EDUZONE: International Peer Reviewed/Refereed Multidisciplinary Journal (EIPRMJ), ISSN: 2319-5045
Volume 11, Issue 1, January-June, 2022, Impact Factor: 7.687, Available online at: www.eduzonejournal.com

Comparative Study on Green Monopropellants for Rocket Engines

Janani Kavipriya VS[1], Bhushan Chavan[2], Krithika C[2], Boparai Manmeetkaur Ajmersingh[2]

[1]Research Supervisor, Department of Research and Development, ASTROEX RESEARCH ASSOCIATION, Uttar Pradesh, India
[2]Graduate Research Trainee, Department of Research and Development, ASTROEX RESEARCH ASSOCIATION, Uttar Pradesh, India

ABSTRACT

The current trend in rocket propulsion is to make propellant consumption more environmentally friendly. Green propellants have a higher economic value due to their beneficial qualities, which allow them to save money on transportation, storage, and handling while also reducing ground operations time. The cost of transporting and handling hydrazine puts a strain on the space industry. So, the greening of classical hydrazine-based propulsion systems is recommended by many space agencies.Many spacecrafts currently use green propellants for space missions, which have environmental and safety concerns in small satellites and nano satellites that operate in planetary orbits. In this article, a selected number of promising green space propellants are reviewed by their performance parameters along with the physical and chemical properties.

Keywords: Propulsion, Hydrogen Peroxide, ADN (Ammonium dinitramide), HAN (Hydroxylammonium), Hydrazine.

1. INTRODUCTION

Green is not just word or view which can be acquire and obtained easily. It must be attaining very slowly and calmly in the race of development. The word propulsion comes from the Latin propulsors, which is the past participle of the verb propeller, meaning to drive away. Propulsion is the very biggest industry which needed to be sustainable in future for better environment. Normal propulsion system not only higher initial cost but also have very low pollution control properties. Currently, alternative fuels have those decrease harmful exhaust properties and a very low-cost system with greater energy produced which can easily become the replacement for greater good. The energy source most useful to rocket propulsion is chemical combustion. The energy from a high-pressure combustion reaction of propellant chemicals, usually a fuel and an oxidizing chemical, permits the heating of reaction product gases to very high temperatures. These gases subsequently are expanded in a nozzle and accelerated to high velocities. Energy can also be supplied by solar radiation and, in the past, also by nuclear reaction [28].

Over the last 30 years, chemical propulsion for space applications has largely relied on highly toxic and carcinogenic effects. Despite their high performance, the handling of these propellants necessitates complicated and costly safeguards to protect operators and the environment [31]. The greening of classical hydrazine-based propulsion systems is recommended by many space agencies. So, to reduce the air pollution during rocket launches, the significance of greener space propulsion becomes more important. Various research projects on the creation and investigation of green propellants are taking place all over the world. Generally, green propellants are easier and safer to handle than the conventional hydrazine propellant and are likely to bring down the costs associated with propellant transport, storage, and ground operations.The goal of this journal article is to highlight a few green space propulsion operations in the space industry.

2. LITERATURE REVIEW

Brandon et.al (2022) Georgia Institute of Technology’s Space Systems Design Lab (SSDL) design a dual – mode propulsion ‘collaboration with MIT & NASA Marshall Space Flight Centre (MSFE). They together design and performance a specture system in various fields such as cold Gas Propulsion, Monopropellant Chemical Propulsion, Electrical Propulsion and Bimodal Propulsion. A specture systems consist of twomodes of propulsion; one with electrosprays of four firing thruster and another one with single chemical thrust which helps to fire the thrust at distinct sets of modes. The results was highly representative which clearly shows that the chemical thruster chemical requires relatively high temperatures and pressures while the electrospray thruster (four firing) gives longer thrust power [1]. Stephen .A Whitmore (2022) studied and established the properties of additively printed acrylonitrile butadiene styrene which was a replace material from hydrazine (N_2H_4). Hydrazine is currently using Monopropellant which was highly toxic also U.S. Environment Protection Agency (EPA) conforms it. He carried out experiments on this material, which is capable of on demand Start, Stop & Restart of the green hybrid thruster(engine). 3-D printed / Additively printed Acrylonitrile butadiene styrene is such a new material that 'No plume contamination' on database still exist and even, the associated contamination potential for spacecrafts surfaces is unknown [2]. Ali Saberimoghaddam et.al (2022) says that liquid propellant most commonly used for satellite launch in upper orbits with help of hydrogen or oxygen propellant system, so they designed a non – hypergolic mixtures of hydrogen/oxygen by designing a spark ignitor to performance seven hot test. They kept the air/fuel ratio at a constant combustion chamber pressure to find out the maximum value of the specific impulse and characteristics velocity. However, keeping the chamber at constant pressure, they found there was an enhancement in pressure with greater impulse, thrust and velocity [3]. Ahmed E. S. Nosseir et.al (2021) says that currently many spacecrafts use green propellants for space mission which environmental sustainability and have safety concerns in small satellites & nano satellites which enabled in planetary orbits system. Green propellant have relative high performance together with simplicity and better storability when compared to gaseous and bi – propellant. They have studied and established a research over three main classes of green propellant they are :- 1) Energetic Ionic Liquids (EILS) (or premixed oxidizer/ fuel ionic aqueous solutions), 2) Liquid NOX Monopropellant (either in binary compound, nitro compound, or premixed / blend form) and 3) Hydrogen Peroxide Aqueous Solution (HPAS). They performance rocket propulsion analysis (RPA) & NASA CEA data compare using EIL AND HPAS. They use EIL AND HPAS with multi-mode & combined chemical – electric propulsion system. To obtain a segmented data for deep space lunar mission will the propulsion work or not, it wasn't suitable for it [4].

Michael et.al (2021), describes in the literature about the first Lunar Flashlighti.e. The first cubesat mission which used ASCENT as the green propellant by replacing hydrazine. The performance of ASCENT is shown with its analysis at different phases of the mission. Fifteen 100mN per studied the complex chemical and physical reaction and inlet mass flow rate on the catalytic decomposition and combustion reaction of the thruster were also investigated. The catalytic decomposition and combustion processes of a HAN/methanol propellant were simulated as a chemical reaction model consisting of 15 species and 11 elementary reactions. The result shows that the porosity of the fore-catalytic bed had the significant effect on the catalytic decomposition and combustion reaction of the propellant, and the combustion characteristics of the fuel were improved with the change of the porosity of the after-catalytic bed [6]. Grayson Huggins et.al (2021) developed a custom-designed Green Monopropellant Propulsion System thruster is manufactured and assembled and then went through various tests [5]. Guan et.al (2021) this pa by Georgia Institute of Technology under the leadership of NASA's Marshall Space Flight Center and support from the Jet Propulsion Laboratory (JPL). The developed system can provide more than the required propulsive capability for full mission success. The system utilizes the Advanced Space Craft Energetic Non-Toxic (ASCENT) green monopropellant that provides more impulsive power than traditional hydrazine as well it's also safer to handle. This was the first on-board propulsion system used in CubeSats rather than using a cold-gas or electric propulsion system [7]. Ali Talaski et.al (2021) of Georgia Tech Space System Design Laboratory in partner with NASAMarshall Spaceflight Centre and NASA Jet Propulsion Laboratory (JPL) developed, manufactured, and tested a 2.5U green monopropellant propulsion system for Lunar Flashlight. The Lunar Flashlight Propulsion system is a green monopropellant propulsion system that is leading the pathfinder project for the upcoming future small satellite propulsion system. The Propulsion system was designed using combine additive manufacturing techniques, hardware, microfluidic components, custom-designed electronics, and unique cleanliness specifications which is capable of producing over 2500N-s of total impulse for orbit insertion around the Moon and for attitude maneuvers that the spacecraft will need to perform during the mission lifetime also critical lesion were throughout the manufacturing process of propulsion system which will be used in future to create such a green monopropellant system in shorter time [8]. Masse et.al (2020) this paper describes the high-performance green monopropellant AF-M315E propulsion system. It is offering a 50% specific impulse greater Isp than hydrazine. The Green Propellant Infusion Mission system delivered in 2015 awaited launch aboard SpaceX's Falcon Heavy rocket have continued to move the technical state-of-the-art of AFM315E advanced green monopropellant technology forward. The AFM315E used in GR-1 thruster on the GPIM demonstration has also spurred the complete development of a miniaturized 0.5-N thruster as an immediate derivative, which promises to extend the enhanced performance and safety benefits offered by AF-M15E technology into the nanosat/CubeSat mission [9].

