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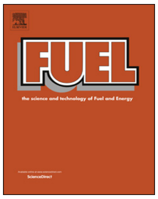

Full Length Article

Highly energetic nitramines: A novel platonizing agent for double-base propellants with superior combustion characteristics

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ABSTRACT

The burning rate-pressure relation of solid propellant is an exponential relation; this is means catastrophic combustion process in case of sudden increase in operating pressure. This study reports on novel approach to minimize the dependence of burning rate on combustion pressure using highly energetic nitramines (RDX). Nitramine-based double base propellants with RDX content up to 20 wt% were manufactured by solventless extrusion technology. The impact of RDX content on burning rate, specific impulse, exhaust velocity, and thrust were evaluated using small-scale ballistic evaluation rocket motor. Specific impulse (Is) was enhanced by 20%. The action burning time (t_b) was increased by 14%. The total thrust impulse (IFT) was significantly improved by 22%. One of the main outcomes of this study is that burning rate pressure exponent (n) was decreased significantly from 0.35 to 0.05. This novel ballistic performance finding means minimal change in burning rate with pressure variation. These findings confirmed that RDX has a dual function as energetic filler and platonizing agent. RDX blowing effect could alter the combustion mechanism by pushing the luminous flame from the burning surface. Furthermore, RDX decomposition can strengthen the platonization action. This is the first time ever to report on burning rate platonization using RDX. It can be concluded that many advantages have been achieved with one shot.

1. Introduction

Double base (DB) propellants consist mainly of high molecular weight nitrocellulose (NC) plasticized or gelatinized with liquid nitrate esters mainly nitroglycerine (NG); they are best known as smokeless propellants [1]. In fact NC and NG bring together carbon, hydrogen, and oxygen necessary for the exothermic combustion reaction [2]. The oxidizing and reducing elements which are involved in the release of energy through combustion are combined in the same molecule; they are known as homogenous propellants [3]. DB propellants are candidate for tactical missile propulsion as they can offer many advantages including [4–7]:

- Little or no solid particles in the gas jet.
- Good mechanical properties.
- High chemical and thermal stability.
- Low sensitivity to propellant temperature.
- Good aging capabilities, particularly under humid conditions.

However the burning rate of DB propellant is highly dependent on the operating pressure. The burning rate-pressure is an exponential relation as represented by Eq. (1).

$$r= aP^n \tag{1}$$

where: a is the burning rate constant, p is the operating pressure, and n is the pressure exponent [8].

Eq. (1) confirms the fact that any minimal change in operating pressure will result in a dramatic increase in burning rate. This means catastrophic combustion process which might lead to rocket motor explosion. NC is the main energetic constituent of DB propellants [6]. The pressure exponent (n) value should be as small as possible (< 0.7) to minimize the sensitivity of burning rate to operating pressure. One of the main features of NC combustion characteristics is that it combust with the generation of large quantity of CHO free radicals [9]. That is why NC is one of the key factors to ensure burning rate modification in smokeless propellants. The inclusion of small quantities of various inorganic lead salts in DB propellants can result in so called plateau or mesa burning over specified region of operating pressure (Fig. 1).

Catalyzed DB propellants can demonstrate an increase in burning

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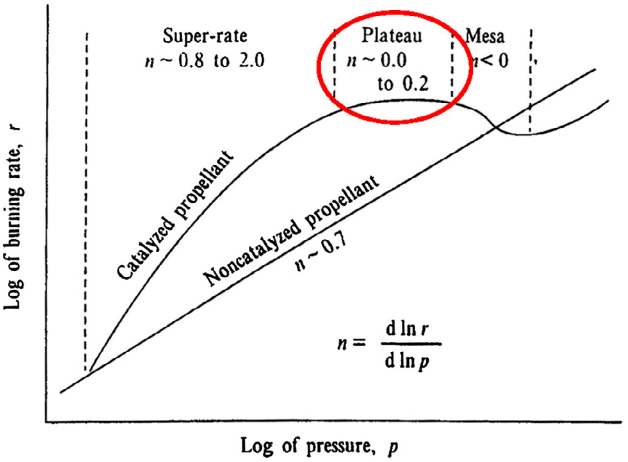

Fig. 1. Burning rate – pressure relation for non-catalyzed and catalyzed DB propellants [10].

rate with pressure at low pressure values. This behavior is followed by plateau burning region, where the burning rate remains almost independent of pressure variation. Platonized region is characterized with n value ranging from 0: 0.2. The post-plateau region is similar to that of un-catalyzed DB propellants [11]. It is clearly apparent that the magnitude of n is one of the most important factors for controlled combustion behavior and the suitability of DB propellants for propulsion systems [12].

