Design and Performance Analysis of Nano Aluminium-Hydro Thruster

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Abstract: The efficacy of using 'green' propellants for powering rockets has always endeavoured Aerospace researchers. Each conventional space flight expels about 200 tons of acidic substance at the exhaust. They also produce extreme levels of noise as the high speed exhaust mixes with the ambient air. In order to overcome these irregularities, a better performing propellant along with an efficient thruster design has become necessary. This report presents an insight into one such proposal of using a mixture of nano-scale aluminium and water as an effective and environmentally benign propellant for powering rockets. The proposed thruster is driven by the exothermic reaction of burning a mixture of nano-scale aluminium powder and ammonium perchlorate with water resulting in an accelerated jet exhaust.

The calorific value of aluminium, after the degradation of the oxide layer is comparable to that of modern day propellants. Also, the final powdered nano particles produced by pulsed plasma method have large surface areas required to be highly reactive [1]. The specific impulse of this particular reactant mixture is theoretically calculated to be higher than the present conventional propellants. The proposed thruster has a bell nozzle because of its high area ratio which in turn produces high thrust. Ignition is initiated by a pyrogen igniter, similar to the case of conventional solid propellants followed by flame spread and overall burning. Compared to the current gushing rocket engine thruster designs, the proposed design expels only a limited amount of hydrogen and aluminium oxide with an added advantage of noise reduction because of water jet injection. Therefore, it has the capability of reducing the pollution levels to an appreciable extent and could potentially serve as an attractive 'green' propellant for future space applications.

Keywords: Nano Aluminium; Thruster; Specific Impulse; Green Propellant.

1. INTRODUCTION

In the current scenario, the number of rocket launches around the world is increasing every year. During their flight, they emit excessive amounts of harmful toxic gases and the burning of ammonium perchlorate with metal powders release chlorine which makes the air particles acidic and affect the stratospheric ozone. Also, when the high pressure exhaust at hypersonic speeds mixes with ambient air, shock waves formation takes place, resulting in unbearable noise levels up to 200dB(A). In this study, an attempt has been made to tackle these issues through the use of nano scale aluminium and water mixture as a potential propellant for space applications. The thruster is based on the exothermic reaction of aluminium, a reactive metal and the third abundant element in earth's crust and uses a bell nozzle. Currently used Solid composite propellants contain about 16% of aluminium causing the heterogeneity to be less influential supporting the fact that aluminium is highly reactive. Moreover, this reaction mixture has a high specific impulse, meaning higher thrust compared to the conventional propellants and also releases reduced amounts of exhaust gases. Noise reduction due to water jet injection is another added advantage. These key points suggest that this Nano Al-H_2O could serve as a green propellant. The study is theoretical and assumes that the various parts have no frictional losses.

2. NANO ALUMINIUM-HYDRO THRUSTER

2.1Aluminium and water mixture

Aluminium, a chemical element in the boron group, is the third most abundant metal in earth's crust, making up about 8-10% by weight of the solid earth. It is highly reactive and found combined in over 250 different minerals. The widespread occurrence of *Al* isotopes has caused the substantial production of aluminium in the cosmos. Its occurrence in the Moon, Meteorites and Asteroids has been reported. It also occurs in the minerals beryl, cryolite, garnet, spinel and turquoise. It also occurs as Alumina, Sulphates, Chlorides, Halides, Oxides, Carbides, Nitrides and Niche compounds. Its production in the recent years has increased exponentially.