A.E.S.Nosseir et.al (2020) have established Modular Impulsive Propulsion System (MIMPS-G) that utilizes Green Monopropellant for high thrust impulsive orbital maneuvers mission for micro and nano spacecraft or CubeSats. Different Pressurized systems were investigated relative to small satellites, a baseline design was created for standardization of spacecraft, required thrust level, and mission impulsive force requirements. Comparative results of the propulsion system properties using different monopropellants are tabulated to understand overall performance, onboard power consumption, and the spacecraft size optimization [10]. Lukas Werling et.al (2020) conducted 134 tests comparing the classical hydrazine, N_2O/fuel with nitrous oxide (N_2O), and ethene (C_2H_4) within its pre-mixed (hydrocarbon mixed with its) gaseous state to investigate mixture ratio (ROF), chamber pressure (p_{cc}) and the characteristic chamber length (L^*) to understand the handling and performance of the propellant mixture[11]. Dawn Andrews et.al (2019) designed the concepts of the Green Monopropellant Propulsion System for the Lunar Flashlight Mission. It was the first lunar-bound small satellite that will investigate the Moon's poles for water ice this spacecraft system was designed by the Georgia Institute of Technology under the guidance by the NASA Marshall Space Flight

Center [12]. Wilhelm et.al (2019) the work in this paper is focusing on the Preliminary tests on thermal ignition with ADN-based liquid monopropellants FLP-106 and LMP-103S . It has been Investigated the thermal ignition methods were based on a pilot flame igniter and a glow plug. And the result shows that ADN-based propellants offer a different propellant behavior compared to conventional liquid monopropellants [13]. Freudenmann et.al(2019) carried out study on compatibility and chemical stability of selected aqueous ADN and HAN based energetic formulations that are e.g. realized in the advanced blends LMP-103S, FLP-106 or LGP 1845 [14].

Wingborg et.al (2019) the most studied oxidizer salts of Ionic liquid monopropellant are hydrazinium nitroformate (HNF), hydroxyl-ammonium nitrate (HAN), and ammonium dinitramide (ADN). High solubility is required to obtain a monopropellant with high performance and for that reason HAN and ADN are preferred. The aim of this paper was thus to thoroughly determine the enthalpy contributions and their influence on the specific impulse. By taking the ADN heat of solution into account, the calculated vacuum specific impulse increases in average by approximately 3 s and must thus be considered in order to accurately determine the performance. The influence of the fuels heats of mixing is low and can be neglected [15]. Igarashi et.al (2019) carried out study on the development status of 0.5N-class thruster using a safe green monopropellant denoted “HNP225”. A 0.5N monopropellant thruster includes the additive manufacturing technologies, which reduce the number of thruster assembly parts, which has been developed using HNP225. A series of hot-firing tests were conducted on the thruster, 2.5 kg of HNP225 was used up and stable combustion results were obtained [16]. Pelletier et.al (2019) The Vacco’s Integration system is taken into consideration. It has 4 thrusters mounted on 4 extension the stages of its analysis are thruster acceptance testing, protoflight testing and final flight testing for thruster which includes examination of products and proof pressure, electrical functional testing, thermal vacuum testing and valve leakage. Burst testing includes external leakages, etc [17]. Hikari et.al (2019) demonstrated the use of Green Propellant Reaction Control System (GPRCS). The propellants are compared based on their classifications which are of 4 types, namely, HAN based, AND based, HNF based and hydrogen peroxide. The criterion of comparison are varied as few of them are Freezing point, density, specific impulse, flame temperature, etc. The performances of these green propellants are compared, and their toxicity is analyzed according to the graphs obtained [18].

Negri et.al (2019) this paper studied thermal igniters of Ammonium dinitramide (ADN, NH4+ N(NO2)2) based monopropellants are extremely promising as hydrazine replacement. They allow a prompter ignition and better suited for larger engines (100-500 N) compared to the currently used preheated catalysts. The experimental campaign conducted on the ignition of two ADN-based monopropellants (LMP-103S and FLP-106) with a torch igniter. The tests conducted clearly showed that a flame holding device facilitates the ignition of the propellants. An important result of the study is that it clearly indicates that thermal ignition of the two ADN-based propellants is achievable only when the propellants are vaporized, while ignition of the propellant in liquid form is not possible [19]. Baek et.al (2018) studied the viability of a high-performance green-monopropellant thruster with hydrogen peroxide and ethanol. The performance of the ethanol blended hydrogen peroxide monopropellant thruster was investigated and demonstrated through ground firing tests. And the results show the feasibility of an ethanol-blended hydrogen peroxide thruster as a high performance [20].

Wada et.al (2018) the paper describes the study conducted firing tests of a 1-N-classthruster with the discharge plasma system under a vacuum condition and evaluate the effects on the combustion characteristics of the combustion chamber characteristic length and the propellant injection method by the measurement of thrust and pressure. The combustion characteristics of the monopropellant are discussed by considering the characteristic exhaust velocity efficiency and power consumption and the thruster lifetime is evaluated in terms of electrode degradation. The result shows that shorter combustion chamber characteristic length increased the characteristic exhaust efficiency. At an accumulated firing time of 1646 s, no effect of electrode degradation on the performance of the thruster was observed [21]. Quentin Levard et.al. (2018) demonstrated the use of green propulsion over spacecraft applications. These models were completely suitable for ignition phase that are short compared to total firing duration [22]. ArioValentini et.al (2018) analyzed the use of green propellants over LEO platforms for active debris removal [23]. Michele Negri et.al (2017) developed and presented new technologies for green monopropellant propulsion systems to replace hydrazine from ammonium dinitramide (ADN) which is more sustainable and better suited for complex missions in future green propellants systems under the guidance of EU Horizon2020 Rheform project [24].

