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Energetic Green Propellants for Upper Stage

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ABSTRACT
Upper stage propulsion is a comprehensive area of importance. In recent decades, conventional propellants have been utilized. Cryogenic Propellants viz., Liquid Hydrogen (LoH) as fuel and Liquid Oxygen (LoX) as an oxidizer is conventionally used for upper stage propulsion. The excessive reliance on Cryogenic Propellants has entailed active research efforts for finding attractive and efficient alternatives. As an alternative, Liquid Methane (CH4) as fuel, and Liquid Hydrogen Peroxide(H2O2) is used as an Upper stage Propellant with a high specific impulse and hypergolic nature. This combination can be used in reaction controls and orbital maneuvers. The present work focuses on the use of green propellants for the upper stages. The selected propellants were tested by using the standard NASA-CEA complex chemical equilibrium program. Specific Impulse and Characteristic velocity were considered as performance parameters. The work is motivated by the need for environmentally friendly green propellants which can replace highly toxic hydrazines. The performance is evaluated in function of chamber pressure, Oxidizer to fuel ratio (O/F), and supersonic area ratio.

Keywords
Green Propulsion, Chemical Propellants, Energetic Materials, Cryogenic Propellants, Liquid Methane, Chemical Equilibrium.

1. INTRODUCTION
Conventional Propellants used for space exploration pose three environmental issues- *1) Biological issue*- This issue bound corrosiveness and toxicity of propellants. *2) Atmospheric issue*- This issue is generally caused because of propellant exhaust interaction with the atmosphere. *3) Ground-based Issue* – This issue range from contamination of Groundwater to Explosions that occurred by improper handling of propellants.

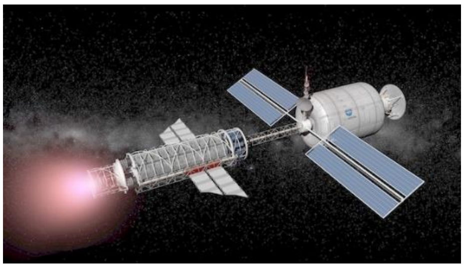

Fig 1: Space Propulsion

In the 1960s at the Institute of Aviation the Rocket propulsion technology was succeeded. For conducting researches on the atmosphere, a sounding rocket was developed by researchers. A solid Propellant based propulsion system was used to develop sounding rockets. As many of the convention propellants are toxic and carcinogenic hydrazine propellants. This challenges Researchers and Engineers to come up with an advanced, efficient, and environment-friendly composition that can be used for future space exploration. The present work highlight the use of Liquid Methane (CH4) as fuel and Liquid Hydrogen Peroxide (H2O2) as an Oxidizer as an attractive alternative for Conventional Hydrazines. Green Propellants are Preferred because of their environmentally friendly behavior. These propellants are considered even they have a moderate performance than standard propellants. Given these facts, green propellants are always preferred as it minimizes environmental impact. Green propellants are responsible to have their own environmental impacts.

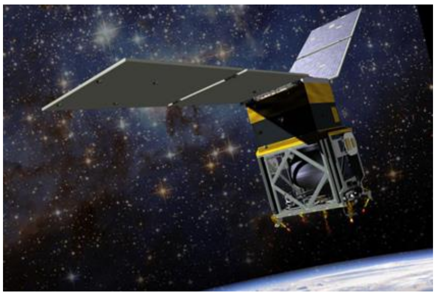

Fig 2: Green Propellant Technology

Since the 1960s, hydrazine and nitrogen oxides have been the primary propellants for chemical space propulsion [1]. These materials are still widely used in the space industry around the world. Hydrazine and nitrogen oxides (particularly nitrogen tetroxide) are considered undesirable propellants because to concerns about their deleterious impact on the environment and humans. These compounds are harmful when inhaled, ingested, or absorbed via the skin. Kao et al. [2] present several incidences of short-term human hydrazine exposure. However, no long-term consequences were observed with effective therapy. Sotaniemi et al. [3] described one deadly case. For six months, a worker was exposed once a week via inhalation. Hydrazine has also been reported to be carcinogenic and mutagenic [4, 5]. The fact is that this study was carried out on animals (mice, rats, rabbits, etc.). When hydrazine was exposed to humans, no cancer or mutagenesis effects were seen. Despite this, the European Chemicals Agency (ECHA) classified hydrazine as a chemical of

