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Novel Method for Investigation the Mass of Different Pyrotechnics MTV Compositions for Rocket Motor Igniter

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Abstract

Pyrotechnic compositions based on magnesium, teflon, (MTV) have many desirable properties for use as igniters for solid rocket propellant. Safety and reliability include low hygroscopicity, easier ignitability, good grain fabrication, stability during burning, and low production costs. This study produces a novel method for designing MTV igniters based on the thermochemical properties of the compositions. A theoretical study has been carried out using the NASA CEA program for modelling the combustion properties for different MTV compositions with different fuel-to-oxidizer ratios (F/O), which vary between 0.18 and 3.75. The study investigates the effect of the (F/O) ratio on the heat of combustion, which decreases with increasing the (F/O) ratio. The output values of the NASA CEA program are the main parameter for the novel method to determine the mass of the MTV igniter for the required rocket propellant. The study concluded that as the F/O ratio increases, the required mass of the igniter increases.

Keywords:. Igniter, pyrotechnic, MTV.

1. Introduction

The chemical composition which contain both fuel and oxidizer coated with binder and different additives to give special effects. The fuel is usually powdered elements, either metals (Mg, B, and Al) or nonmetals (C), all of which, when oxidized, provide heat energy [1, 2]. Pyrotechnic composition which consist of metal and teflon pyrolants, as magnesium and flourel , are the largest value of energetic materials that emitted the highest temperature, which is very important in the area of countermeasures and propulsion systems [3]. The pyrotechnic compositions based on metal and fluorocarbon with binder are the main compositions for the payload on different military applications as countermeasures like decoy flares for fighter planes, igniters, and other different applications [4]. Pyrotechnic compositions in powder grains are usually mixed then processed inside pellets. Binder usually used for protection to more reactive metals from environmental atmosphere. Also, it modifies the pyrotechnic performance by changing burning rate [5]. The main igniter ingredient is aluminum with or magnesium which plays the main metal fuels and also polymer of (carbon monofluoride) (PMF) or poly (tetrafluoroethylene) (PTFE) as fuels and oxidizer also fluoroelastomer binder like Viton A [6]. The performance of metal-fluorocarbon compositions in different applications like igniters is strongly connected with the heat combustion and the flame size, which are the main factors for ignition ability for the solid rocket propellant [7]. The advantages of using MTV igniters for solid rocket propellants are the high energy output, safety, reliability, easy ignition, low hygroscopicity, easy and adjustable burning rate, high stability during storage conditions, and low effect of temperature and pressure on burning rate [9]. The traditional pyrotechnic compositions have been replaced by MTV compositions as they have solid and liquid particles and many considerable species of combustion products, which enhance the ability for the ignition of solid propellant [10]. The hot species product enhances the reactivity of the ignition efficiency and makes the MTV igniter a better candidate for use in base-bleed rocket systems, which are very difficult to ignite [11–13]. The performance of different formulations of MTV has been carried out in different research papers [14–15]. It has been shown

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that the performance of the igniter depends on compositions and the physical form of the igniters, and different studies on MTV compositions concerned the ballistic properties, which are the main parameters for rocket motors containing new formulations [16–17]. Researchers proved that the performance parameter and the sensitivity of the MTV igniter depend mainly on physical and chemical parameters like heat of combustion, chemical compositions, percentage of binder, and different operating environment conditions [18].

Figure (1) shows the effect of different percentages of viton on the physical form of MTV compositions.

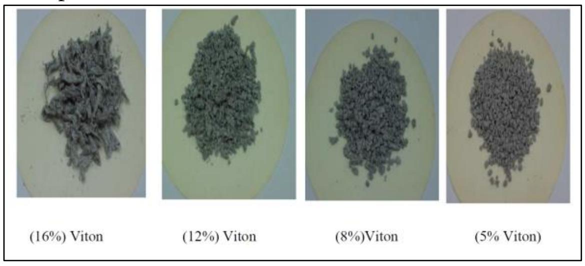

Figure (1) effect of different percentage of Viton on the physical form of MTV compositions.

The aim of the study is to develop a theoretical method for performance prediction of different solid igniter compositions like MTV, which is used for solid rocket propellant. This method saves a lot of time and money in laboratory experiments that are used to determine the most appropriate mixture for safe and reliable combustion of rocket propellant. For this goal, different thermochemical calculations were carried out for different percentages of fuel to oxidizer ratio (F/O) for Mg/Teflon/Viton (MTV) compositions, which depend mainly on the enthalpy of formations and chemical formula. MTV compositions were investigated the effect of fuel to oxidizer ratio on different parameters as combustion characteristics (combustion heat). Different values of Mg with respect to Teflon give us the ability for choosing the more candidate compositions for MTV igniters that produce the required amount of heat for suitable and safe combustion with an accurate mass charge. This study used the recommended output values (Qv) with the most suitable methods for calculating the optimum igniter mass charge for the designed rocket motor

2. Ignition charge mass equations

The calculation methods for the igniter charge mass are very difficult, and it is too hard to investigate the suitable analytical process for determining the mass of the igniter. The main research objective is to research the effect of changing the F/O ratio percentage on the required mass of the MTV igniter for complete combustion. Reference [21] provides a simple way for calculating the igniter charge mass depending on the free volume

$$Mg = 0.016944(Vc)^{0.7} \quad (1)$$

Mg is the mass of the igniter. (gm)

VC the free volume of the combustion chamber.