Amir S. Gohardania et.al (2014), describes the first mission using the concept of green propulsion. The mission named PRISMA demonstrated high performance system using green propulsion i.e. HPGP system. PRISMA and PICARD were deployed in the sun synchronous orbit in 2010. The main element of the propulsion system was LMP-103S, the pros of using LMP-103S as a propellant are it being non-carcinogenic and has low toxicity, non-flammable, and environmentally friendly not sensitive to airand water vapor [25]. Robert et.al. (2014) exclaims that the definition of Green propulsion possesses ambiguities. The preferable being the system where the level of toxicity is low, giving rise to a question about the tenure of propellant being safer for use. For instance, the propellants can be advisable under certain time spans and can cause long term and acute life risks later [26]. K. Anflo et.al (2010) the basic requirement for a green propellant is its safety which is seen in hydrazine. It provides cost effectiveness in terms of handling and meets the safety standards. The other candidates being ADN (Ammoniumdinitride), it's a storable liquid monopropellant for space applications. The factors that prove to have an advantage over others are its low toxicity, safer handling, high performance compared with monopropellant hydrazine. Hydroxylammonium nitrate (HAN) and Hydrazinium monopropellants also prove to be a good alternative [27].Ankit et.al described about different classification of propellants used for launch vehicles. The cryogenic propellants taken for comparison are liquid hydrogen, liquefied methane and for semi cryogenic fuels considered are RP-1 (kerosene) and UDMH with liquid oxygen as the oxidizer. The scope of this work addresses the comparison among the propellants, on their chemical properties, overall efficiency and fatigue life which is a major criterion for launch vehicles [32].

3. METHODOLOGY

A. Propulsion System & Its Working

Propulsion is the act of changing the movement of the body by using a distinctive feature of applying force. Jet propulsion is a means of locomotion whereby a reaction force is imparted to a device by the momentum of ejected matter. The two types of jet propulsion are characterized as the rocket propulsion and duct propulsion. The rocket propulsion characterizes as the propulsion type where thrust is produced by ejecting matter that is already stored in the flying vehicle called propellant. The duct propulsion can be seen in Ramjet and Turbojets, utilizes mostly the surrounding medium as fluids with some vehicle stored fuels. The engines using duct propulsion systems are known as air breathing engines. Propulsion systems are classified based on energy source namely, chemical, nuclear and solar propulsion. Chemical combustion is the main source of rocket propulsion energy. Many sources other than sun transmit energy by microwave and laser beams, EM waves and protons electrons, etc. classified to provide radiation energy. Nuclear Energy is caused by either fusion of fission. Ejected Matter can be solid, liquid or combination of both. Even plasma is at high temperatures.

B. Chemical Rocket Propulsion & Types

The energy from an excessive-pressure combustion reaction of propellant chemical substances, generally a fuel and an oxidizing chemical, permits the heating of reaction product gases to very excessive temperatures. These gases expand in the nozzle and are accelerated at high temperature to produce thrust.

- Liquid propellant rocket engines

  Liquid propellant rockets use liquid propellants that are fed in the thrust chamber using pressure through tanks. Liquid bipropellants consists of a liquid oxidizer and a liquid fuel. A monopropellant is a single propellant with oxidizer and fuel properties.

- Solid propellant rocket motors

  Solid propellant is known as grain and it contains all the elements for complete burning.

- Hybrid propellant rocket propulsion systems

Hybrid propellants consist of both solid and liquid propellants [28].

C. Green Monopropellant

For many years, the toxic and carcinogenic hydrazine propellant has been used in space propulsion. More environmentally safe propellant choices that provide a low degree of environmental problems are needed to reduce harmful and carcinogenic consequences .To replace the currently used highly toxic and carcinogenic propellants (e.g. hydrazine, MMH, UDMH). These alternative, so-called green propellants will lessen the risk of harm to humans and the environment while also lowering the associated handling costs. When compared to other harmful propellants, it ensures safe handling and storage [4]. Because of the low toxicity and ease of handling, ground processing time might be reduced from weeks to days, making the satellite and spacecraft launch easier. Some green propellants have a higher specific impulse (which is a measure of the amount of thrust that is produced per unit of propellant consumed) than conventional propellants. They also have a lower freezing point than hydrazine, thus they require less spacecraft power to keep the propellant at the proper temperature.

The Glenn Lightsey Research Group's first experience with monopropellant propulsion will be on the Lunar Flashlight Mission. Rather than describing heritage projects and their established methodology, it is required to start with a basic grasp of monopropellant propulsion and the desire to convert to "Green Monopropellant" systems. Much of the approach used to develop the LFPS stemmed from the inherent requirements of monopropellant propulsion systems[28].Monopropellants are fundamentally defined as propellants consisting of chemical compounds (for example N2H4), which release energy through exothermic chemical decomposition. Monopropellant propulsion is a decomposition-based form of chemical propulsion. It can be accomplished either thermally (electrically or flame heated) or with the use of a catalytic substance. The breakdown is triggered by heating and flowing the stored propellant across a catalyst bed. A monopropellant must be chemically and thermally stable enough to maintain correct liquid storage qualities, while also being easily dissolved and reactive enough to provide complete decomposition swiftly.

For some applications, the simplicity of monopropellant feed and control systems make this type of propellant highly appealing applications. Hydrazine is used extensively as monopropellant in small attitude and trajectory control rockets for the control of satellites and other spacecraft and in hot gas generators. Other monopropellants (ethylene oxide or nitromethane) were tried experimentally but are no longer used today. Concentrated hydrogen peroxide (usually 90%) was used for small thrusters between 1945 and 1965 and for monopropellant gas generator in the United States, United Kingdom or Britain, and Germany is still being used in Russia [33]. Green monopropellants based on hydroxyl ammonium nitrate (HAN), ammonium dinitramide (AND), hydrogen peroxide are under development as alternatives to hydrazine.

D. Hydrogen Peroxide (H_2O_2)

Hydrogen Peroxide or H_2O_2 propellant is not only a powerful liquid oxidizer when burning with an organic fuel but also clean burning. When utilized as a monopropellant, it emits harmless exhaust. In rocket applications, hydrogen peroxide must be 70 to 98 percent concentrated (known as high-test peroxide or HTP), with the remaining being largely water. Between 1938 and 1965, hydrogen peroxide was employed in gas generators and rocket applications (X-1 and X-15 research aircraft). Since then, the most frequent concentration for rocket engine and gas generator applications has been 90% hydrogen peroxide. As a monopropellant, it decomposes according to the following chemical reaction, forming superheated steam and hot gaseous oxygen:$H_2O_2 \rightarrow H_2O + 1/2\ O_2$ + Heat.The action of catalysts suchas silver screens, different liquid permanganates, solid manganese dioxide, platinum, or iron oxide causes this breakdown, however many materials can catalyst hydrogen peroxide. When utilized as a monopropellant with a solid catalyst bed, the theoretical specific impulses for 90% hydrogen peroxide can be approximately 154 sec. H2O2 is a bipropellant that is hypergolic with hydrazine and burns effectively with kerosene [29].

E. Ammonium dinitramide (ADN)

Ammonium dinitramide (ADN) -based monopropellants mainly consist of ammonium dinitramide, a fuel, water and a stabilizer. Since ADN is an ionic liquid, those propellants or propellant mixes are also known as energetic ionic liquids. LMP 103S, invented by the Swedish firm ECAPS, and FLP-106, developed by FOI, are the most often used ADN-based propellants (Swedish Agency). LMP-103S has an 8% greater specific impulse (253 s) and a 24% higher density than hydrazine despite being less toxic and noncarcinogenic. LMP-103S has previously been tested for storage for more than 7 years, and the propellant may be ignited using a warmed catalyst (about 355°C). FLP-106 has a greater specific impulse due to higher combustion temperatures. The fundamental distinction of the FLP-106 is that it uses less volatile fuel [11].

