Simulations on the novel Solid Propellant Compositions for advanced Missile Technology

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ABSTRACT

Missile form an essential and integral component of National Defense System. That alleviates the monotonous necessity of keeping up with the state-of-the-art technological advancements. Present study is aimed out on developing hybrid propellant compositions for advanced and futuristic missile systems. The work is motivated by the need to find advanced propellant composition(s) yielding highest and lowest 'Isp' values. The study addresses to find an attractive alternative solution to the excessive dependence of Cryogenics. Simulations were carried out on the NASA-CEA with different groups (Hydrides, Hydrocarbons, Metals, Non-Metals) as catalyst(s) keeping the conventional base composition viz., Aluminium (cr) as fuel, Hydrogen Peroxide(L) as binder and Ammonia perchlorate as the Oxidizer. From the results obtained one can infer that, the right composition of propellent can result in an enhanced missile performance with a high Isp helping in an enhanced missile performance while the low Isp helping in thrust termination. However, there are hazardous implications to the environment due to the use of NH4CLO4 as an Oxidizer. The results from the study are expected to provide useful insight about the strengthening of the missile systems.

Keywords: Missiles, Specific Impulse (Isp), Characteristic velocity(C*), Energetic materials.

1. INTRODUCTION

Composite solid propellants are widely used in modern rockets and missiles. The solid propulsion looks to the future with enhanced requirements in terms of reduction of costs, increased performance, improved reliability and more friendly environmental impact. In this perspective, new generation of solid propellants consisting new oxidizers and binders are needed. Composite Propellants consists of oxygen donating inorganic salts and a binder made of plastic. The polymeric binders include polysulfides, polybutadiene-acrylic acid (PBAA), Polybutadiene-Acrylonitrile Acrylic Acid (PBAN), Polyurethane (PU) and Carboxyl or Hydroxyl Terminated Polybutadiene (CTPB or HTPB). Nitrates and Perchlorates are used as oxidizers. The composition includes of a polymeric matrix, loaded with a solid oxidizer, a metal powder that plays the role of a secondary fuel component along with cross-linking agents and curing agents, plasticizers and other additives. The unified combination is designed to produce the highest performance. Energetic materials used as ingredients in both propellants and explosive formulations are either high melting crystalline solids or liquids at room temperature. The search for new energetic materials with a given performance, sensitivity and physical properties is one of the major challenges to the chemical industry.

New energetic compounds with higher densities are often designed by modifying known substances by addition and/or modification of explosophoric groups (-NO2, NO3, -ONO2, N3, etc.). All energetic materials contain oxygen, which is needed for the explosive reaction to take place. Oxygen can be introduced by chemical reactions (nitration) or by mechanical incorporation of materials containing bound oxygen. The most important solid oxidizers are nitrates -Ammonium Nitrate, Sodium Nitrate, Potassium Nitrate and Chlorates - Potassium Chlorate, Ammonium Perchlorate. The characteristics of a good oxidizer are the capability of supplying oxygen to burn the binder and other fuels with maximum heat of combustion and highest enthalpy of formation.




(a) (b)

Figure 1: Pictorial representations of the different missile systems (a &b) (* www. google.com).

Binders are compositions that hold together a charge of finely divided particles and increase the mechanical strength of the resulting propellant grain. These are usually functionally terminated prepolymers such as hydroxy-terminated polybutadiene (HTPB), carboxyl-terminated polybutadiene (CTPB), resins, plastics, or asphaltics used dry or in solution. The enthalpy of formation (ΔHf,) should be more positive and the binder must have suitable structure, which on combustion produces low molecular weight gases, thereby leading to high specific impulse. Most explosives and pyrotechnic compositions are prepared by mixing of oxidizers and fuels. Fuel means any substance capable of reacting with oxygen and oxygen carriers with the evolution of heat. Aluminium is virtually the universal fuel for composite propellants.

It is available in spherical powders, with small diameters and it is well suited for high solid loading. Aluminium is safe to handle because of the fine layer of Aluminium Oxide, which inactivates the grains in humidity.

Apart from Aluminium, Boron, Beryllium and Lithium have also been used in very specific applications. Because of the increased cost, toxicity, long-term instability and toxic combustion products, the latter fuels are not used. The function of a cross-linking agent is to facilitate curing of the prepolymer molecules by forming a cross-linked network. It plays a critical role in kinetics of the crosslinking reaction and in achieving the desired mechanical properties of the propellant. Examples are trimethyl propane (TMP), glycerol etc., in addition to cross-linking agents, curing agents like toluene diisocyanate (TDI), isophoronediisocyanate (IPDI) or hexamethylene diisocyanate (HMDI) are used, which react with the terminal functional groups of the binder and crosslinking agent to give rigid matrix with very good mechanical properties to the propellant. Plasticizer plays the essential role of complementary element to reduce the viscosity of the slurry and to improve the mechanical properties by lowering the T, and the modulus of the binder. Typically, it is oil that is non-reactive with the polymer chains, thereby reducing their interaction in the liquid state as well as in the cross-linked state. Examples includes, diisooctyl azelate, diisooctyl sebacate, isodecyl pelargonate, dioctyl phthalate and dioctyl adipate. These are liquid or solid products added in small quantities (a few %) of the binder. Their function is to modify the characteristics of the propellant. Burning rate modifiers are used to modify the propellant burning rate and to adjust the pressure exponent ‘n’ of the burning rate pressure curve in the pressure zone where the propellant grain will be operating (discussed later). Examples include ferrocene, n-butylferrocene, copper chromate etc. Antioxidants are essential to ensure satisfactory ageing of the propellant in ambient conditions. Examples are ditertiary butyl paracresol viz., 2-methylene bis (4-mettiy-6-tertiary-butyl phenol) etc., Catalysts are often necessary to reduce the curing time of the propellant. They have a significant impact on the mechanical properties by facilitating some favorable reactions, thereby giving direction to the formation of the polymer network. They are usually salts of transition metals. Examples include Dibutyltindiiaurate, Lead Octoate, Iron Acetyl Acetonate, Lead Chromate etc.

