing spectrally adapted flare using binder (epoxy) and second adapted compositions to obtain an adapted decoy flare with thermal signature more closely to the target will be protected. The Radiant intensity was calculated using a computer program.
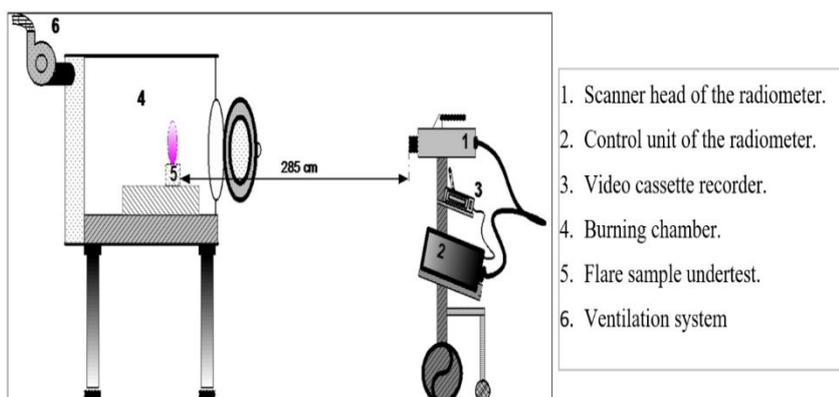
Experimental

Experimental setup

The experimental setup consists mainly of specially designed chamber, thermal imager, data acquisition system. The chamber, used for testing the pellets was specially designed and constructed for the ignition of high energetic pyrotechnic compositions. It is equipped with suction fans as well as a lock for human safety. The setup used for measurements is illustrated in Figure 3.
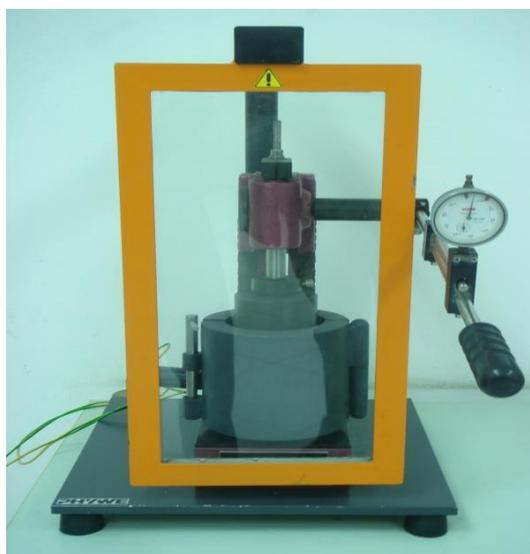
During pellet ignition, the radiometer has measured the flame temperature and burning time. The emittance against wavelength was calculated with MATLAB. The maximum mass could be loaded in this pellet was about 9 g including 1 g intermediate charge (0.5 g compositions, 0.5 g igniter). The chemical composition of the applied igniter was Mg 85%, KNO_3 10% and iditol 5% weight percentage. Then the compositions were pressed into pellet using hand press shown in Figure 4 for 3 seconds

at temperature 21 °C with 1 kN. The pellet was made of Aluminum Figure 5. The thermal imager and the accompanied devices for recording and processing were placed in front of the chamber at distance 285 cm. Each sample was measured and characterized for 3 trials.

Preparation procedures spectrally adapted decoy flare compositions

The calculated weight of metal and Teflon was mechanically mixed. Binder was dissolved on acetone then the binder liquor was added to the dry mixture. Granulations have been carried out after mixing with the binder.

Figure 3. Setup used for measurements

1. Scanner head of the radiometer.
2. Control unit of the radiometer.
3. Video cassette recorder.
4. Burning chamber.
5. Flare sample undertest.
6. Ventilation system

Figure 4. Hand press used in the experimentation

Figure 5. Metallic casing for decoy flares compositions (L=2.8 cm, Ø=2.8 cm)

A drying process of the granules was performed on a tray in the open air for a minimum of 4 hours then the compositions were dried in an oven at 37 °C for 3 days. Finally, the compositions were pressed into pellet using a hand press.

Samples compositions

All solid ingredients are characterized in Table 1 with their chemical formula density, grain size and physical appearance. To study the advanced decoy flares (spectrally adapted flares), two formulations were prepared as shown in Table 2. From these formulations, three samples based on Viton were prepared by using different percentages of such formulations as given in Table 3.