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extremely high concern in 2011 [6]. In the field of space propulsion, a new phrase has been coined: "green" propellant. It is a chemical that is non-toxic and environmentally beneficial. Many hydrocarbon fuels are considered "green" among all known propellants that may be stored for lengthy periods of time at ambient temperatures. The number of possible choices for monopropellants and oxidizers is substantially shorter. GRASP (acronym for Green Advanced Space Propulsion), a European Commission-funded study, selected rocket grade hydrogen peroxide (RGHP) as the most promising candidate for use as a hydrazine replacement in both monopropellant and bipropellant modes [7].

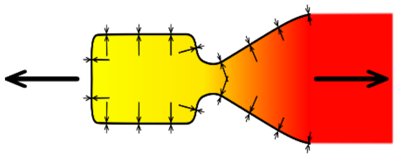

Fig 3: Rocket Thrust Force

When propellant is combusted, it produces a thrust due to the production of gaseous products. The burning process of the propellant in a rocket motor can be determined using thermodynamics. The Specific Impulse (Isp) is regarded as a performance metric. High specific impulse denotes high performance, implying that less propellant will be required to produce thrust, hence increasing rocket efficiency by reducing specific fuel consumption. We can link a specific impulse to the energy released in the form of-

$$I_{sp} = \Delta H^{1/2} \quad (1)$$

Where,

$$\Delta H = H_{Chamber} - H_{Exit} \quad (2)$$

'I_{sp}' is related to Combustion Chamber Temperature 'T_c'

$$I_{sp} = T_c^{1/2} N^{1/2} \quad (3)$$

where "N" is the number of moles of produced. The flame temperature 'T_c' increases when heat is released during combustion (equation 4).

$$T_c = \frac{-\Delta H_r}{C_p} N^{1/2} \quad (4)$$

Where, 'ΔH_r' *is* the heat of reaction, 'C_p' is the specific heat capacity.
The heat of reaction (ΔH_f) is given by:

$$\Delta H(T) = \Delta H_f(T)_P - \Delta H_f(T)_R \quad (5)$$

2. NUMERICAL SIMULATION AND METHODOLOGY

The approach incorporates the use of chemical propulsion software developed by CEA, a NASA-affiliated company (Chemical Equilibrium with Applications). This application calculates the parameters of sophisticated mixtures containing any number of reactants, as well as the final product's thermodynamic and transport properties. Shock-tube parameters for the incident and reflected shocks, assigned thermodynamic states, Chapman-Jouguet detonations, and theoretical rocket performance are all included in this program. Two cases of elevated conditions were considered. In starting The chamber pressure was fixed to 60 bar and Supersonic area ratio to 100 and the performance of fuel and Oxidizer was investigated in aid of Specific Impulse by Varying oxidizer to fuel ratio. Later, the chamber pressure was fixed to 330 bar and Supersonic area ratio to 40, and the performance was investigated.

3. VALIDATION OF SOFTWARE

The results were compared with recent research papers and it was well matched. The Software shows 98% accuracy when it is compared with Experimental Results. Evey data represents the repeatability and reproducibility of second order.

4. RESULT AND DISCUSSION

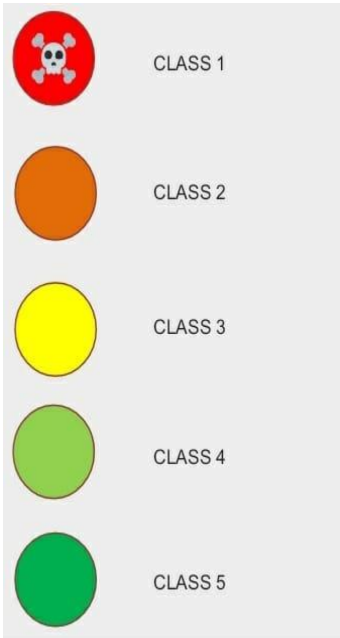

Fig 4: Toxicity Levels

In the Initial Stage, the toxicity of each propellant and oxidizer was checked. Only the propellants which fall in the Class 5 category were selected. Ranging from Class 1 to 5 as per Globally Harmonized System of Classification and Labelling of Chemicals.