A solid propellant develops thrust or recoil force due to discharge of gaseous products when it undergoes combustion. The burning process in the rocket motor is influenced by the thermodynamic performance values of the propellant, the burning characteristics of the propellant grain, depending on its shape and by the pressure influence of the burning rate. The specific impulse ‘Isp’ is a means of characterizing and evaluating the properties and is viewed as a key measure of propellant performance. Isp is a theoretical maximum of the

mechanical work that can be derived from the adiabatic decomposition of a unit mass of propellant followed by expansion of the decomposition products into an environment of specified pressure, which is usually the near total vacuum of outer space. In other words, it is the enthalpy release converted into the kinetic energy of the exhaust jet. It is expressed by a simplified relation given by Equation 1.

$$I_{sp} = T_c^{1/2} N^{1/2} \qquad (1)$$

where, 'Tc', is the combustion chamber temperature and 'N' is the number of moles of gaseous products produced. The heat released during the combustion increases the flame temperature 'Tc' which is given by Equation 2.

$$T_c = \frac{-\Delta H_f}{C_p} N^{1/2} \qquad (2)$$

Where, 'ΔHf' is the heat of reaction, 'Cp' is the specific heat capacity. Specific impulse is also defined as the thrust or impulse achieved per unit weight of propellant and is given by equation 3

$$I_{sp} = \frac{F \times t}{W} \qquad (3)$$

Where,

Isp = specific impulse

F = Thrust (N)

T = Time (s)

W = weight of propellant

The heat of reaction (ΔHf) is given by Equation 4.

$$\Delta H(T) = (\Delta H_f(T)_P) - (\Delta H_f(T)_R) \qquad (4)$$

The heat of formation (ΔHf) depends on the bond energies between the atoms of the various ingredients used in propellant formulations. (ΔHf)P represents formation enthalpy of products and (ΔHf)R of reactants. To get as high a combustion temperature as possible, one must select reactants with large positive heats of formation and products with large negative heats of formation. The maximum energy output is possible from a material when it contains bonds with as small bond energies as possible and products with as high bond energies as possible.

Following the classical work of Summerfield et. al., [1] and Urbanski [2], Research efforts have contributed significant experimental, numerical, and theoretical, analytical efforts in the advancement in enhancing performance of composite solid propellant with energetic materials by developing hybrid compositions. The science of energetic materials evolved slowly (nearly 200 years) to reach its current status, because the newly developed energetic materials need years of vigorous field-testing. Number of innovative explosives, oxidizers and binders were explored for use in space propulsion. The investigations on solid propulsion have grown over the years and continue to emerge with special attention on key concerns viz., safe handling and operation, performance reliability, and cost minimization.

Sparks [3] examined the use of lunar material for hybrid rocket propellants. Liquid oxygen was identified as the primary oxidizer and metals such as aluminum, magnesium, calcium, titanium and silicon were compared as possible fuels. Due to the reduced transportation costs, the use of lunar materials for both oxidizer and fuel was expected to dramatically reduce the cost of a sustained space program. The study pointed out that hybrid rocket propellants could also be obtained from asteroidal and planetary soils, thereby facilitating the

exploration and industrialization of the inner solar system. In the last decade Lengelle et.al., [4] worked on pursuing interest of hybrid propulsion for missile applications. The study advocated the increasing need for many missile applications to be able to manage the thrust evolution during the mission. which required either thrust impulses, separated by time delays without thrust, or thrust modulation. Propulsion by hybrid propulsion, in which a liquid oxidizer is injected and quickly gasified into a solid fuel grain for missile applications deserved attention. The study detailed that in order to investigate the applicability of hybrid propulsion to missile missions, at least three themes need to be addressed: the experimental knowledge of the of the hybrid system operation, the modelization and dimensioning of the hybrid fuel grain, The work discussed that the experimental work on hybrid propulsion is best carried in a set-up which allows in particular the measurement of the instantaneous and local regression rate. As opposed to solid propellant combustion, sensitive to pressure essentially hybrid combustion is sensitive essentially to the flow conditions in the strongly sheared, and flame containing layers in the channels inside the fuel grains and thus the regression rate can be time evolutionary and to a lesser degree evolving in space. A set-up used at ONERA with such ultra-sonic measurements was displayed. Cantwell et. al., [5] reviewed and highlighted the idea of the hybrid rocket and need for, producing a design that minimizes the chance of a chemical explosion. The study pointed that while the hybrid enjoys many safety and environmental advantages over conventional systems, large hybrids have not been commercially viable. The reason noted was that traditional systems use polymeric fuels that evaporate too slowly, making it difficult to produce the high thrust needed for most applications. The work stated that entrainment of droplets from the liquid–gas interface can considerably increase the rate of fuel mass transfer, leading to a much higher surface regression rate. a series of scale-up tests using several oxidizers were carried out on intermediate-scale motors and the data from tests was found to be in agreement with small-scale, low pressure, and low-mass-flux laboratory tests which confirm the high regression rate behavior of the fuels at chamber pressures and mass fluxes representative of commercial applications. Venugopal et.al., [6] conducted experiments to investigate the regression rates of mixed hybrid propellants using Red Fuming Nitrous Acid (RFNA) as liquid oxidizer, Hydroxyl-Terminated Polybutadiene (HTPB) with the addition of Ammonium Perchlorate (AP) upto 20 % as the solid fuel. The study highlighted one of the effective ways of increasing the regression rates in hybrids is the addition of solid oxidizer such as AP in the fuel in small percentages. and draw applications due to its higher regression rate characteristics, greater fuel value, higher carbon/hydrogen ratio and solid loading capability. A series of static tests were conducted to establish the ignition and combustion in the hybrid mode. It was noted that the hybrid propellant burnt smoothly besides the ignition pressure could also be controlled and kept to a reasonable value. Stable combustion within a variation of chamber pressure ±2% and combustion efficiency above 0.95 was achieved. The characteristics of the combustion products was evaluated using the NASA CEA code. Regression rate correlations for the different combinations were obtained using the experimental data and ballistic code developed for predicting the performance of hybrid system. Wibowo [7] carried out a study on the development of propellant research in Indonesia to support the mastery of rocket technology to formulate the direction of the propellant research that must be done. The exploration emphasized pertinent discussions on the development of propellant technology in the world, and the position of propellant research to support the development of sounding rocket and satellite orbiter. The study identified the challenges that must be addressed by propellant researchers in Indonesia, in order to pursue the mastery of up-to-date propellant technology as in the developed countries. Wilson [8] worked on wired end burners to increase burning rates along the wire to develop larger burn areas which produce higher thrust thus improving tactical missile range by increasing the total impulse through the addition of wires in solid propellant. a novel model was developed to add wires, with or without discontinuities, to an end burner design and to provide performance results such as thrust, chamber pressure, mass flow, and impulse. The study compared a wireless baseline propellant to both single and multi-wire embedded configurations with varying materials and break locations. Five different wire materials were tested to investigate the performance for various thermal diffusivities and melting temperatures. Wire diameters were varied from 1-10 mm to find the optimal geometry for heat transfer into the propellant and nine evenly spaced locations for breaks along the wire were selected to investigate the impact a break has on total impulse. To ensure results are comparable, the geometry of the throat was adjusted for the various test runs to obtain missile performance at a typical operating chamber pressure near 4 MPa. The results exhibited small gaps have negligible impact on performance and carbon nanotube fibers can theoretically provide up to 25% more total impulse than star and internal tube grains while still producing comparable thrust over similar action times.