Table 1. Solid ingredients specifications

Filler	Chemical formula	Appearance	Density	Grain size	Solubility
Teflon	$[-C_2F_4-]_n$ n = 20000	Fine white powder.	0.5 kg/l	10%<2 μm 90%<20 μm	--
Magnesium Powder	Mg	Silvery white powder without any other admixtures.	0.5 ±0.05 kg/1	100% pass through sieve 75 μm 65% pass through sieve 45 μm	Insoluble admixture in HCl 0.2%, Humidity 0.1%
Aluminum	Al	Fine grey powder		100μm	Max. 0.5% Insoluble in HCl
Viton A	$[-C_5H_2F_8-]_n$	White pellets, crystalline form	1.85 g/cm^3	---	Completely soluble in acetone
Hexamine	$(CH_2)6N_4$	White crystalline powder	--	---	Max 1% insoluble in water
Potassium Nitrate	KNO_3	White powder	--	95 % < 0.15 mm	Clearly soluble in water

Table 2. Decoy flares compositions based on two formulations

1st formulation (MTE)		2nd formulation (Adapted composition)	
Components	%	Components	%
Magnesium	45%	Aluminum hexamine	20%
Teflon	45%	Potassium nitrate	10%
Epoxy	10%	Ammonium perchlorate	10%
Density gm/cm^3	0.169	Epoxy	50 %
		Density gm/cm^3	10%
			0.16

Table 3. Different adapted decoy flares compositions based on epoxy

Constituents	Sample SA1	Sample SA2	Sample SA3	Sample SA4
MTE	80%	70%	60%	0
Adapted composition	20%	30%	40%	100
Density gm/cm^3	0.187	0.16	0.177	0.169

MATLAB program for thermal signature assessment

The program was designed with MATLAB which is a high-level technical computing language. The radiant emittance could be determined either experimentally or theoretically. However, in this program, the radiant emittance was determined theoretically using a computer program taking into account that there is no atmospheric absorption and the emissivity is similar to the black body.

Program description

The program simulated the IR signature of decoy flare and provides the maximum radiant emittance as a function of wavelength. The adapted model was based on plank's law, Equation 3.1.

$$W_\lambda = \frac{2\pi hc^2}{\lambda^5} \frac{1}{e^{hc/\lambda kT} - 1} \qquad (2.1)$$

Where
W_λ: Radiant Emittance (W cm^{-2}/μm^{-1})

λ: Wavelength (μm)
h: Planck's constant (6.6260755 ± 0.0000040W × 10^{-34}. s^2)
T: Absolute temperature (K)
C: Velocity of light (2.99792458 ×10^{10} cm/s^{-1})
K: Boltzmann constant (1.380658 ± 0.000012 ×10^{-23} W. s/K^{-1})

The model inputs were the measured flame temperature of different pyrotechnics decoy flares and it figure out the IR Signature for each composition for comparison.

Flowchart and theory of operation

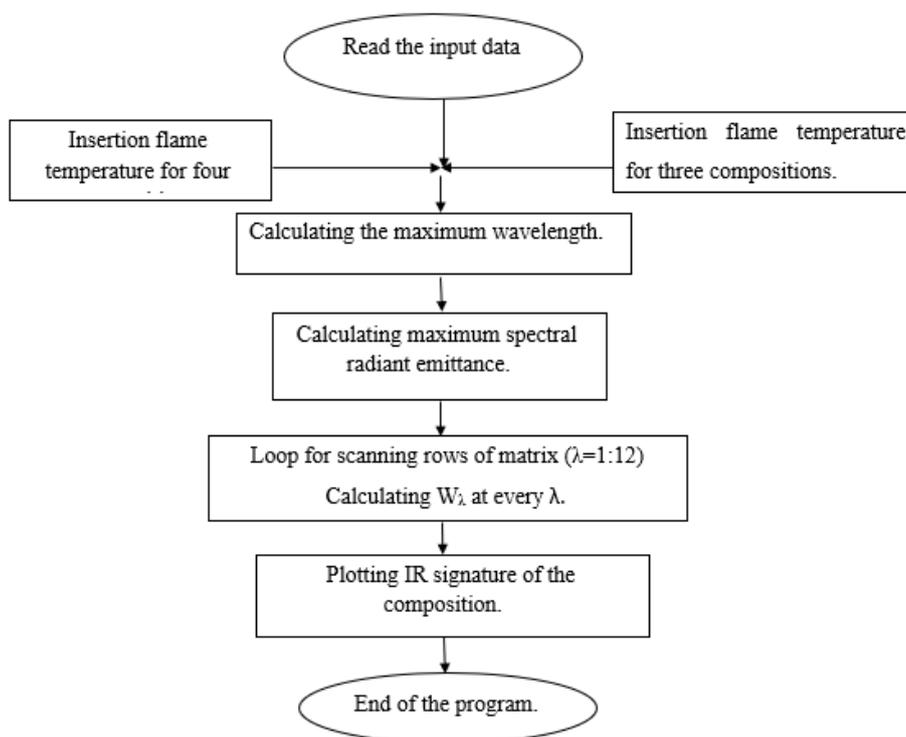The determination of maximum wavelength according to the Wien displacement law,