F. HAN (Hydroxylammonium nitrate)

HAN (hydroxylammonium nitrate)-based propellants are another class of energetic ionic liquids. Since the 1960s, these propellants have been extensively researched for usage as liquid gun propellant. Finally, the liquid gun propellant LP1846 was created in the 1980s. HAN-based propellants became the subject of study as a result of the hunt for high-performance alternatives to hydrazine. The research operations resulted in the creation of the HAN-based propellant AF-M315E as well as the propellant formulation SHP 163. The AF-M315E was chosen for the Green Propellant Infusion Mission (GPIM) and is now in orbital testing. AF-M315E may have an Isp of 248 s and a density that is 46% greater than hydrazine. A warmed catalyst ignites the thrusters. Because the combustion temperature of AF-M315E is higher than that of standard hydrazine, high temperature catalysts and chamber materials are required [11].

G. Hydrazine

Hydrazine is frequently utilized as both a bipropellant and a monopropellant fuel. The physical and thermochemical characteristics of hydrazine, monomethyl hydrazine (MMH), and unsymmetrical dimethylhydrazine (UDMH) are comparable. Hydrazine is a poisonous, colorless liquid with a very low freezing point (275.16 K or 35.6 F). Hydrazine has a short ignition delay and may be ignited spontaneously with nitric acid, nitrogen tetroxide, and concentrated hydrogen peroxide. Pure anhydrous hydrazine is a stable liquid that may be safely heated to around 416 K. It has been kept in sealed tanks for more than 15 years. Space probes using the monopropellant hydrazine have been going outside the solar system for approximately 40 years. Because it explodes when a detonation temperature is surpassed, it cannot be utilized safely in cooling jackets of bipropellant thrust chambers. Hydrazine is widely employed as a monopropellant in tiny attitude and trajectory control rockets for satellite and other spacecraft control, as well as in hot gas generators. Green monopropellants based on hydroxylammonium nitrate or ammonium dinitrate aqueous solutions are now being developed as hydrazine replacements. Monopropellant decomposition can be accomplished thermally (electrically or flame heated) or with the use of a catalytic substance. A monopropellant must be chemically and thermally stable enough to maintain correct liquid storage qualities, while also being easily dissolved and reactive enough to provide full breakdown swiftly[30].

4. RESULT & DISCUSSION

In this section, collective data of the three propellants are discussed. The performance parameters of any propellant, as well as its physical and chemical properties, are critical data for early design and assessment of various propulsion systems used in diverse applications.

A. Density

Density is the quantity or mass per unit volume of a certain material. Density is defined technically as mass divided by volume. One of an object's most essential and readily measured physical attributes is its density. Densities are commonly used to identify pure substances as well as to describe and estimate the composition of various types of mixes. The density of air is determined by its temperature, pressure, and the amount of water vapor present. We'll start with dry air, which means we'll simply be concerned with temperature and pressure. Figure 1 represent the density with respect to propellants (Hydrazine, LMP 103S , hydrogen peroxide). Hydrogen peroxide has higher density when compared to hydrazine propellant. The high density of 98 percent HTP (1.433 g cm3) makes it a promising choice for storage in propulsion systems.

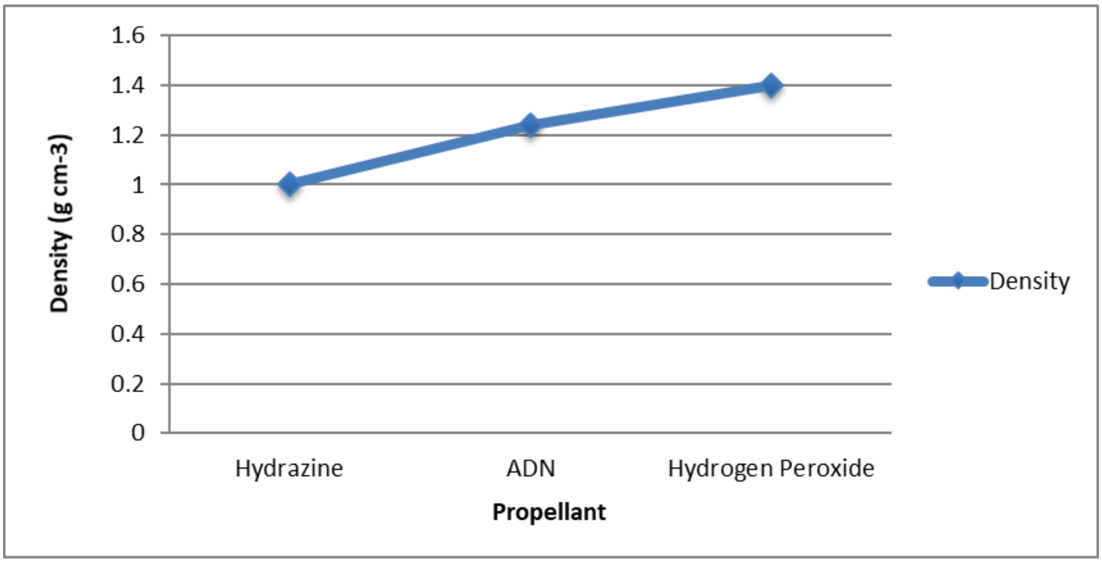

Figure 1.Density v/s Propellants

B. Specific Impulse

The thrust generated per unit rate of propellant consumption, commonly stated in pounds of thrust per pound of propellant used per second, is a measure of a rocket engine's efficiency. A propulsion system with a greater specific impulse makes better use of the propellant's mass. In the case of a rocket, this means that less fuel is used for a given delta-v, allowing the vehicle coupled to the engine to acquire height and velocity more effectively. The specific impulse of a rocket propellant is an approximate estimate of how quickly the propellant is expelled from the rocket's rear end. A rocket with a high specific impulse requires less fuel than a rocket with a low specific impulse. Greater the impulse, greater the push for the gasoline that rushes out. Figure 2 represents the theoretical Isp and Vacuum Isp with respect to the propellants; Hydrazine has a higher theoretical specific impulse. LMP-103S has higher Vacuum specific impulse than the others and Performance of HTP 98% in monopropellant systems is 20% less than hydrazine with Isp 186s.