Lysien et. al., discussed the latest developments in solid propellants and their components. Precise attention was given to emerging energetic binders and novel, 'green' oxidizing agents and their use in propellant formulations. A brief overview of the latest reports on fuel additives was included. Finally, a summary of the state of the art and challenges in its development were speculated on. In recently, the research calculations show that the global rockets and missiles market size is projected to grow from USD 58.3 billion in 2021 to USD 73.8 billion by 2026, at a CAGR of 4.8% from 2021 to 2026. The rockets and missiles market is expected to witness growth due to consistent increase in defense budget across the globe and the need for advanced rockets and missiles to counter the modern combat around the country's border. Furthermore, increasing number of conflicts, and high defense spending are some of the major factors driving the market globally.

Governments of various countries, such as the US, China, India, and Russia, are spending heavily on modernizing their military resources. Thus, a large number of weapon manufacturers are shifting their focus towards developing rockets and missiles. However, issues related to the integration of missiles pose a challenge for rockets and missiles market growth [10]. Although significant research contributions have been made, one aspect which is yet to be comprehensively explored is to analyze combustion and propulsion characteristics of Missile systems by understanding the effect of the varying energetic catalyst concentration in Fuel and Oxidizer under varying operating conditions thus resulting in formation of hybrid propellant compositions.

The work is primarily motivated by the prevailing issues in solid propellants in the conventional missile system(s) viz., Low Specific Impulse and Uncontrollable combustion, Strong over-dependency on low temperature chemicals (i.e., cryogenics) for the Missile propulsion, Absence of the state-of-the-art facilities for mission completion. The specific objectives of the study are:

a) To develop advanced hybrid propellant compositions for enhanced performance and innovations viz., thrust termination.
b) To fundamentally investigate and understand the role of key controlling parameters/operating conditions on performance.
c) To draw useful insights and develop correlations from the governing physics to reason out the trends obtained under varying conditions.

2. SIMULATIONS AND SOLUTION METHODOLOGY

The work involves utilization of specialized chemical propulsion software NASA CEA (Chemical Equilibrium with Applications). The software tool calculates chemical equilibrium compositions and properties of complex mixtures from any set of reactants and determines thermodynamic and transport properties for the product mixture. Applications include assigned thermodynamic states, theoretical rocket performance, Chapman-Jouguet detonations, and shock-tube parameters for incident and reflected shocks. The composition of the energetic oxidizers and fuels are varied stepwise and the theoretical rocket performance parameters like Specific Impulse, Characteristic Velocity are noted down and parametric analysis is done based on the software predictions. The present study is carried out for chamber pressure of 25 bar, initial oxidizer temperature as 298.15 K and supersonic Area Ratio as 10. The species present in the composite solid propellant composition are chosen either directly by choosing the solid propellant option or if new options are to be investigated then the atoms of the fuel to be chosen are selected from the periodic table.

3. RESULTS

The first oxidizer used in composite propellants was potassium perchlorate (KP, KClO4). It is stable, compatible, and relatively insensitive but contributes little energy. Thus, it was soon replaced by Ammonium Perchlorate (AP), which is more energetic and is now the most commonly used oxidizer in composite propellants. Composite mixtures of Ammonium Perchlorate and hydroxyl-terminated-polybutadiene (HTPB) containing Aluminium powder are the most frequently used in solid rocket propellants. AP is a white crystalline solid, usually in powdery form is oxidizer rich and can sustain self-deflagration above at 20 bars. it is usually very safe to handle and even grindable. Propellants with fine AP burn faster in general, than those

with coarse AP; so, significant burning rate tailoring is affected by the choice of suitable distribution of particle size of AP in the propellant. The greatest advantage with AP is the immense experience and vast information on AP-based propellants available over several decades, which imparted growing confidence in that oxidizer. Ammonium Nitrate was considered early as an environment-friendly alternative to AP, because of its low cost, low sensitivity and absence of chlorine. But its multiple crystal phase transition at low temperatures and poor performance precludes its use. The binder used in propellant formulations should have good mechanical properties and good adhesion between the oxidizer and metal additives. The work initializes combination of Al/ H2O2/AP as the base composite solid propellant. Over the years, high performance, insensitive munitions, and pollution prevention issues in relation to solid rocket propellants have grown in importance. In the past, a number of ingredients that increase performance suffered from instability problems as well as incompatibility with binders. Still others, especially oxidizers, were hygroscopic and became strongly acidic on absorbing moisture. In addition, many compounds were hazardous because of their extreme sensitivity. Most of the current operational solid propellants make use of AP as oxidizer. The most perceptible disadvantage of AP is its chlorinated exhaust products that are detrimental to the environment and produce a distinct smoke signature behind missiles that can be easily detected. Hence there is a need for development alternate materials, which are both environment-friendly as well as more energetic to meet future space missions. The work highlights on incorporating the use of energetic materials like energetic fuels; Boron, Lithium, energetic oxidizers like Nitramide, burn rate catalysts like Iron in the base propellant composition of Al/ H2O2/AP (15/15/70) to get an enhanced propellant performance. Use of high energetic materials like Hydrides, Hydrocarbons, Metals, Non-Metals in the present propellant mixture are expected to significantly modulate the performance.