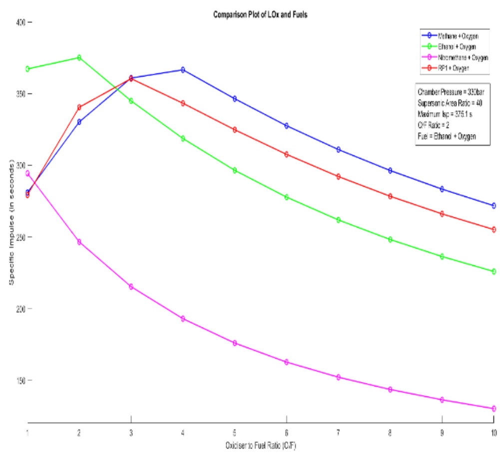

Fig 5: When Liquid Oxygen was Fixed as Oxidizer

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Liquid Methane, Liquid Ethanol, RP-1, and Niromethane were selected as fuels, and Liquid Oxygen, Hydrogen Peroxide, Nitrous Oxide, Dinitrogen Tetroxide were selected as Oxidizers.

Fig 6: Liquid Oxygen

In the Initial Stage (Figure 5), Liquid Oxygen was fixed as Oxidizer and the effect of Different Fuel was Investigated with the aid of Specific Impulse. The O/F ratio was Varied from 1 to 10 and Highest Performance was Observed when Ethanol was fixed as Fuel at O/F = 2. The Chamber pressure was maintained at 330 bar and a Supersonic area ratio of 40. The Specific Impulse of **375.1 Sec** was achieved when Ethanol was fixed at fuel. The trend followed is non-monotonic when different fuels were investigated with Liquid Oxygen.

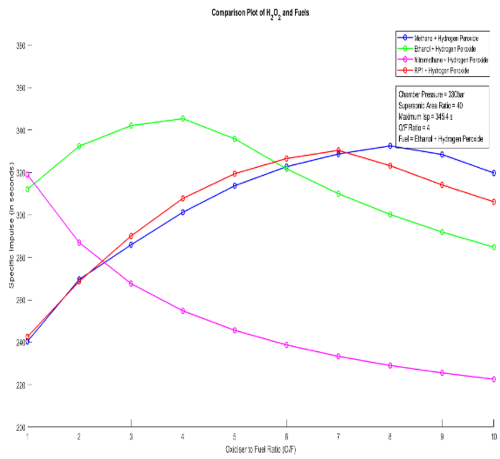

Fig 7: Liquid Hydrogen Peroxide as Oxidizer

Fig 8: Liquid Hydrogen Peroxide

In figure 7, Liquid Hydrogen Peroxide was fixed as Oxidizer and the effect of Different Fuel was Investigated with the aid of Specific Impulse. The O/F ratio was Varied from 1 to 10 and Highest Performance was Observed when Ethanol was fixed as Fuel at O/F = 4. The Chamber pressure was maintained at 330 bar and a Supersonic area ratio of 40. The Specific Impulse of **345.4 Sec** was achieved when Ethanol was fixed at fuel. The trend followed is non-monotonic when different fuels were investigated with Liquid Hydrogen Peroxide.

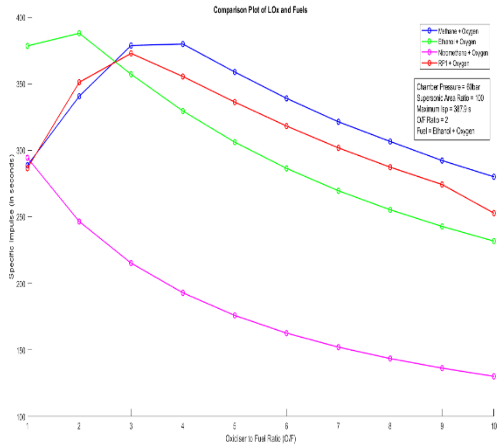

Fig 9: Liquid Oxygen as Oxidizer

In figure 9, Liquid Oxygen was fixed as Oxidizer and the effect of Different Fuel was Investigated with the aid of a Specific Impulse. The O/F ratio was Varied from 1 to 10 and Highest Performance was Observed when Ethanol was fixed as Fuel at O/F = 2. The Chamber pressure was maintained at 60 bar and a Supersonic area ratio of 100. The Specific Impulse of **387.9 Sec** was achieved when Ethanol was fixed at fuel. The trend followed is non-monotonic when different fuels were investigated with Liquid Oxygen.

