Study of The Potency of Reducing Smoke on Composite Propellant with High Specific Impulse

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Abstract— Composite propellant formulation is important to determine of rocket performance. The composite propellant consists of oxidizer, fuel, and binder. The widely utilized composite propellant is composed of Ammonium Perchlorate (AP) that serves as the oxidizer, hydroxyl-terminated polybutadiene (HTPB) that functions as the binder and fuel, and aluminium powder that serves as the fuel. Besides being famous for their superior performance and low manufacturing costs, composite solid propellants containing AP and HTPB have the potential to be poisonous and detrimental to the environment. When AP-based composite propellants burn, they typically generate white smoke. Perchlorate contamination has become a growing concern in a number of countries throughout the world. The research conducted is to find the material and composition which can reduce HCl gas as a result as combustion with high specific impulse. The research uses descriptive-analytic method, in which data was collected from literature studies. The data shows that the composition which AP include in it still have high of percentage mol HCl. The composition without AP shows the best result on percentage of mol HCl, the material of this composition is 2,2,2-trinitroethyl-formate (TNEF), Ammonium dinitramide (ADN). CL20 also show good result even combination with Ammonium Perchlorate (AP), although the number of percentages is not 0% but still below compared with AP+RDX+HTPB or AP+Mg+HTPB. The best of specific impulse was obtained by composition of ADN+ETN+HTPB. This means, decrease hazardous in the atmosphere can be done without reducing the performance of propellant.

Keywords— Composite propellant, minimum smoke, HCl, high specific impulse.

I. INTRODUCTION

The term solid composite propellants refer to elastomers that are densely packed. They are commonly used as energetic materials in military ordnance and rockets, as well as for commercial applications like gas generation [1]. An oxidizer, fuel, and binder make up a solid composite propellant. Oxidizers are the essential components that produce much energy when they burn. Because of its excellent qualities, such as compatibility with other propellant ingredients, and availability, performance one of the most frequently utilized AP outperforms the oxidizer list [2]. Metal fuels like aluminium and boron are commonly used in propellant formulations [3][4]. Among the most important metal additives, aluminium can be utilized in a broad range of solid propellants as small spherical particles (5–60 m). Aluminium particles make up 14–20 percent of the weight of most propellants. The heat and temperature of combustion, the specific impulse, and propellant density are all increased when metal fuel is added. Binder materials are typically used as a fuel that is oxidized during combustion. In other words, HTPB, CTPB, and NC are the most popularly used binders. GAP is sometimes functioned as an energetic binder, boosting the propellant's energy density and performance. Recently, the use of HTPB has been growing because it allows for higher solid fractions (total 88–90% AP and Al) and great physical properties [5][6].

Ammonium Perchlorate (AP) functions as an oxidizer, aluminium powder serves as a fuel source, and Hydroxyl-terminated Polybutadiene (HTPB) works as a binding agent. When AP-based composite propellants burn, they tend to generate white smoke. This is due to the fact that one of the combustion products, HCl, causes moisture in the atmosphere to condense, leading to formation of fog or mist [2]. Given such excellent performance characteristics and minimal cost of production, composite solid propellants built from AP and HTPB are relatively popular. Nonetheless, they have a poor track record in terms of toxicity and impact on the environment. Contamination with perchlorate is becoming a growing concern in many countries worldwide [7][8]. Perchlorate can affect thyroid gland function at high concentrations. A significant amount of Hydrochloric acid (HCl) is generated during the burning of AP, but this does not affect thyroid activity in humans. To ensure the safety of the team and ground handling workers, prospective propellants should not exhibit high dangers. There would be significant reductions in environmental contamination, spacecraft contamination, toxicity, and operational complexity due to the use of green propellant formulations (which do not contain chlorine) [9].

The rocket industry expects launchers to be reliable, more stable, faster, and capable of carrying the maximum payload possible (operational envelope). In order to minimize the chances of a negative oxygen balance and detonation, new propellants must include optimized ignition and combustion time rates. As a result, raising the specific impulse of existing propellant formulations is highly desirable. High-energy, low-signature solid propellants, or "smokeless," are among the most popular areas of studies in this field. The use of these propellants eliminates the potential for the missiles' positions being revealed during the firing process.

II. METHOD

The literature review method was used to obtain data, by using the keywords composite propellant research, and the criteria for potential smokeless material, the data obtained in the form of the results of the development material to produce minimum smoke for propellant.

There have many publications related to material of smokeless propellant. From these publications we can see the parameter to measure the smoke in propellant. HCl is the main component to be measured.