$$\lambda_{max} = 2897.756 \, T^{-1} \qquad (2.2)$$

Where
λ: Wavelength (μm)
T: Absolute temperature (K)
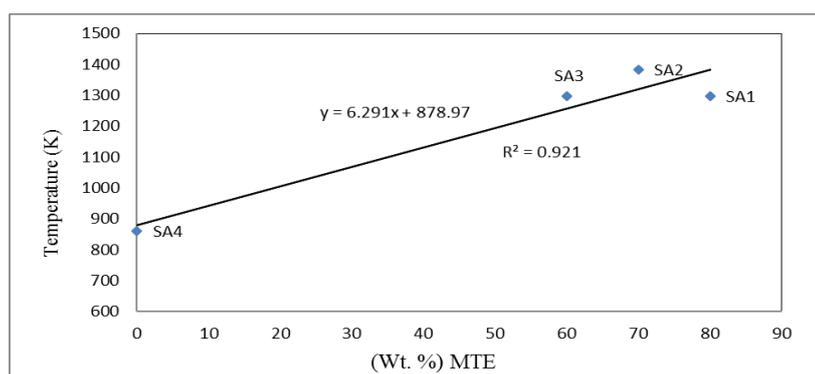The flowchart of the model can be divided into main parts as follows:

Result and discussion

Spectrally adapted flares using epoxy as a binder were prepared by mixing Mg/Teflon/Epoxy and the adapted composition. Four samples of spectrally adapted flares were prepared using different weight percentages of MTE (composition 1) and the adapted flare (composition 2). Sample (1) contains 80% MTE + 20% adapted composition, while sample (2) contains 70% MTE + 30% adapted composition. Sample (3) contains 60% MTE+ 40% adapted compositions and sample (4) contains 100% adapted compositions. An intermediate charge was used (0.5 g igniter + 0.5 g composition) to enhance the ignition of the compositions similar to real decoy flare. On ignition, the flame temperature and burning time are measured using the IR radiometer and the spectral radiant was calculated using a mathematical model. It is to be noted here that the temperature range during measurements was 1000-2000 °C [7].

From Figure 6, it is notable that sample (2) gives the highest flame temperature, (1382 K). This is the same result as we obtained with spectrally adapted flare using Viton as a binder. Also, from the Figure 6 it is obvious that the lowest flame temperature was obtained from the sample (4). This may be due to the zero percentage of MTV composition in this sample as MTE compositions are more energetic than the adapted compositions. However, sample (1) gave flame temperature less than sample (2) which is not expected. This may be attributed to the short burning time obtained.

The maximum radiant emittance was obtained with sample (2) was 6.6 W/cm^2/μm as shown in figure (6) which is expected. Also, from Figure 7 the maximum wavelength was obtained with sample (2), 2.096 μm. The adapted composition possesses low spectral radiant emittance (0.628 W/cm^2/μm) at a long wavelength of (3.365 μm). These results demonstrate that the wavelength shifts towards longer wavelengths than in the case of the MTV compositions. The bandwidth in the case of MTV decoy flare is approximately constant at (2.3 μm) and the bandwidth in case of the spectrally adapted flares are (2.0-3.36) μm this demonstrates the ability of spectrally adapted flares using epoxy as a binder to counter modern guided missile

From Figure 8 we can see that the burning time increases as the weight % of MTE decreases. Sample (1) which possesses a high percentage of MTE, has a high burning rate this is because of the higher ignitability of MTE composition. From this result, we can estimate the optimum weight percentage of MTE to the adapted compositions that produce the radiant emittance at a selective wavelength to obtain a thermal signature similar to the aircraft. This is useful in designing decoy flares against modern IR guided missiles. It is noted that epoxy provides easy mixing and processing better than Viton. It was experimentally noticed that in case of using epoxy, the dissolving time is lower than Viton, also Viton requires heating during dissolving. Granulation of the paste and pressing of the grain when using epoxy is easier and required little time than Viton.