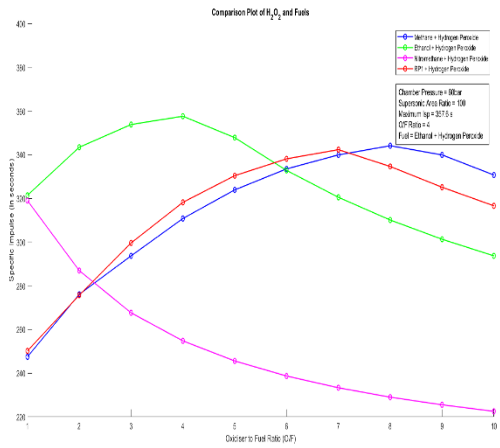

Fig 10: Liquid Hydrogen Peroxide as Oxidizer

Figure 10, shows when Liquid Hydrogen Peroxide was fixed as Oxidizer and the effect of Different Fuel was Investigated with the aid of a Specific Impulse. The O/F ratio was Varied from 1 to 10 and Highest Performance was Observed when Ethanol was fixed as Fuel at O/F = 4. The Chamber pressure was maintained at 60 bar and a Supersonic area ratio of 100. The Specific Impulse of **357.6 Sec** was achieved when Ethanol was fixed at fuel. The trend followed is non-

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monotonic when different fuels were investigated with Liquid Oxygen.

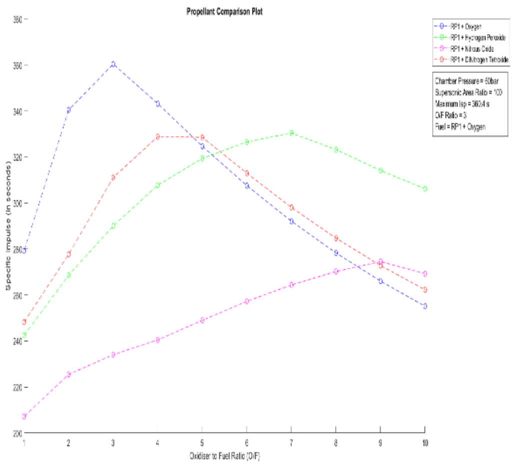

Fig 11: RP-1 as Fuel

Fig 12: Liquid RP-1

Figure 11 represents a comparison of Different Oxidizers when RP-1 was Fixed as fuel. Oxidizers like Liquid Oxygen, Hydrogen Peroxide, Nitrous Oxide and, DiNitrogen Tetroxide were Investigated. When Chamber Pressure was fixed to 60 bar and supersonic area ratio to 100 the highest performance of **360. 4 sec** was observed when O/F = 3 and Liquid Oxygen Fixed as Oxidizer. The O/F ratio was Varied from 1 to 10 and performance was evaluated.