III. RESULTS AND DISCUSSION

From the data obtained, the research of development material to produce minimum smoke in propellant can be summarized as follows:

Table 1: *Summary of research minimum smoke propellant*

Author	Material	Result
Elghany *et al.*, 2018 [9]	TNEF + HTPB	Produce 0% HCl compared to AP+HTPB which produce 15.2% HCl
Youssef *et al.*, 2019 [11]	RDX + AP + HTPB	5.53% mol HCl
	Mg + AP + HTPB	5.49% mol HCl
Yoo *et al.*, 2010 [12]	HMX + RDX + K_2SO_4	22% IR irradiance rate
	HNW + RDX + K_2SO_4	66,68% IR irradiance rate
Menke *et al.*, 2002 [13]	AP + CL20 + GAP	Produce 3.7 mol % HCl
Cican *et al.*, 2017 [14]	ADN + GAP	Produce 0% HCl compared to AP+Al+HTPB
	EDN + ETN + HTPB	

From the table 1, in recent years there is some research focus on determine best composition of to reduce HCl gas. HCl gas produced during the burning process of Ammonium Perchlorate (AP) in propellant. One of the most commonly used oxidizers is ammonium perchlorate, which has a more secure and solid form of perchloric acid than its chlorate counterparts [10]. During the burning process namely combustion, ammonium perchlorate decomposes as shown by the equation below.

$$2NH_4ClO_4 \rightarrow N_2 + 3H_2O + 2HCl + 5/2O_2$$

From the above equation, HCl is one of the combustion products from AP beside N_2, H_2O, and O_2. Thus, during the combustion of the propellant, a large volume of HCl gas and other chlorine compounds are emitted into the exhaust plume.

These by-products of propellant fuel combustion generate a severe white smoke in the atmosphere due to the moisture in the air. When exposed to high levels of moisture, exhaust gases become extremely caustic and poisonous. Moreover, semi-opaque clouds are formed. As a result, there is a formation of "acid rain" and the ozone layer is depleted [11].

Subsitute Ammonium Perchlorate (AP) with other material which can reduce HCl gas is the main purpose of research nowadays.

Beside to decrease hazardous in the atmosphere, the purpose is to avoid detection by opponent. Avoiding detection by smoke can be done by adding potassium to the propellant formulation.

Potassium, namely the oxidation of CO and H2, is added to prevent afterburning. Due to the high potassium content of solid propellants, K_2CO_3 is formed during propellant combustion in a rocket engine. Additionally, K_2CO_3 in the plume could be in a form of a noticeable smoke from solid particles generally categorized as a primary smoke. From the table 1, addition of potassium was added by Yoo *et al*., (2010) which use K_2SO_4.