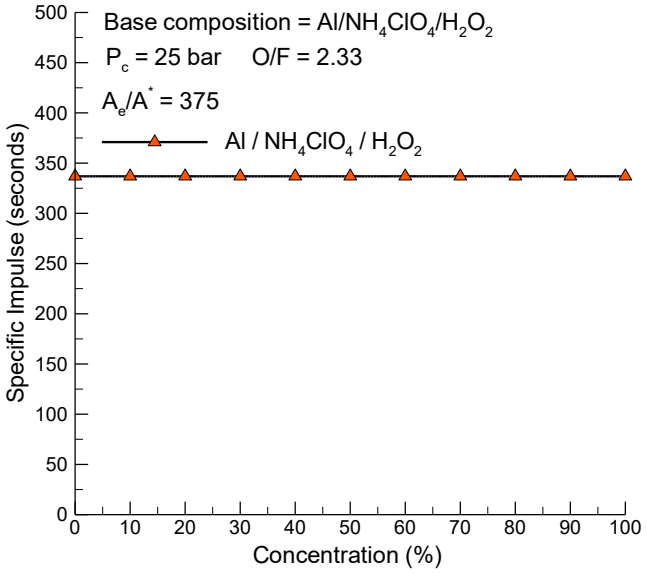
The energetic materials are added in the base propellant composition of Ammonium Perchlorate as the oxidizer (70%), H2O2 (Hydrogen Peroxide) (15%) as the binder and Aluminium (15%) as the fuel. The energetic materials are utilized in the form of energetic fuels, oxidizer and binder.

The addition of energetic materials to the base propellant composition is likely to have a potential to release a large amount of energy on reaction. Prior to the main results, the software predictions were validated with existing experimental and theoretical data (please see Table 1). Analyzing the Table one can clearly note that the software tool predictions match reasonably well with the preceding experimental and theoretical work. Hence, it is likely to give good physical insight into understanding the effect of energetic high energy materials in composite solid propellants. The first part of the study is devoted to determine the optimum composite propellant composition. This is done to compare this result with increment/ decrement in performance parameters associated with the energetic materials. First, the base composition AP/HTPB/Al- [70/15/15] is validated for extensive utilization. Figure 1 shows the variation of performance parameter specific impulse with aluminium concentration. It is important to note that, aluminium is used in crystalline form. Looking at the plot, one can note that the ‘Al’ gives the maximum ‘Isp’ at 15%(weight).

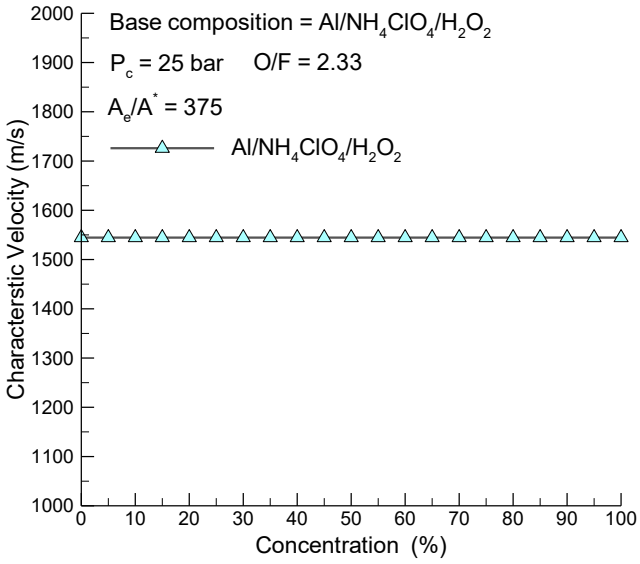
Table 1: Validation of Simulation predictions with preceding Experimental and Theoretical work.

Composition	*Exp./ Theo. (sec)*	*Simltn. (sec)*
AP (80%)/Al (20%) (by volume). ***K. S. Williams, PhD thesis, Texas, A&M University,2012.***	246	242.59
AP/HTPB/Al [70/10/20] (mass). ***K. S. Williams.,2012.***	258	247.08
AP/HTPB/Al [70/15/15]. ***P. Kuentzmann.,2002.***	265	260
AP/HTPB/Al [64/14/18]. **Venkatachalam *et. al.,2002.***	265	263.37
AP/HTPB/Al[(50-10)/(35-75)/15]. ***Nevada Aerospace science associate(nassarocketry.com).***	(238-175)	(230-170)
AP/HTPB/Al[68/14/18] at (Pc=6.89MPa) ***www.lr.tudelft.nl***	266	264.02
AP/PBAN/Al[70/12/16] at (Pc=6.89MPa) ***www.lr.tudelft.nl***	267	263.97

The optimum composition is determined by increasing the mass fraction of Al in steps of 1 %, ranging from no Al to 45 % of 'Al' by total mass. The results are shown in Figure 1. A non-monotonic trend is seen that peaks around 15 % of 'Al' by mass. The corresponding 'Isp' is around 265s. The high Isp values seen are largely explained on basis of the flame temperature of 'Al' which is around 3700 K, which is significantly higher than the adiabatic flame temperature for hydrocarbon fuels. The non-monotonic trend seen is also a result of the variation of the adiabatic flame temperature with the fuel concentration. Lower and higher concentration of fuels lead to lower flame temperatures and hence have lower 'Isp'.



(a)



(b)

Figure 2: Specific impulse (Isp) and Characteristic velocity (C*) (a & b) for the base composition.

The results are cross-checked with secondary parameter viz., characteristic velocity 'C*' (Figure 2). The 'C*' variation indicates trend similar to the 'Isp' that on increasing the 'Al' concentration from 0 to 15% the characteristic velocity increases till 15% and then decreases drastically. The above-mentioned result certifies usage of 15% Aluminium in the base composition. One of the important attributes of 'Al' is generation of high temperatures generated (4100 K) as increase in pressure results increasing effective velocity and hence increased thrust. Aluminium agglomerates in the liquid state help to dampen combustion instabilities. Figure 3 shows the variation of specific impulse with PBAN concentration. The study verifies the incorporation of

HTPB as a potential binder in composite propellant. The plot shows the effect of decreasing concentration of HTPB by interchanging its composition with PBAN (0-15%) to form a blended binder.