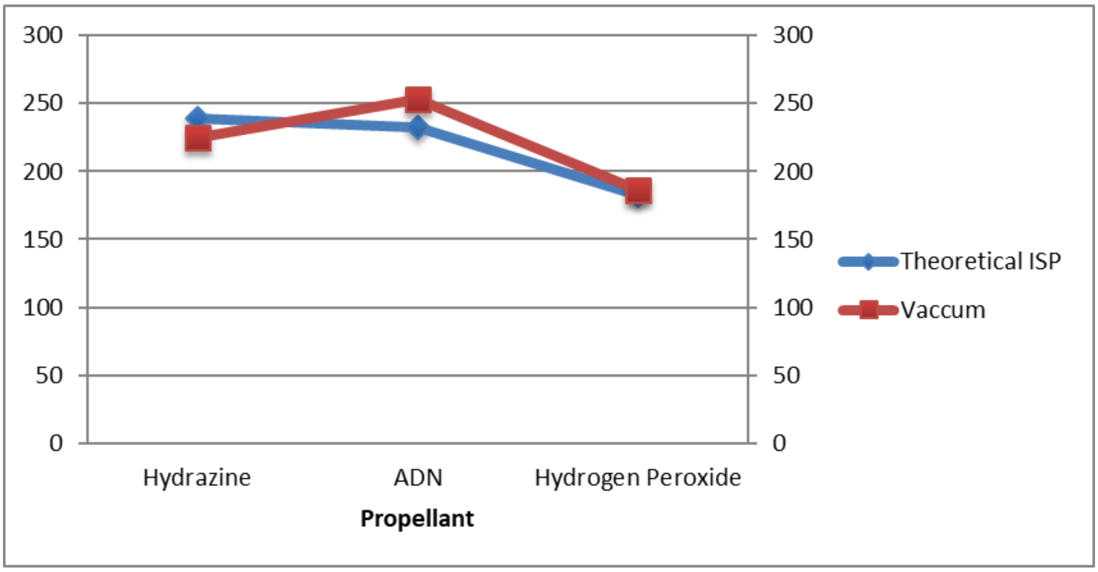

Figure 2. Theoretical ISP & Vacuum ISP v/s Propellants

C. Freezing Point

Freezing point is the temperature at which a liquid becomes a solid at normal atmospheric pressure. A melting point is the temperature at which a solid transform into a liquid under normal air pressure. Freezing points are an important aspect of workplace safety. When a chemical is held below its freezing point, it might become harmful. The freezing point test is critical for aviation fuels since restricting fuel flow can have disastrous consequences for aircraft, such as interfering with fuel atomization. Fig. 3 Freezing point with respect to propellants, Freezing point of ADN is lower and most preferable i.e., -7 and hydrazine has high freezing point than that of other propellants.

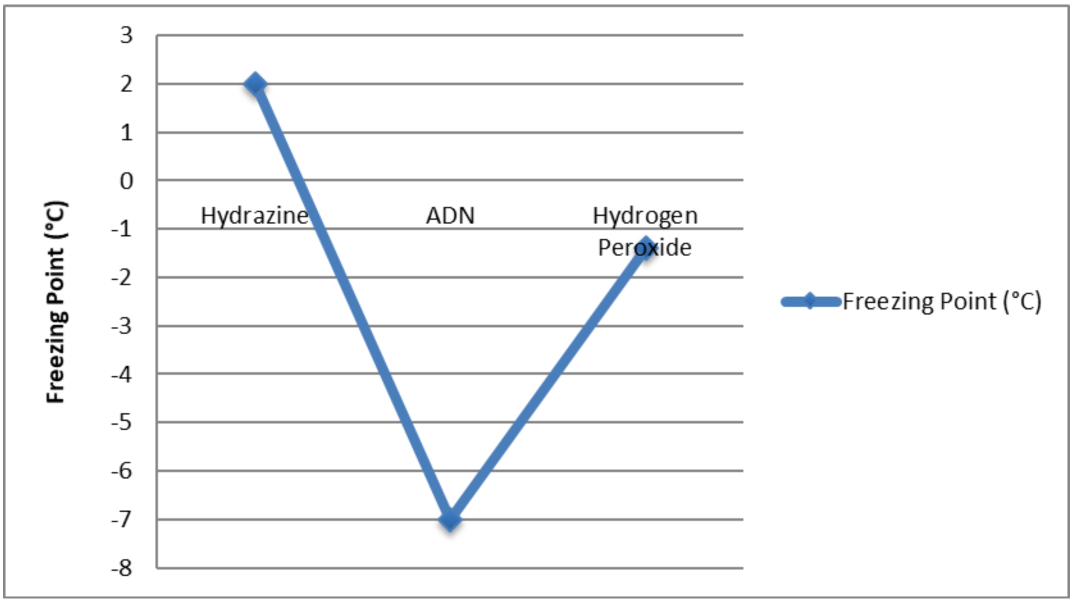

Figure 3. Freezing Point v/s Propellants

D. Adiabatic Flame Temperature

The adiabatic flame temperature (AFT) is defined as the temperature attained when all the chemical reaction heat released heats combustion products. The temperature of an adiabatic flame is thetemperature of full combustion with no heat loss or gain to the surroundings. It's roughly 2000 degrees Celsius or 3500 degrees Fahrenheit for most fuels. These fields can maximize the beginning ratio of their reactions in order to get an optimal combustion outcome by being able to compute the adiabatic flame temperature. The primary elements influencing adiabatic flame temperature are the fuel-air ratio, initial air temperature, pressure, and fuel type. The adiabatic flame temperature is a strong function of the relative air-fuel ratio, with a maximum value that is somewhat beyond the stoichiometric range due to dissociation effects. Fig. 4 represents the Adiabatic flame temperature with respect to propellants, Adiabatic flame temperature of AND (LMP -103S) being 1900 is preferable over the other two propellants.

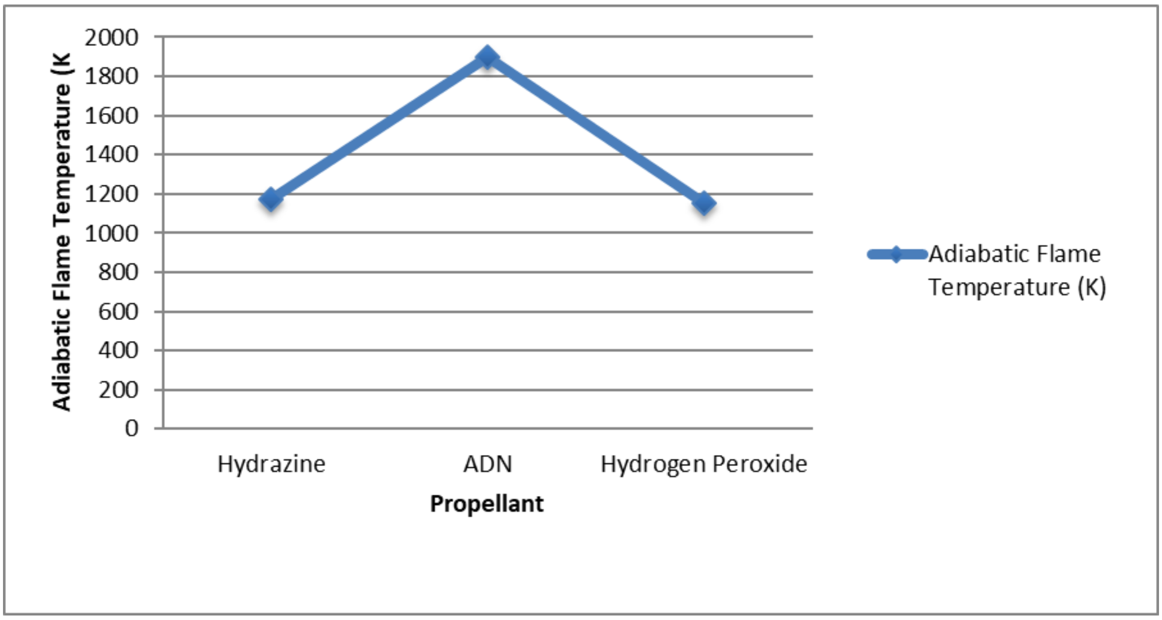

Figure 4. Adiabatic Flame Temperature v/s Propellants

E. Vapor Pressure

Vapor pressure (or equilibrium vapor pressure) is the pressure exerted by a vapor in thermodynamic equilibrium with the condensed phases (solid or liquid) at a given temperature in a closed system. It is critical to understand a substance's vapor pressure when determining dangers. At a temperature, the vapor pressure is the pressure at which a liquid and its vapor are in equilibrium. It is believed that the vapor is "pushing" against the atmosphere. The vapor pressure of a liquid is the point in a closed container at which equilibrium pressure is established between molecules leaving the liquid and entering the gaseous phase and molecules leaving the gaseous phase and entering the liquid phase. The vapor pressure of gasoline is an essential quality criterion. Specifically, vapor pressure is a measure of a fuel's volatility, or how much it vaporizes at a given temperature. Fig. 5 represent the Vapor pressure with respect to propellants, Vapor pressure for ADN has a preferable value of about 15.1 although hydrogen peroxide in vapor phase is extremely unstable.