Another relation as shown in equation (2) was carried out by Barrere, Marcel, et al [22]. Equation (2) represent different parameter as the following:

$$mg = \frac{1}{1-\varepsilon} + \left(\frac{P_I V_I}{\frac{R_U}{M} T_I} \right) \quad (2)$$

V_I combustion chamber free volume.

P_I the ignition pressures.

T_I ignition temperature.

ε solid fraction for the combustion gaseous phase.

R universal constant of gase, J/(mol-K).

T_I temperature of the combusted ignition charge K.

PI The pressure at ignition, N/m^2.

The final equation is the Brayan-Lawrence equation [23]. This relation, as shown in equation (3), depends on the ignition energy and the propellant characteristics, including dimensions and the ignition surface area

$$Q = \left[Q_C A_S \quad \left(\frac{L_G \ A_S \sqrt{4\pi} A_P}{2a} \right)^{0.59} \right]^{1.06} \quad (3)$$

Q ignition energy cal.

A_S burning surface area, cm^2.

Q_C experimental ignition energy, cal/cm^2.

L_G grain length, cm.

A_P port cross-sectional area, cm^2.

The mass of the igniter has been calculated by using the output result (Q) obtained from equation (3) as shown in equation (4).

$$Q = M_I \Delta H_I \quad (4)$$

M_I igniter mass gm.

ΔH_I heat of combustion of igniter material, cal/gm. In this study the values of ΔH_I have been Calculated by NASA (CEA) code which was used for the calculation of the igniter mass

3-Thermo chemical calculation.

Many thermodynamic computer codes used for modelling the combustion parameter for explosives (detonation and shock wace) and pyrotechnics. The CEA NASA code was used for this study because of its significantly greater data base and its proven ability with pyrotechnic compositions. Ignoring the influence of the air on the combustion of the MTV compositions and using thermo chemical calculation resulted from (CEA) NASA Code which calculate the combustion characteristics based on the chemical formula of the elements, density, and heat of formation.

4. Combustion characteristics for different MTV compositions with different fuel to oxidizer ratio.

Thermo chemical calculations were carried out for different percentage of Fuel/oxidizer MTV compositions (table1). Magnesium and Teflon contents were changed from 15 to 75% and from 20 to 80% respectively. The lower value of Viton content is 5 % and it maintains constant and this value are suitable for pellet consolidation, whereas the higher values are appropriate for extrusion and injection molding. These different Compositions were studied to determine the effects of fuel to oxidizer ratio on different output values mainly Heat of combustion which can be used to determine the mass charge of the MTV igniter.

Table (1) Different percentage of Fuel/oxidizer MTV compositions

Comp.	Comp. 1	Comp 2	Comp 3	Comp 4	Comp5
Mg	15	30	45	60	75
Teflon	80	65	50	35	20
Viton	5	5	5	5	5
F/O ratio	0.16	0.42	0.8	1.5	3

The heats of formation of Teflon and Viton used in this study were - 817.5 kJ/mole and - 1394.0 kJ/mole respectively [19-20]. The majority of the computer calculations were conducted assuming adiabatic combustion.

5 Results and Discussion

5.1 Combustion characteristics for different MTV compositions

The burning pressure range in the calculations were carried out at applied pressure nearly 1 bar. The pressure was chosen to simulate the firing conditions for normally ground level launching missile. Figure (2) show the distribution of the calculated heat of combustions which shows the effect of the change of fuel to oxidizer ratio on the resulted heat of combustion for the selected MTV compositions.

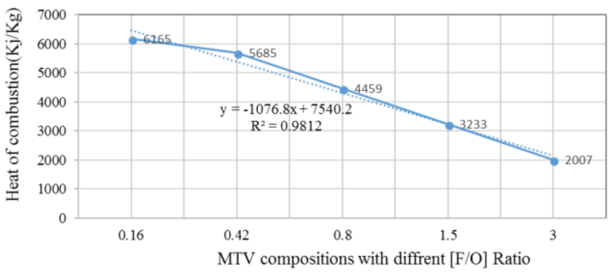

Figure (2) effect of change of fuel to oxidizer ratio on the heat of combustion for different MTV compositions.

The heat of combustion decreases with increasing the (F/O) ratio this due to the more percentage of Mg at the expense of Teflon which have higher heat of formation.

The combustion product of MTV compositions has been studied and showed the following conclusion:

- Increases of the percentage of MgF as (F/O) ratio increases and the values rise from .04 to .0248 and decreases in the comp (5) due to formation of MgF_2 (L).
- Increases of the percentage of Mg(s) as (F/O) ratio increases and the values rise from .014 to 0.67.
- Formation of unburned carbon during combustion of comp (4) and comp (5), this due to the compositions became a fuel rich composition and the oxidizer can't oxidize all fuels.