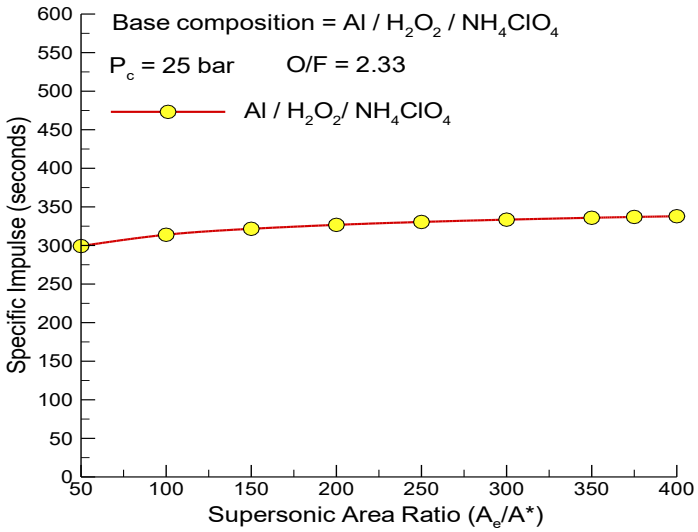
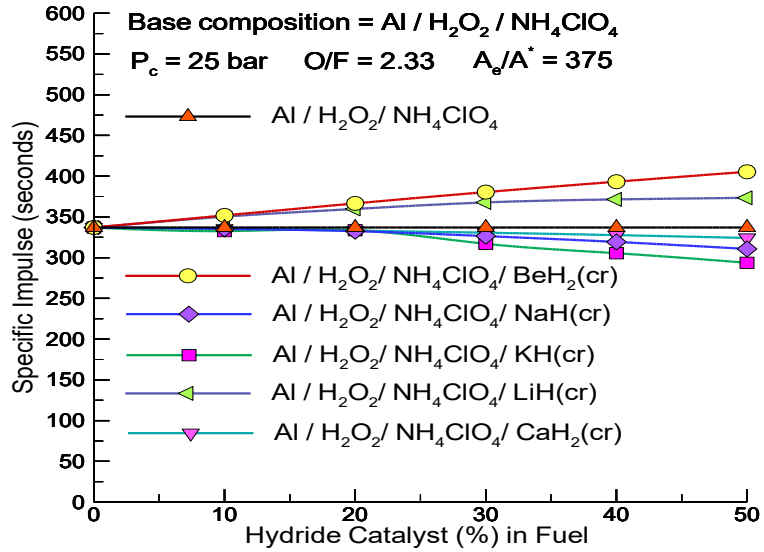
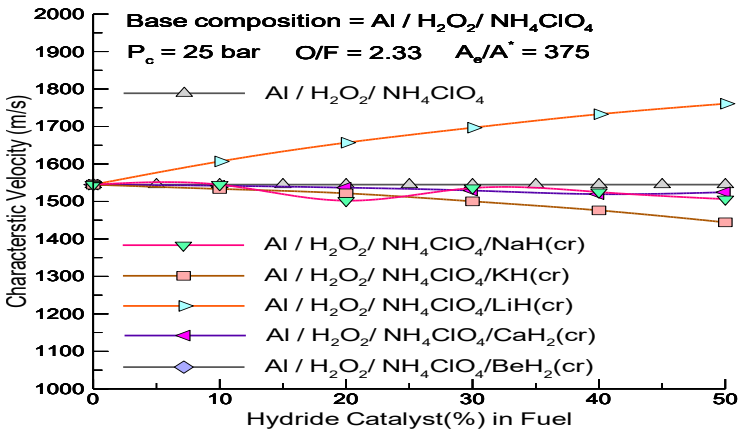


Figure 3: Variation of Specific impulse with the supersonic area ratio.



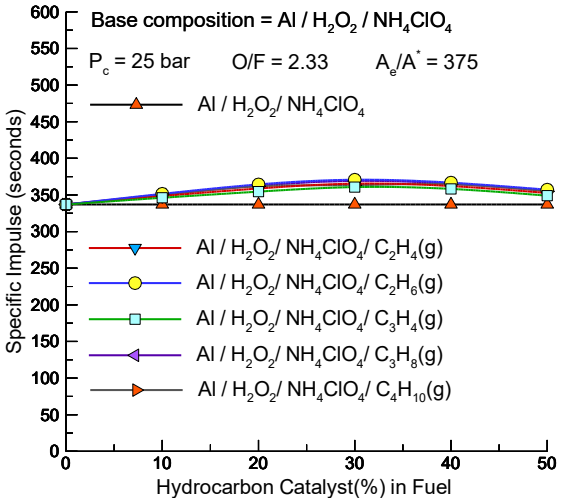
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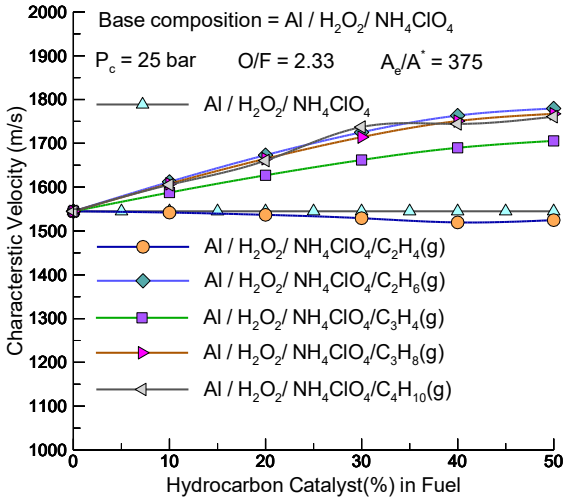
(b)

Figure 4: Variation of Specific impulse and Characteristic velocity (a & b) for the base composition with varying hydride energetic catalysts in Fuel proportion.

With increase in PBAN in the base composition from 14% HTPB and 1% PBAN to 14% PBAN and 1% HTPB, performance is noted to drop linearly from 262.201 secs to 260.499 secs. The trend was verified with the characteristic velocity which validates the decrease gradually from 1574.8 m/sec to 1566.2 m/sec. The results largely certify and validate the AP/HTPB/Al- [70/15/15] as the widely utilized base composition owing to the maximum performance. Next, we look in to the role of energetic fuels and of oxidizer to fuel (O/F) ratio in propellant composition.