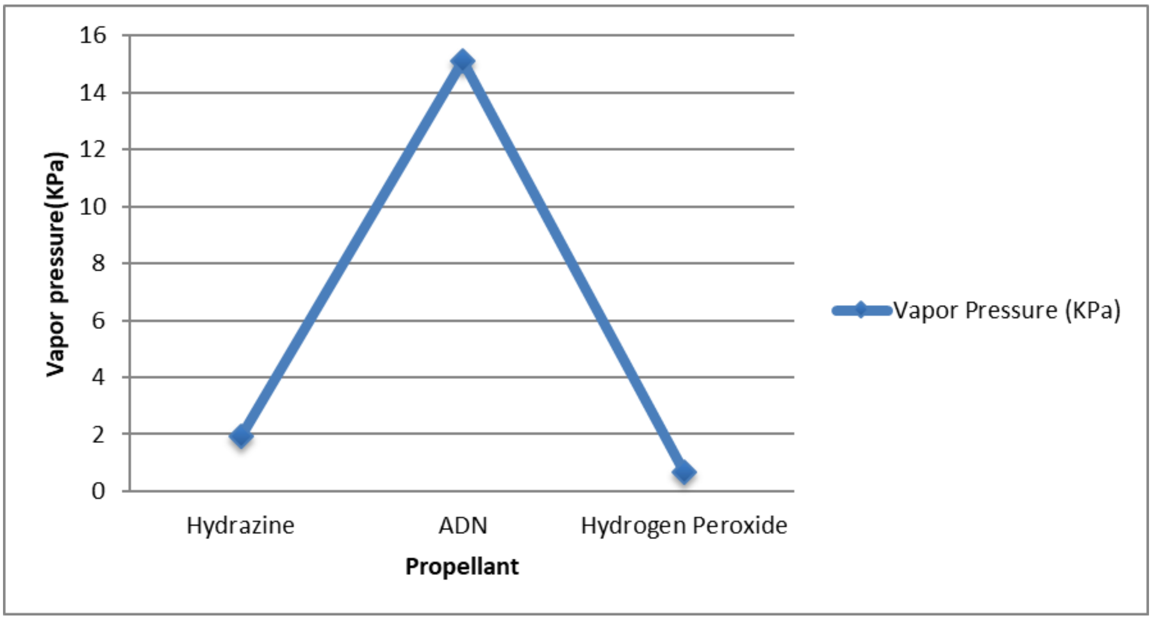

Figure 5. Vapor Pressure v/s Propellants

F. Adiabatic Decomposition Temperature

An estimate of the calculated temperature attained by a specimen if 100% of the enthalpy (heat) of the decomposition reaction were absorbed by the sample itself. Significant numbers indicate a high-risk potential. Figure 6 represents the Decomposition temperature with respect to propellants; Adiabatic decomposition temperature for hydrazine is preferable which has the lowest value of 850.

