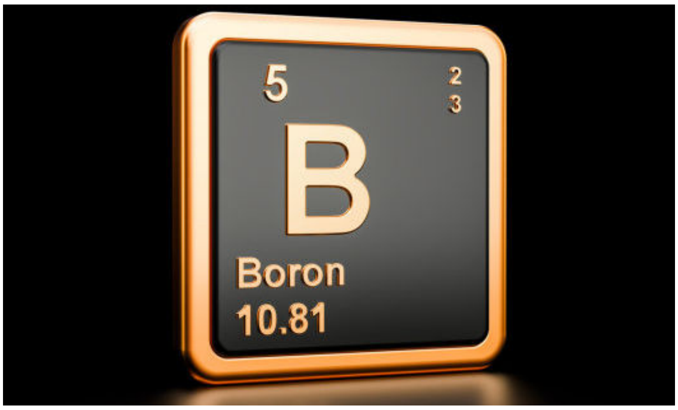
BORON AND ITS APPLICATIONS IN ROCKET PROPULSION: A SHORT REVIEW

Prajakta P Nandanwar and Dr. Syed Alay Hashim

ABSTRACT

The article talks about the benefits of boron-based fuels, particularly for rocket propulsion. These fuels burn efficiently and produce a lot of energy. It also covers studies on the impact of boron particle size and oxygen content on their burning. Getting these right helps the particles burn completely and start burning at lower temperatures. Researchers use a tool named the Opposed Flow Burner (OFB). They study how efficiently boron particles burn. They also examine how quickly the fuel in solid fuels disappears. Because boron is more environmentally friendly, it's considered a better option than other fuels like hydrocarbons. However, using boron as fuel has issues. One problem is that it starts burning slowly. This happens because a layer of B2O3 forms on the particles. This issue lowers the burn efficiency and the speed at which the fuel is used up. Lastly, the article compares boron fuels to others, showing they are cleaner for the environment.



INTRODUCTION

Over several years, advancements in Ramjet technology have progressively brought more attention. Ramjets hold unique properties, such as fast velocity, long range, and less propellant load, when compared to others. Because of these properties, ramjets are used in various missile technologies [1]. There are basically three types of Ramjet engines: solid fuel ramjet (SFRJ), liquid fuel ramjet (LFRJ), and ducted rocket (DR) [2]. Gany et al. conducted numerous experiments and proposed that DR has two combustion chambers [3]. If the solid rocket motor is replaced with a hybrid rocket motor, it is known as Hybrid Fuel Ducted Rocket (HFDR). In 1999, Russo Sorge proposed this theoretical idea [4]. Later, an experiment was carried out by Komornik and Gany to confirm this idea [3]. The hybrid fuel-driven rocket is versatile and cost-efficient. It has the efficiency and control of liquid propulsion systems. It also has the simplicity and durability of solid propulsion systems. This design enhances how the air flows around it, making it more efficient. This results in stronger thrust and better control during flight.

Researchers often study adding particles of metals and metalloids to polymeric fuels. Examples of these additives include titanium, magnesium, iron, and carbon. They improve the burning of fuels like paraffin wax and hydroxyl-terminated polybutadiene (HTPB) [5]. The additives ensure the fuel burns completely when ignited. They achieve this by lowering the ignition temperature, due to their high reactivity. This makes the fuel burn more quickly. Among these additives, boron is the most effective. It has an exceptionally high energy density. Boron powder, in particular, is added to solid propellants and high-pressure explosives. This addition enhances the efficiency of ignition and combustion.

Boron and its properties

Currently, the most popular metal additives include Aluminium (Al), Titanium (Ti), Magnesium (Mg), Zirconium (Zr), Beryllium (Be), and Boron (B). Aluminium (Al), beryllium (Be), and boron (B) are highly reactive metals. They boost the performance of explosives and propellants because of their reactivity. Beryllium (Be) is the most energetic among them but is dangerous. Its byproducts are toxic, causing skin issues and severe health problems when inhaled. This makes beryllium a bad choice for some uses. Boron (B) is the second most energetic. It has properties similar to beryllium, which interests researchers. Boron's high-heat combustion improves rocket performance. It increases the energy output of propellants.

Compared to HTPB, boron has a 40% higher gravimetric heating value (58 MJ/kg versus 42 MJ/kg). It also has a 200% higher volumetric heating value (136 MJ/L compared to 44 MJ/L).