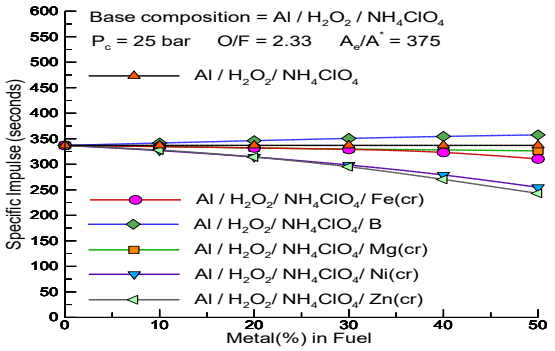


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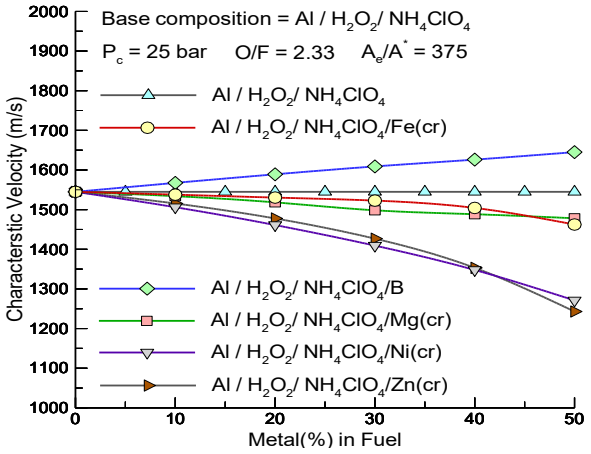


(b)

Figure 5: Variation of Specific impulse and Characteristic velocity (a & b) for the base composition with varying hydrocarbon energetic catalysts in Fuel proportion.

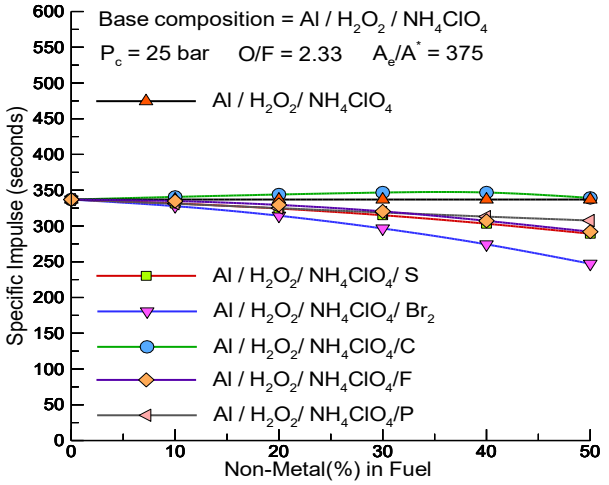


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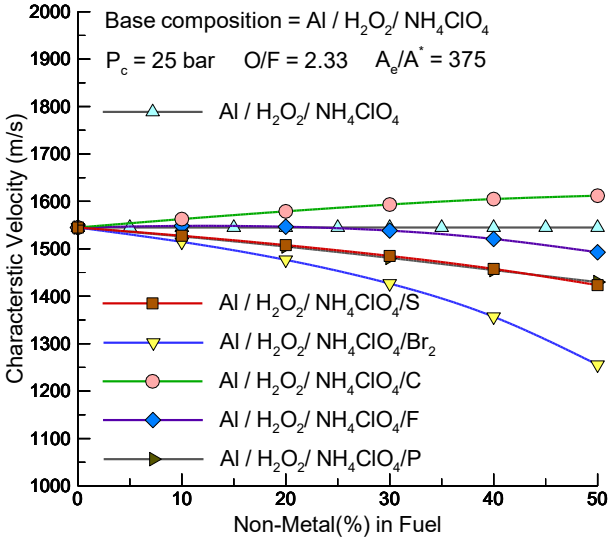


(b)

Figure 6: Variation of Specific impulse and Characteristic velocity (a & b) for the base composition with varying metal energetic catalysts in Fuel proportion.

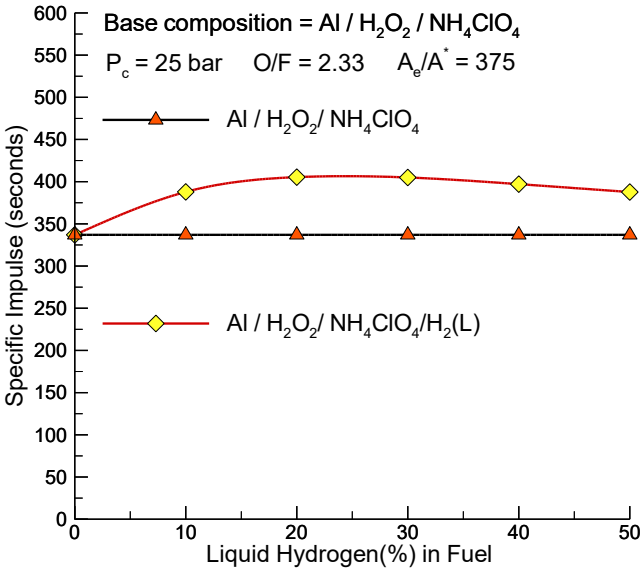


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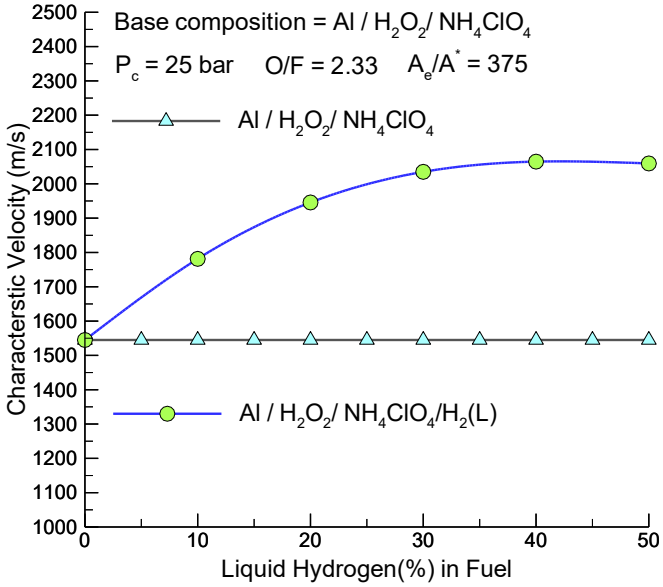


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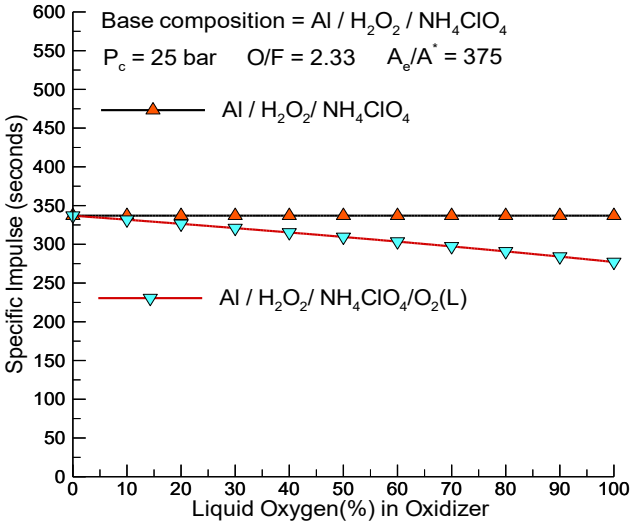
Figure 7: Variation of Specific impulse and Characteristic velocity (a & b) for the base composition with varying non-metal energetic catalysts in Fuel proportion.