Figure (3) and figure (4) shows the Mg and MgF combustion product behavior with increasing the percentage of (F/O) ratio.

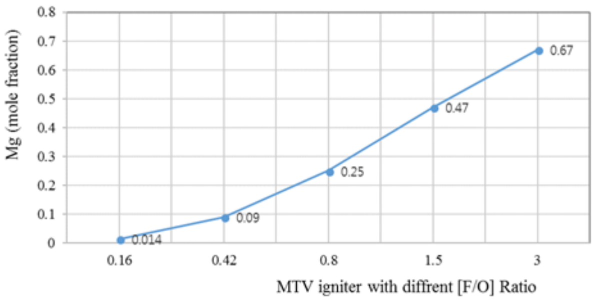

Figure (3) effect of change of fuel to oxidizer ratio on the Mg resulted from combustion process.

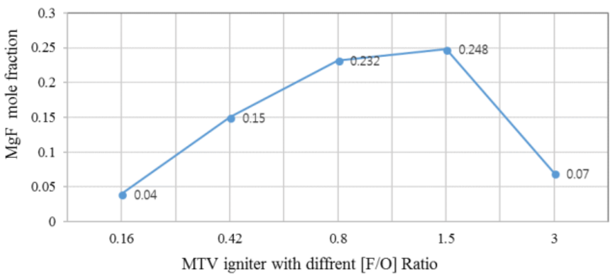

Figure (4) effect of change of fuel to oxidizer ratio on the MgF resulted from combustion process.

5.2 Mass of the different MTV igniter.

According to the three previous equation which can be used for calculating the igniter mass charge and according to reference [24] the Brayan–Lawrence equation is more promising for this study as it can be used after thermochemical calculations which can be carried out using NASA (CEA) code. For certain XEH designed tested rocket motor using aluminized composite propellant the required calculated energy (Q) for complete combustion according to Brayan–Lawrence equation is 16036 cal. Figure (5) shows the mass of the different MTV igniter with different (f/O) ratio according to the resulted heat of combustion calculated by NASA (CEA) code.

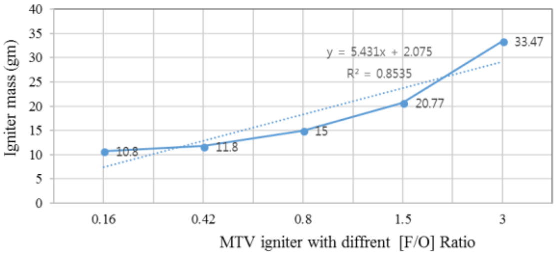

Figure (5) effect of change of fuel to oxidizer ratio on the mass of MTV igniter.

The figure also shows that as the values of the (f/O) ratio increases the mass of the MTV igniter required for complete ignitions to XEH rocket motor increases due to the higher percentage of fuel compositions which mean that the compositions needs more amount of oxidizer and the higher percentage of fuel can't be oxidized completely. New relation has been obtained between the (f/O) ratio and the mass of the MTV igniter which can be used for predictions the effect of the ingredient percentage on the igniter designed.

5.3 Novel methods for estimation MTV igniter mass

Novel relation has been obtained between the heat of the combustion for the selected compositions and the mass of the MTV igniter charge as shown in figure (6). It has been cleared that as the heat of combustion increases, the mass of the igniter decreases and this will be a good selection for the designer of the rocket motor systems. This conclusion lead to the high energy compositions should be the more favorable MTV igniter during design rocket propellant systems.

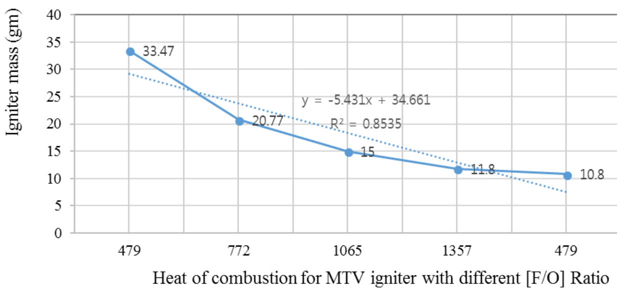

Figure (6) effect of change of fuel to oxidizer ratio on the mass of MTV igniter.

6. Conclusion

The novel method which depends on the heat of combustions resulted from NASA (CEA) code is a good tool for predicting the mass of the MTV igniter used for rocket propellant systems. Brayan–Lawrence equation is more candidate equations suitable for applications on this method as it depends mainly on the heat of combustion of MTV igniter. The resulted novel relations obtained between heat of combustions for different MTV igniters compositions and the mass of the MTV igniter can be studied to be used with different types of igniter as Metal/KNO3 in the future work.

. Increasing the (F/O) ratio for different MTV composition decrease the values of the heat of combustions and increasing the mass charge of the MTV igniter. The undesirable effect of the high MTV igniter mass contains high percentage of Mg not limited to large volume required on the rocket propulsion systems but also on the short storage period resulted. Application of the experimental result of the MTV igniter compositions can be one field for validation MTV igniter mass.

7. Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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