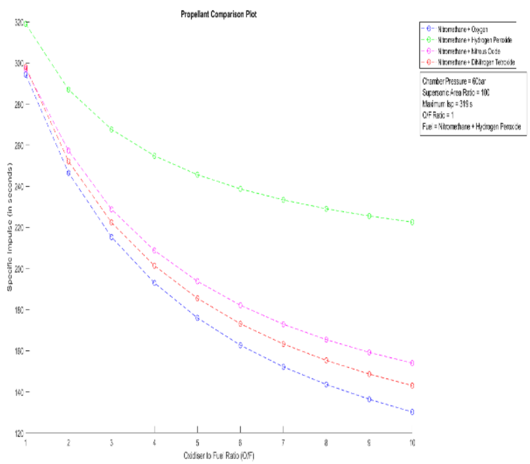

Fig 13: Nitromethane as Fuel

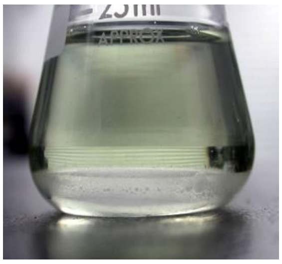

Fig 14: Liquid Nitromethane

Figure 13, represents a comparison of Different Oxidizers when Nitromethane was Fixed as fuel. Oxidizers like Liquid Oxygen, Hydrogen Peroxide, Nitrous Oxide and, DiNitrogen Tetroxide were Investigated. When Chamber Pressure was fixed to 60 bar and supersonic area ratio to 100 the highest performance of **319 sec** was observed when O/F = 1 and Liquid Oxygen Fixed as Oxidizer. The O/F ratio was Varied from 1 to 10 and performance was evaluated.

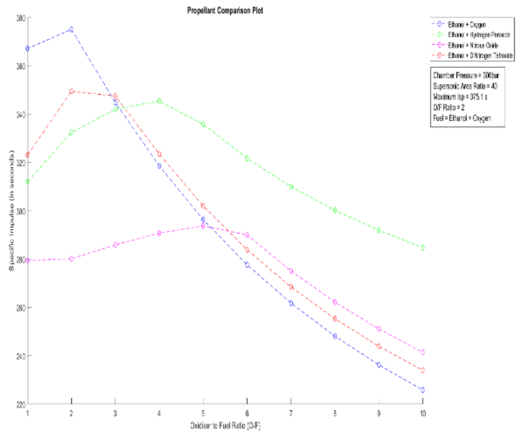

Fig 15: Ethanol as Fuel

Fig 16: Liquid Ethanol

Figure 15, represents a comparison of Different Oxidizers when Ethanol was Fixed as fuel. Oxidizers like Liquid Oxygen, Hydrogen Peroxide, Nitrous Oxide and, DiNitrogen Tetroxide were Investigated. When Chamber Pressure was fixed to 300 bar and supersonic area ratio to 40 the highest performance of **375.1 sec** was observed when O/F = 2 and Liquid Oxygen Fixed as Oxidizer. The O/F ratio was Varied from 1 to 10 and performance was evaluated.

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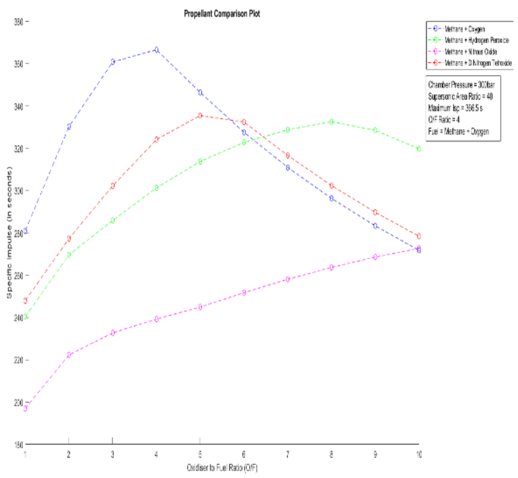

Fig 17: Methane as Fuel

Figure 17, represents a comparison of Different Oxidizers when Methane was Fixed as fuel. Oxidizers like Liquid Oxygen, Hydrogen Peroxide, Nitrous Oxide and, DiNitrogen Tetroxide were Investigated. When Chamber Pressure was fixed to 300 bar and supersonic area ratio to 40 the highest performance of **366.5 sec** was observed when O/F = 4 and Liquid Oxygen Fixed as Oxidizer. The O/F ratio was Varied from 1 to 10 and performance was evaluated.

5. Conclusion

1. The Performance of Different Fuels and Oxidizers were Compared.
2. The Highest Specific Impulse was Observed when Liquid Ethanol was Selected as Fuel and Liquid Oxygen was Selected as Oxidizer.
3. The Trend Followed by all the Propellant Combinations is the same. They Follow Non-monotonic Trend.
4. Liquid Ethanol and Liquid Oxygen can act as an attractive alternative to conventional cryogenics.
5. Liquid Ethanol, Liquid Methane Shows Highest Performance within Green Propellants Under elevated pressure conditions.

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