Figure 6. Flame temperature for compositions based on Epoxy binder

Figure 7. Radiant emittance for compositions based on Epoxy binder
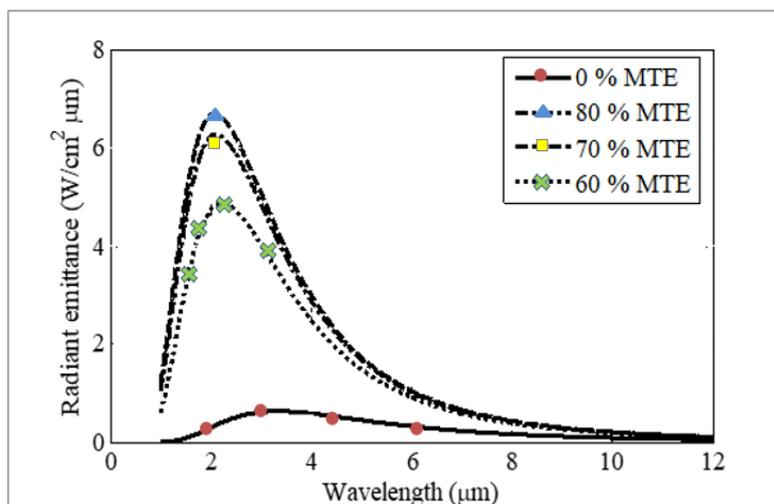
Figure 8. Burning time for different compositions based on Epoxy binder
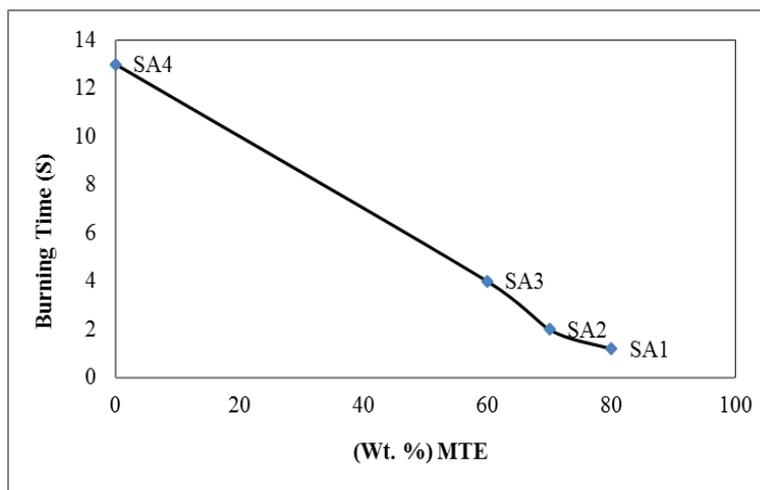
Conclusion

Spectrally adapted flares are different from MTV flares as MTV flares counter the first generation of IR seeker which depends on the highest flame temperature. Spectrally adapted flares can counter modern dual seeker because it can spread over a wider band than MTV flares also, spectrally adapted decoy flares give higher spectral radiant intensity than MTV decoy flares.

Sample (1) that contains 20% of the adapted compositions and 80% MTE produces high flame temperature (1300 °C) and the highest radiant emittance (6.6 W/cm^2/μm) and this value decreases - by reduction of MTE and increasing the adapted composition - to low emittance (0.628 W/cm^2/μm) obtained by sample (4) which contain 100% of the adapted compositions. A new approach has been concluded on designing spectrally adapted decoy flares based on epoxy as a binder, as the composition is easier during mixing. The burning time increases as the weight percentage of MTE decreases which controls the time of the aircraft protection against IR seekers.

Acknowledgment

Disclosure statement

No potential conflict of interest was reported by the author.

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