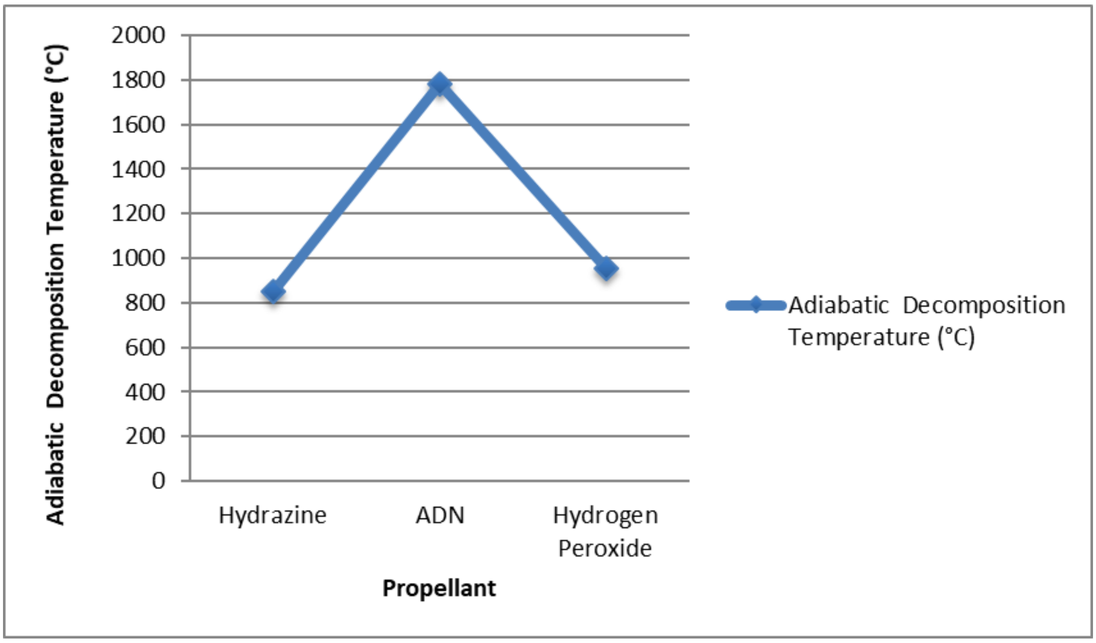

Figure 6. Decomposition Temperature v/s Propellants

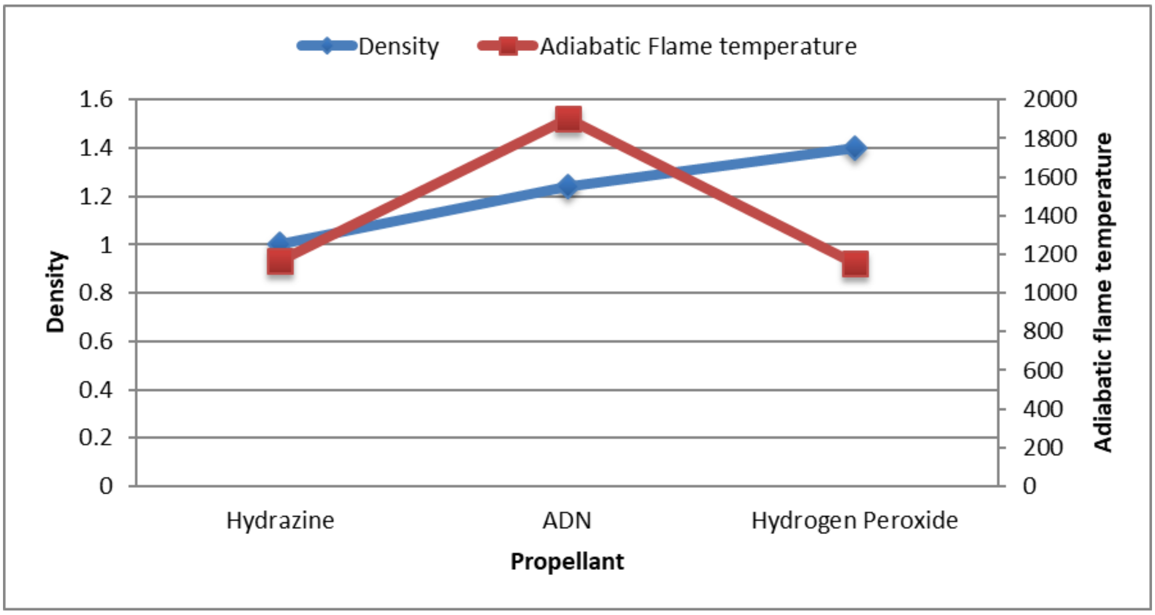

Figure 7. Density v/s Decomposition Temperature

The following graph represents a comparative nature of the propellants' (Hydrazine, ADN, Hydrogen Peroxide) density with respect to adiabatic flame temperature. Density is the physical property of a material while adiabatic flame temperature is the chemical property. The temperature which the propellant gains when the heat is not liberated from the products during the combustion reaction is the adiabatic flame temperature of the propellant. Adiabatic flame temperature is inversely proportional to density as seen from the graphs above. However, there is an ambiguity with ADN. The increase in adiabatic flame temperature with respect to density has a drastic change in value, when compared to the hydrogen peroxide and hydrazine.

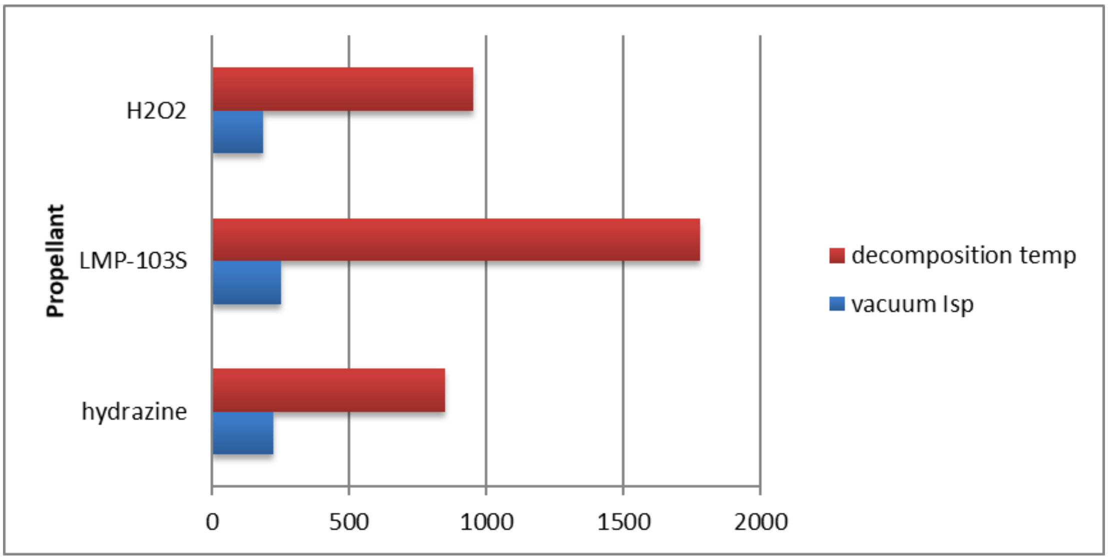

Figure 8. Propellants v/s Decomposition Temperature & Vacuum ISP

The following chart represents the comparison between decomposition temperature and vacuum Isp with respect to the propellants. . LMP-103S has higher Vacuum specific impulse than the others and Performance of HTP 98% in monopropellant systems is 20% less than hydrazine with Isp 186s. Adiabatic decomposition temperature for hydrazine is preferable which has the lowest value of 850.

G. Safety

Hydrazine can be stored without adverse effects, either to the container or to the product, when proper materials of construction are used. To avoid explosive circumstances in storage or processing, extreme caution is required. Before introducing the hydrazine, all systems should be completely cleaned, and a nitrogen environment should always be maintained over the system . A cushion of nitrogen gas should be maintained in process equipment and storage tanks to minimize dangerous circumstances and maintain strength integrity. The LMP-103S is nonpoisonous and does not require any special handling or storage precautions. The procedures for LMP-103S are substantially easier, requiring simply standard protective clothes for chemical handling. This reduces the time and cost of pre-launch fueling. LMP-103S, unlike hydrazine, is not affected by air or humidity, making it much easier to handle and de-fuel if necessary. Careful handling required (H2O2 not as robust / failure tolerant as Hydrazine). There are four strategies to ensure that safety and quality are maintained: Passivation - Ensuring that all H2O2 components are passivated appropriately. Inspection - Every two years, inspect the tanks and delivery system. Sampling -Water quality testing and hydrogen peroxide testing .Maintenance -Repair any flaws right away and re-passivate any equipment that needs it.

H. Composition

Hydrazine - N_2H_4 , LMP-103S - ADN 63.0 wt. %,methanol 18.4 wt. %,ammonia/water 18.6 wt. % Hydrogen peroxide - Concentration % Stability 98.0–99.0

I. Toxicity

Hydrazine is a toxic and corrosive fuel that is dangerous to handle and store. Hydrazine has high acute toxicity from inhalation and ingestion and extreme acute toxicity from dermal exposure. hydrazine is highly toxic and carcinogenic, while LMP-103S is only moderately toxic. The toxicity and handling qualities of hydrogen peroxide are comparable to or better than those of hydrazine. Because hydrogen peroxide has a low vapor pressure and is less likely to induce tissue damage, inhalation is usually the most harmful means of transfer for toxic propellants.

CONCLUSION

This paper was a result of physical and chemical properties of green monopropellant propulsion system. The performance parameters along with the physical and chemical properties of hydrazine, AND (LMP-103S), Hydrogen peroxide are compared and plotted as a graph. However, AND (LMP-103S) is preferable when compared to hydrazine and hydrogen peroxide only exception in adiabatic decomposition temperature. Although Hydrogen Peroxide has the lowest performance values among green monopropellants, it has a unique trait that makes it of great interest from the standpoint of green propulsion in terms of improving overall system performance and size optimization.

ACKNOWLEDGMENT

We would like to express my gratitude towards Mr. Ankit Kumar Mishra, Executive Director and Research Advisor at **ASTROEX RESEARCH ASSOCIATION, DEORIA** for helping us throughout the research work and providing his sincere guidance and support for successful completion of the project.