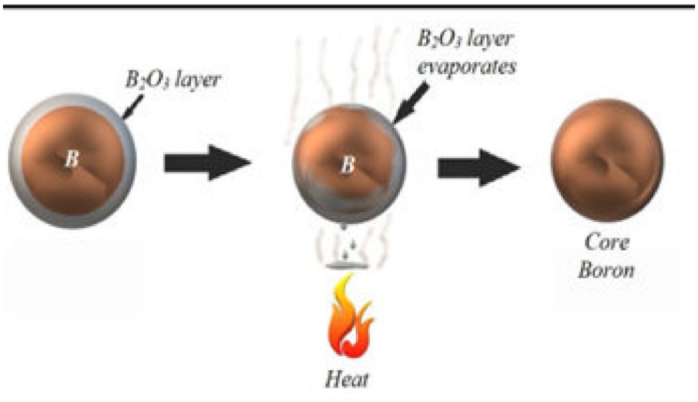


Fig. 1: Two stage combustion process of boron particle

IGNITION AND COMBUSTION PROCESS

Macek and Semple first studied boron as a fuel in 1969 and 1971. They explored its burning properties through experiments at different air pressures. Their work showed that boron burns in two main phases. Boron reacts quickly with air, forming a layer of boron oxide (B2O3) on its surface. This layer slows down the ignition and burning of boron [6, 9, 10]. The first phase of combustion involves the vaporization of this B2O3 layer. Then, the boron that was exposed enters a second phase. In this phase, it reignites. The combustion process of boron is shown in Figure 1. This figure highlights the importance of a two-stage process.

This phenomenon is especially important for Ducted Rocket (DR) technology. Here, burning boron works better. Boron particles light up at different temperatures in wet and dry gases. In moist gases, they ignite at 1860 K. In dry gases, the ignition temperature is 1992 K [11].

CHALLENGES AND LIMITATIONS

Boron-based fuels have great potential but come with challenges. The main problem is the boron oxide layer that forms on boron particles. This layer delays ignition, leading to a two-stage combustion process and reduced combustion efficiency. To improve this, surface coatings or metal additives can be used. Fixing the ignition delay is crucial for efficient and reliable rocket propulsion. Additionally, the manufacturing, purification, and extraction processes for boron particles are costly. They also require many surface treatments to remove the oxide layer. The goal of research on boron-based fuels is to overcome these challenges. This will fully unlock boron's potential and enhance rocket propulsion performance.

APPLICATIONS IN AIR-BREATHING PROPULSION AND ROCKET

Boron-based fuels improve the performance of air-breathing and rocket engines. They are used in aircraft, especially with Ramjet technology, to make fuel use more efficient. When added to rocket propellant, boron has many advantages. It increases thrust and improves engine performance. Boron is lightweight, which helps air-breathing systems use fuel more efficiently. In solid rocket fuels, boron powder increases the energy produced during combustion [9].

RECENT DEVELOPMENTS AND INNOVATIONS

Recent advances have made big strides in research on boron fuel. Scientists are using tiny boron particles to burn fuel better. These particles help start the fire faster by increasing the contact area. They are also tweaking the size and form of boron particles for better ignition. Additionally, there is a lot of research on blending boron with different fuels to improve burning [6,7].

ENVIRONMENTAL IMPACT

We are looking into boron-based fuels and have noticed both good and bad effects. Boron-based fuels produce fewer harmful emissions than traditional fuels. Traditional fuels emit greenhouse gases and pollutants when burned. However, producing and refining boron requires a lot of energy. Mining for boron can damage the environment. On the other hand, standard fuels increase pollution by releasing more carbon dioxide and pollutants. In conclusion, boron-based fuels are better for the environment. But, it's crucial to think about their impact during production and manufacturing.

CONCLUSION

This article discusses how boron has found its application in various other sectors, mainly in rocket propulsion. The text talks about the good things boron adds to fuels. Boron has a lot of energy and burns well. The text proposes adding boron to fuel to make it burn better. But, it also points out a big issue: previous studies have found that boron forms an oxide layer. This layer harms combustion and raises the temperatures needed to start burning. Furthermore, it explores boron's role in air-breathing propulsion systems and its environmental benefits. Boron burns cleaner than traditional hydrocarbon fuels. The conclusion emphasizes the need for more research on boron. It suggests three crucial steps. First, address its challenges. Second, improve how it's made. Third, analyze how to better integrate boron into existing energy systems.

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Prajakta P Nandanwar is a third-year Aerospace Engineering student pursuing a B.Tech. degree at the Department of Aerospace Engineering, Alliance University, Bangalore, India. She can be contacted via email at prajaktan1342@gmail.com

Dr. Syed Alay Hashim holds a Ph.D. from the Department of Aerospace Engineering, specializing in aircraft and rocket propulsion. He currently serves as an Associate Professor at the Department of Aerospace Engineering, Alliance University, Bangalore, India. He has reviewed, edited and oversaw the present work. Reach out to him at syed.hashim@alliance.edu.in