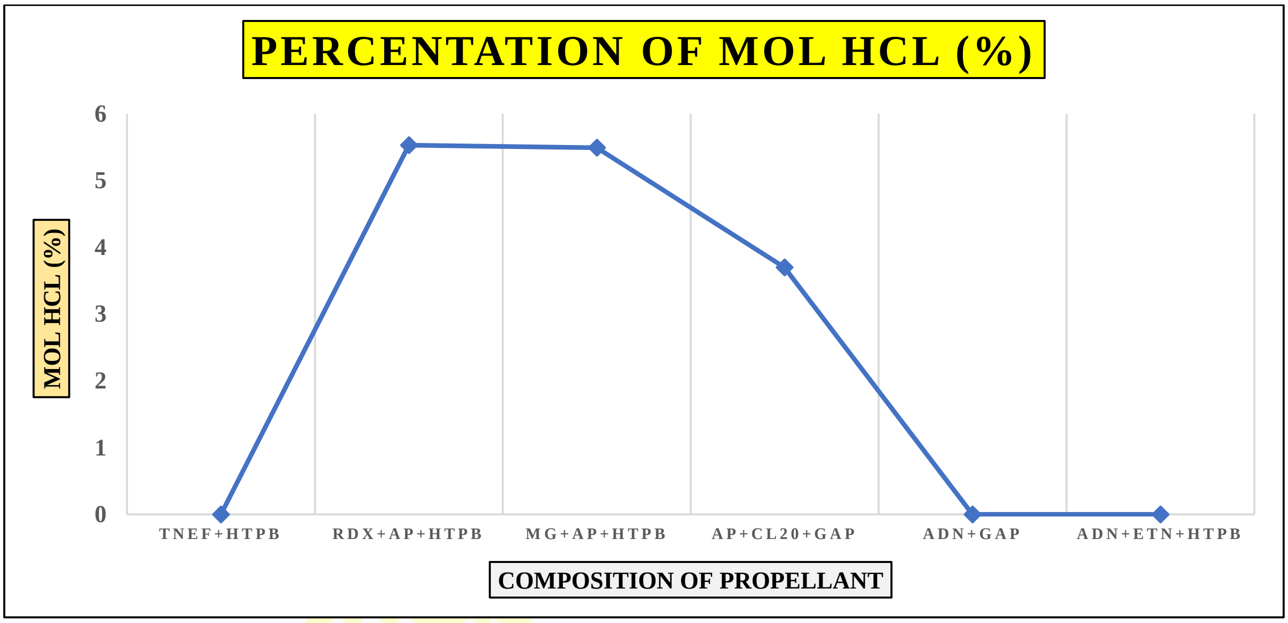

Figure 1: *Percentation of HCl gas produced by each composition of propellant*

Based on Figure 1 above, it can be seen that the composition propellant with Ammonium Perchlorate (AP) still have high mol of HCl. This number actually still give good result if compared to mol HCl produced by most common composition AP/Al/HTPB.

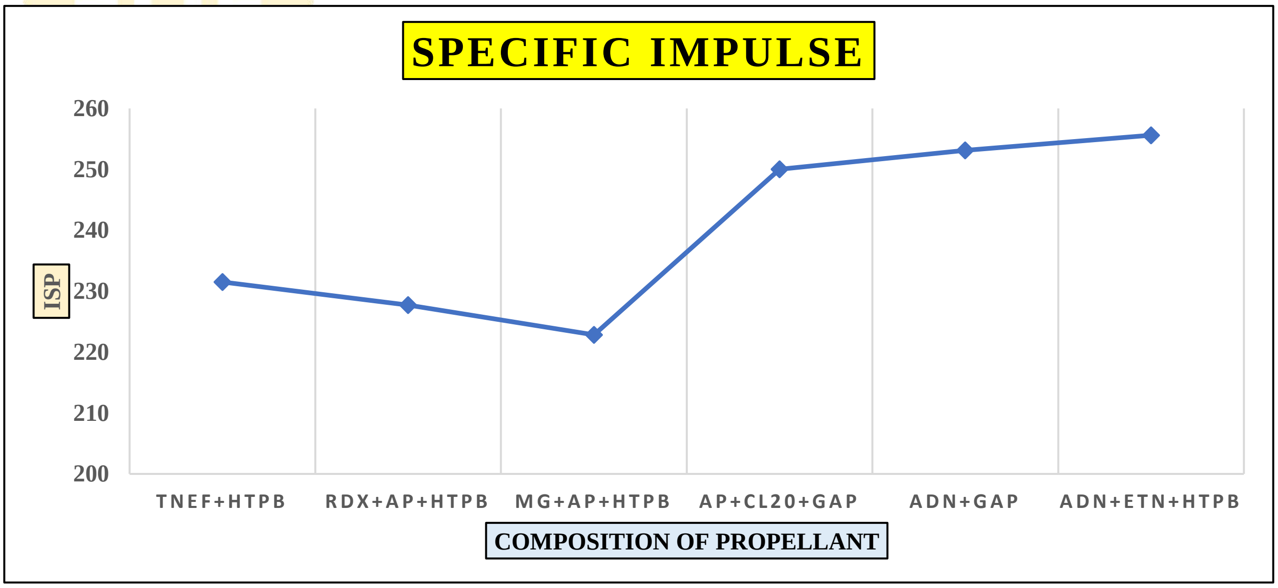

Figure 2: *Percentation of specific impulse by each composition of propellant*

The specific impulse (Isp) refers to a critical performance indicator that shows how well propellants burn and how much energy they use. It is closely linked to the thrust of the rocket engine [15]. Based on figure 2, it can be seen that composition propellant ADN+ETN+HTPB has higher specific impulse than other. In other words, Ammonium dinitramide (ADN) emerges as a possible environmentally friendly alternative to AP. Despite having a lower oxygen balance and significantly less heat of reactant formation than AP, AND carry a higher specific impulse. Furthermore, their exhaust gas contains no hydrogen chloride [16].

IV. CONCLUSION

The research conducted is to find the material and composition which can reduce HCl gas as a result as combustion with high specific impulse. The data shows that the composition which Ammonium Perchlorate (AP) include in it still have high of percentage mol HCl. The composition without Ammonium Perchlorate (AP) shows the best result with 0% percentage of mol HCl, the material of this composition is 2,2,2-trinitroethyl-formate (TNEF), Ammonium dinitramide (ADN). CL20 also show good result even combination with Ammonium Perchlorate (AP), although the number of percentages is not 0% but still below compared with AP+RDX+HTPB or AP+Mg+HTPB. The best of specific impulse was obtained by composition of ADN+ETN+HTPB. This means, decrease hazardous in the atmosphere can be done without reducing the performance of propellant.

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