Base composition = Al / H_2O_2 / NH_4ClO_4
P_c = 25 bar O/F = 2.33 A_e/A^* = 375
Al / H_2O_2/ NH_4ClO_4
Al / H_2O_2/ NH_4ClO_4/H_2(L)
Specific Impulse (seconds)
Liquid Hydrogen(%) in Fuel

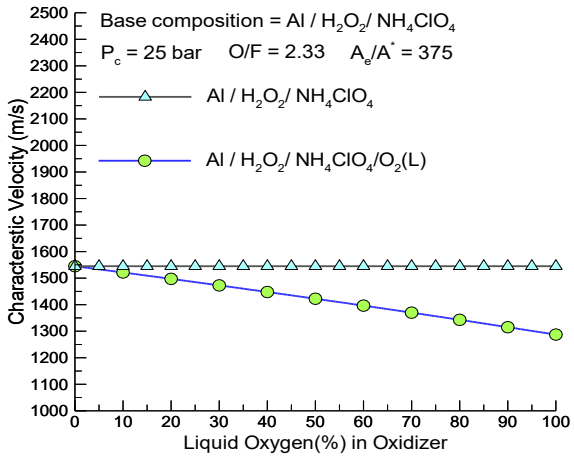
(a)


Base composition = Al / H_2O_2/ NH_4ClO_4
P_c = 25 bar O/F = 2.33 A_e/A^* = 375
Al / H_2O_2/ NH_4ClO_4
Al / H_2O_2/ NH_4ClO_4/H_2(L)
Characterstic Velocity (m/s)
Liquid Hydrogen(%) in Fuel

(b)

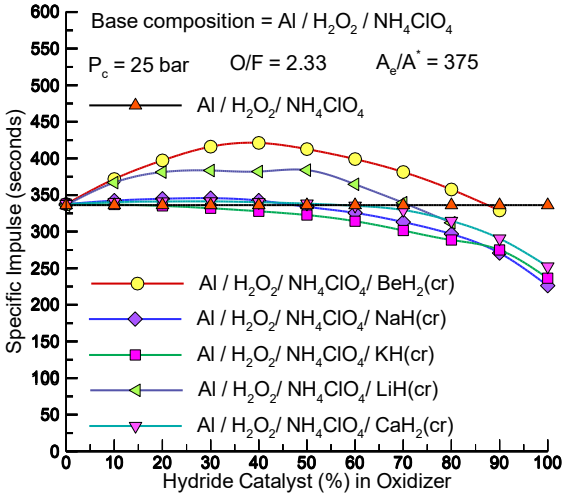

Base composition = Al / H_2O_2 / NH_4ClO_4
P_c = 25 bar O/F = 2.33 A_e/A^* = 375
Al / H_2O_2/ NH_4ClO_4
Al / H_2O_2/ NH_4ClO_4/O_2(L)
Specific Impulse (seconds)
Liquid Oxygen(%) in Oxidizer

(c)

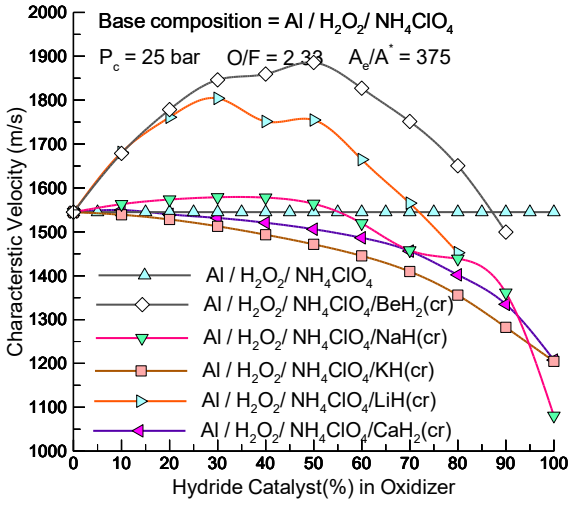


(d)

Figure 8: Variation of Specific impulse and Characteristic velocity (a, b, c, & d) for the base composition with Liquid Hydrogen and Liquid Oxygen Energetic Catalysts in Fuel and Oxidizer on Propulsive Performance of Missile (Semi-Cryogenic Hybrid Compositions).

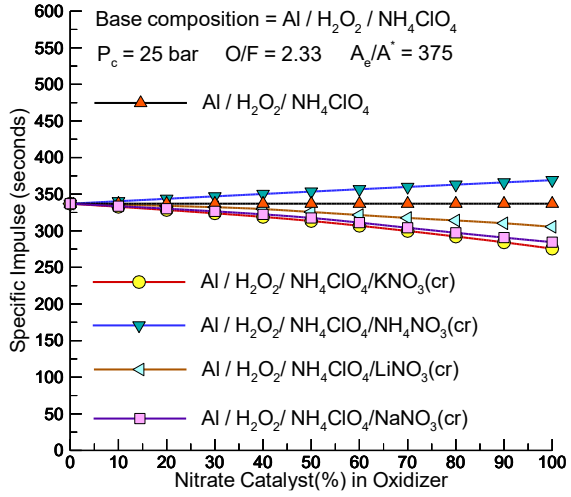


(a)

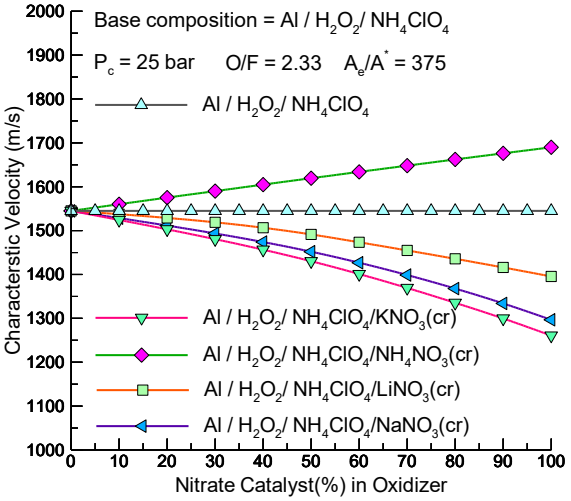


(b)

Figure 9: Variation of Specific impulse and Characteristic velocity (a & b) for the base composition with varying hydride energetic catalysts in Oxidizer proportion.