The combustion wave can have a significant impact on DB propellant platonization. Energetic constituents that can self-decompose with the release massive free radicals as well as inert gases have the potential to minimize the burning rate dependence on operating pressure [2]. It is widely accepted that the combustion wave of DB propellant consists of five distinctive zones; each zone is associated with specific chemical reaction as demonstrated in Fig. 2.

1.1. Heat conduction zone

No chemical reactions associated with this zone. The thermal effect provided by heat conduction from the burning surface causes temperature increase from the initial temperature T_o to the onset decomposition temperature T_u [14].

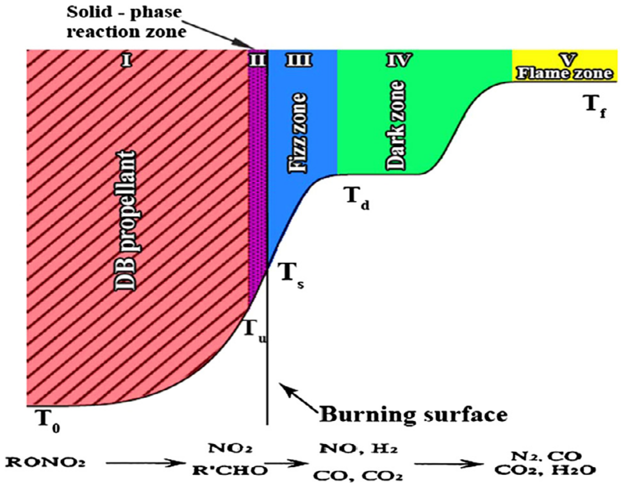

Fig. 2. Combustions zones of DB propellants with associated chemical reactions [13].

1.2. Solid phase reaction zone

The solid phase reaction zone is a very thin layer with temperature equal to the burning surface temperature T_s. The overall reactions in this zone are exothermic degradation.

1.3. Fizz zone

This zone is just above the burning surface where a series of degradation reactions occurs very rapidly in the early stages of the gas phase reaction zone.

1.4. Dark zone

This zone is characterized with very slow oxidation reactions between the products.

1.5. Flame zone

This zone is characterized with high flame temperature where final combustion products are formed, and the combustion products reach the thermal equilibrium state.

Energetic heterocyclic nitramine (RDX) could be an ideal energetic filler for DB propellants; it can offer potential characteristics including [15]:

- High thermal stability with decomposition temperature 213 °C
- High enthalpy of formation +318 kJ/kg
- High heat of combustion 5.647 kJ/kg
- High volume of gaseous products 903 L/kg

All these features can inherit RDX a vital role for the development of DB propellants. Therefore RDX can significantly enhance the combustion characteristics in terms of specific impulse (thrust per unit weight of effective propellant), as well as burning rate. RDX can act as a blowing agent generating large amount of inert gasses pushing the luminous flame from the burning surface. Therefore it can minimize the sensitivity of burning rate to combustion pressure [16].

In this study, MDB formulations based on RDX as energetic filler were developed by solventless extrusion technique. The impact of RDX content on combustion characteristics particularly burning rate, specific impulse, exhaust velocity, and thrust were evaluated using small-scale ballistic evaluation test motor; which has been established as the most representative testing mean [17,18]. RDX demonstrated a dual effect as energetic filler and as a platonizing agent. It offered enhanced the specific impulse and action burning time by 20% and 14% respectively. Therefore, the total thrust impulse was significantly improved by 22%. Furthermore, RDX offered novel platonized burning rate with pressure exponent (n) value of 0.05. This is the first time ever to report on platonization of burning rate using RDX.

2. Manufacture of DB propellants

The manufacture technology should emphasize mixing of different ingredients to molecular level, good homogenization, high density, as well as dimensional stability of final product [6]. Solventless extrusion technique can fulfill these requirements. The production technology includes different main stages including [19]:

- Mixing of different ingredients to insure homogenization.
- Rolling phases to remove water and insure gelatinization by dual effect of pressure and heat.
- Screw extrusion with variable feeding system under controlled temperature and pressure to obtain the final shape.

Fig. 3 is a schematic of solventless extrusion technology. Further