REFERENCES

[1]. Brandon J. Colón, Mackenzie J. Glaser, E. Glenn Lightsey, Amelia R. Bruno, Daniel P. Cavender,Paulo Lozano, Spectre: Design of a Dual – Mode Green Monopropellant Propulsion System, AAS-094
[2]. Stephen A. Whitmore, Plume Contamination Measurements of an Additively Printed Green- Propellant Hybrid Thruster, Journal of Propulsion and Power, https://doi.org/10.2514/1.B38612
[3]. Ali Saberimoghaddama, Elahe Basafaa, Performance vertification of a laboratory scale hydrogen/oxygen combustion chamber, Iranian Journal of Hydrogen & Fuel Cell 1 (2022), 27-38, https://doi.org/10.22104/IJHFC.2021.5273.1232.
[4]. Ahmed E. S. Nosseir, Angelo Cervone, Angelo Pasini, Review of State -of-the- Art Green Monopropellants : For Propulsion Systems Analysts and Designers, Aerospace 2021, 8(1), 20; https://doi.org/10.3390/aerospace8010020
[5]. Michael Zaluki, Tomas Hasanos, AnatoliySchetkovskiy, And Tim Mckechnie ,Green Monopropellant 100mn Thruster, 2021.
[6]. Guan, J.W., Li, G.X., Li, H.M., Zhang, T., Chen, J. and Gu, Y.J., 2021. Effect of catalytic bed porosity and mass flow rate on decomposition and combustion processes of a HAN-Based monopropellant thruster. Vacuum, 194, p.110566.
[7]. Grayson Huggins, Ali Talaksi, E. Glenn Lightsey, Dawn Andrews, Daniel Cavender, Carlos Diaz, Donald McQueen, Hunter Williams, John Baker, Matthew Kowalkowski, Development of a CubeSat – Scale Green Monopropellant Propulsion System for NASA's Lunar Flashlight Mission, AIAA 2021-1976, https://doi.org/10.2514/6.2021-1976
[8]. Ali Talaksi, E. Glenn Lightsey, Manufacturing, Integration, and Testing of the Green Monopropellant Propulsion System for NASA's Lunar Flashlight Mission, American Institute of Aeronautics and Astronautics Journals (2021).
[9]. Masse, R.K., Spores, R. and Allen, M., 2020. Af-m315e advanced green propulsion–gpim and beyond. In AIAA Propulsion and Energy 2020 Forum (p. 3517).
[10]. A. E. S. Nosseir, A. Pasini, A. Cervone, MODULAR IMPULSIVE GREEN-MONOPROPELLANT PROPULSION SYSTEM FOR MICRO/NANO SATELLITE HIGH-THRUST ORBITAL MANEUVERS (MIMPS – G), IAC-20- C4.8-B4.5A (57488).
[11]. Lukas Werling, Patrick Bätz, Parameters Influencing the Characteristics Exhaust Velocity of a N_2O/C_2H_2 Green Propellant, American Institute of Aeronautics and Astronautics Journals (2020).
[12]. Dawn Andrews, E. Glenn Lightsey, Design of a Green Monopropellant Propulsion System for the Lunar Flashlight Mission, American Institute of Aeronautics and Astronautics Journals (2019).
[13]. Wilhelm, Marius, Michele Negri, Helmut Ciezki, and Stefan Schlechtriem. "Preliminary tests on thermal ignition of ADN-based liquid monopropellants." Acta Astronautica 158 (2019): 388-396.
[14]. Freudenmann, D. and Ciezki, H.K., 2019. ADN and HAN-Based Monopropellants–A Minireview on Compatibility and Chemical Stability in Aqueous Media. Propellants, Explosives, Pyrotechnics, 44(9), pp.1084-1089.
[15]. Wingborg, Niklas. "Heat of Formation of ADN-Based Liquid Monopropellants." Propellants, Explosives, Pyrotechnics 44, no. 9 (2019): 1090-1095.
[16]. Igarashi, S., Matsuura, Y., Ikeda, H. and Hatai, K., 2019. Safe 0.5 N Green Monopropellant Thruster for Small Satellite Propulsion Systems. In AIAA Propulsion and Energy 2019 Forum (p. 4427).
[17]. Nicolas Pelletier, Jean-Yves Lestrade, Overview Of The CNES "High Performance Green Monopropellant Project": Requirements, Organization & Breakthroughs, 2019.
[18]. Hikaru Uramachi, Daijiro shiraiwa, Tsutomu takai, Nobuhiko tanaka, Takao kaneko, Katsumi furukawa, Green Propulsion Systems For Satellites - Development Of Thrusters And Propulsion Systems Using Low-Toxicity Propellants, Mitsubishi Heavy Industries Technical Review Vol. 56 No. 1 2019.
[19]. Negri, Michele, Marius Wilhelm, and Helmut K. Ciezki. "Thermal Ignition of ADN-Based Propellants." Propellants, Explosives, Pyrotechnics 44, no. 9 (2019): 1096-1106.
[20]. Dawn Andrews, E. Glenn Lightsey, "Design of a Green Monopropellant Propulsion System for the Lunar Flashlight Mission"(2019). Baek, Seungkwan, Woosuk Jung, Hongjae Kang, and Sejin Kwon. "Development of high-performance green-monopropellant thruster with hydrogen peroxide and ethanol." Journal of Propulsion and Power 34, no. 5 (2018): 1256-1261.
[21]. Wada, Asato, Hiroki Watanabe, and Haruki Takegahara. "Combustion characteristics of a hydroxylammonium-nitrate-based monopropellant thruster with discharge plasma system." Journal of Propulsion and Power 34, no. 4 (2018): 1052-1060.
[22]. Quentin Levard, Neven Louis, N. Pelletier, Duc Minh Le, Olivier Rouzaud, Christine Lempereur, JoukeHijlkema, Jean-Yves Lestrade, JerômeAnthoine ,Numerical simulation of a green monopropellant for spacecraft application, 2018.
[23]. ArioValentini, Angelo Pasini, Giovanni Pace, HarshrajRaiji,GREEN PROPELLANT THRUSTER DESIGN FOR LEO PLATFORMS ACTIVE DEBRIS REMOVAL, 2018.
[24]. Michele Negri, Marius Wilhelm, Christian Hendrich, Niklas Wingborg, Linus Gendiminas, Leif Adelöw, Corentin Maleix, Pierre Chanbernaud, Rachid Brahmi, Romain Beauchet, Yann Batonneau, Charles Kappenstein, Robert-Jan Koopmans,

Sebastian Schuh, Tobias Bartok, Carsten Scharlemann, Kjell Anflo, Mathias Persson, Wilhelm Dingertz, Ulrich Gotzig, Martin Schwentenwein, Technology development for AND-based green monopropellant thrusters – an overview of the Rheform project, 7th European Conference for Aeronautics and Space Sciences (EUCASS).

[25]. Amir S. Gohardania,n , Johann Stanojev b , Alain Demairé b , KjellAnflo c , Mathias Persson c , NiklasWingborg d , Christer Nilsson, Green space propulsion: Opportunities and prospects, Progressin Aerospace Sciences, 2014.

[26]. 2. Robert L. SackheimMadison, Robert K. Masse, Green Propulsion Advancement: Challenging the Maturity of Monopropellant Hydrazine, JOURNAL OF PROPULSION AND POWER Vol. 30, No. 2, 2014.

[27]. K. Anflo, B Crowe, M Persson, The First In-space Demonstration of Green Propulsion System, 24th AIAA/USU Conference on Small Satellites, 2010.

[28]. George Sutton ,Oscar Biblarz, Rocket Propulsion Elements , Edition 8, chapter 1, 1.1,1.2 , Pg no. 1-9.

[29]. George Sutton ,Oscar Biblarz, Rocket Propulsion Elements , Edition 9 , chapter 7 liquid propellants, 7.2 liquid oxidiser, Pg no. 256-257.

[30]. George Sutton ,Oscar Biblarz, Rocket Propulsion Elements , Edition 9 , chapter 7 liquid propellants, 7.4 liquid monopropellant, Pg no. 262-263.

[31]. George Sutton ,Oscar Biblarz, Rocket Propulsion Elements , Edition 9, chapter 7,7.4, Pg no. 244-264.

[32]. Ankit Kumar Mishra, Madhumitha M, Rama Devi, Prathiksha G Shetty, “Comparative study on propellant characteristics for reusable launch vehicles”, International Journal of Universal Science and Engineering,vol.7(1), pp.40-47, 2021.