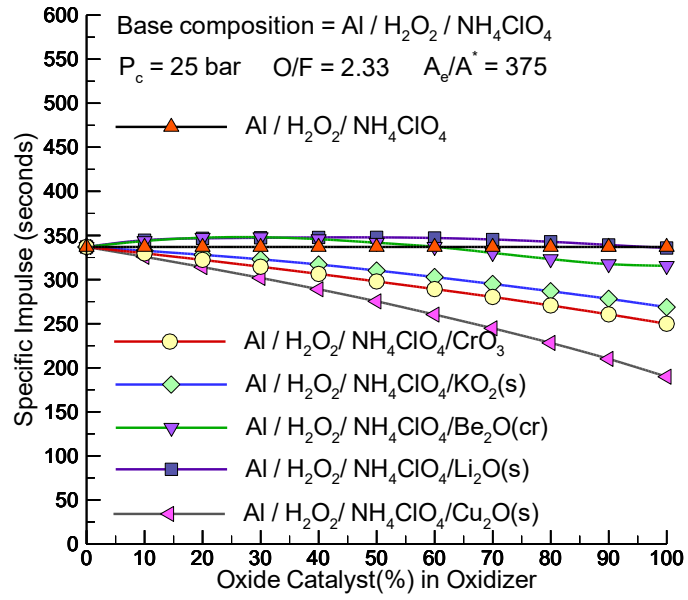


(a)

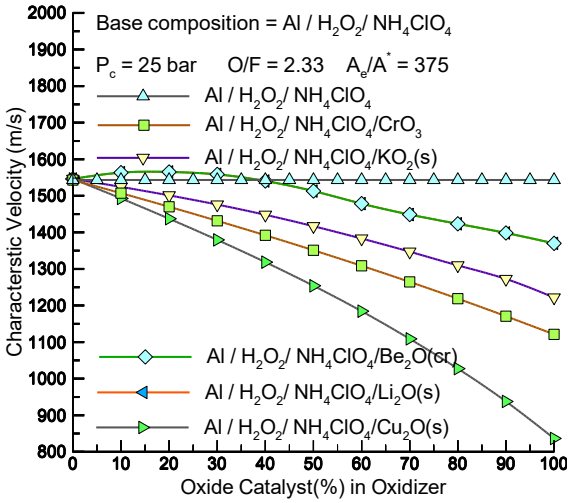


(b)

Figure 10: Variation of Specific impulse and Characteristic velocity (a & b) for the base composition with varying nitrate energetic catalysts in Oxidizer proportion.



(a)



(b)

Figure 11: Variation of Specific impulse and Characteristic velocity (a & b) for the base composition with varying Oxide Energetic catalysts in Oxidizer proportion.

4. CONCLUSIONS

Thorough numerical experiments were carried out on hypergolic propellant combination of MMH/N2O4 (Dinitrogen Tetroxide as the oxidizer (71.18%), and Monomethyl Hydrazine (28.82%) as the fuel). Selected energetic materials were utilized in the form of energetic fuels and oxidizers to evaluate the performance amplification. The predictions were compared with the source work [19] and benchmark experimental and theoretical works and matched reasonably well. Based on the results following conclusions may be drawn:

1. Under similar conditions, the cryogenic propellant combination of LH2/LOX exhibits higher performance than the base composition.
2. Metallized fuels viz., Aluminium, Iron, Gallium behaves as stark performance inhibitors owing to the induced chemical interference. The phenomenon prevents the activation of reactions owing to addition of materials leading to suppressed chemical progression.
3. The predicted upper stage energetic composition with carbon gives the highest increase of nearly followed by Boron, Beryllium, Deuterium, and liquid Hydrogen. Boron yields maximum amplification at 90% with 10.46% rise whereas, carbon results in maximum performance amplification of 21.20% than conventional cryogenic LH2-LOX combination. The results give a useful insight that adding liquid cryogenic hydrogen to the fuel doesn't do any good to the performance at large.
4. All hydride compounds result in enhanced upper stage propellant performance. Unlike their metal additives, the metallic hydrides outcomes increased performance possibly due to the direct consequence of inclusion of hydrogen in the molecules. Beryllium Hydride gives the highest rise in 'Isp' followed by Lithium Hydride and lastly Aluminum Hydride. Beryllium Hydride and Lithium Hydride exhibits increasing performance profile whereas, Aluminum Hydride depicts gradual rise till peak and then the change of rate of change drops.
5. Liquid Oxygen difluoride results in a maximum linear rise with 90% addition in the oxidizer. While the liquid ozone follows a monotonically increasing trend, the liquid oxygen exhibits neutralizing effect. Ozone is a triatomic allotrope of oxygen and much more reactive than oxygen due to its unstable nature and hence is a powerful oxidizing agent.
6. Liquid nitrogen trioxide yields increasing performance while, nitric acid and sodium nitrate drops propellant performance. It can be inferred that liquid nitrogen trioxide, nitric acid and sodium nitrate cannot be used as energetic materials as liquid nitrogen trioxide gives an insignificant rise in performance while nitric acid and sodium nitrate act as inhibitors. Hence establishing that primary effect in performance enhancement is done by the energetic oxidizer and the energetic fuel performs the secondary effect.
7. The present results represent repeatability and reproducibility of the order three.

Application of the work: The work primarily aims enhancement in the upper stage propellant performance along with minimization of over-dependence on cryogenic propellants. The result provides verified and validated compositions which are expected to perform better than the conventional cryogenics. The specific energetic materials can be used as per mission requirement for different upper stage operations and wide range of engineering, scientific, research, and practical applications.

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