Aluminium reacts exothermically with oxygen as follows

$$2Al(s) + 3/2\ O_2\,(g) \leftrightarrow Al_2O_3\,(g) \quad (\Delta H^\circ\ (298K) = -\ 404\ kcal/mol) \qquad (1)$$

In order to ignite the oxide layer, the surface temperature is raised (~2300K). By "Glassman's Criterion", aluminium reacts with steam to produce aluminium oxide and hydrogen

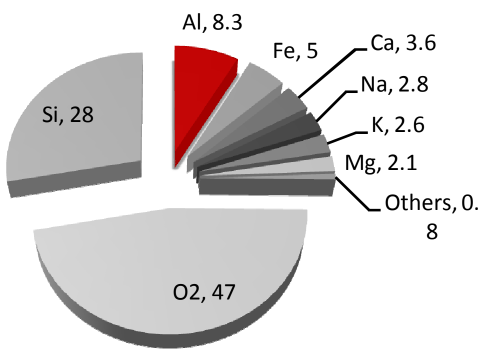
$$2Al(s) + 3H_2O\ (g) \leftrightarrow Al_2O_3(s) + 3H_2\,(\Delta H^\circ\ (298K) = -230\ kcal/mol) \qquad (2)$$

With addition of water the ignition temperature is reduced (~1600-1700K).

$$3H_2\,(s) + 3/2O_2\,(g) \leftrightarrow 3H_2O\ (g) \quad (\Delta H^\circ\ (298K) = -174\ kcal/mol) \qquad (3)$$

2.2 Preparation of Nano-Aluminium & Water mixture

Aluminium particles undergo a stepwise breakdown using a powered plasma setup in order to attain a particle size within the nanoscale range, typically about 80-100nanometres [2]. It is chosen over Dynamic Condensation because of its ability to synthesize richer quality powder. This powder is further processed by Supercritical Extraction to attain ultra-pure products free of impurities. The nano-sized aluminium powder is then, mixed with an apt solvent, generally oxides with ammonium perchlorate using a resonant mixer by coagulation to enable crystal habit formation. Electrostatic repulsion rate and pH levels must be monitored to correlate well with the thruster'sperformance. Catalyst polytetrafluoro-etheylene is used which also ensures that the final particles have high surface area necessary to be highly reactive. The resulting nanoparticles are identical crystal structures, That is, nano aluminium – ammonium perchlorate. They are coated with nickel in order to prevent the formation of oxide layer during ignition. The products of the exothermic reaction are aluminium oxide, aluminium chloride, water and nitrogen. The fuel is kept frozen in order to keep it intact and to avoid preliminary reactions. Sol-gel mixture is used in order to attain extra oxidative energy [3].



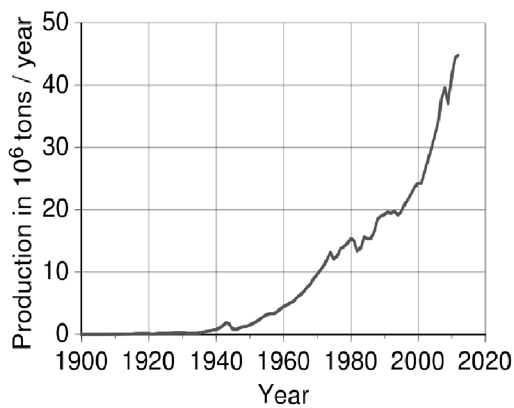


Figure 1.Abundance of elements in the cosmos **Figure 2.Production of Aluminium over the years**

The reaction of aluminium on Ammonium perchlorate is as follows

$$10\ Al + 6\ NH_4ClO_4 \rightarrow 4Al_2O_3 + 2AlCl_3 + 12H_2O + 3N_2 \quad (3)$$

2.3Thruster

The thruster is axis-symmetric and made up of aramid with a steel-aluminium alloy metal backup, which is selected because of its low coefficient of thermal expansion. The nozzle is of contour or bell shape, convergent-divergent type. In this type, the exit angle of a nozzle is suitably brought down by decreasing the semi divergent angle and shaping the nozzle in the form of a bell and keeping the length to be small. The initial divergence angle is about 25^o since the higher values of pressure in this region would not allow flow separation at walls. The final divergence angle is about 5^{o} in order to straighten up the flow and reduce the divergence loss. The area ratio is higher for a bell nozzle with respect to a comparable conical nozzle [4]. Its inner surface is lined with ablative liners such as carbon phenolic and silica phenolic. The throat is lined with graphite to maintain the mass flow rate under extreme temperature. In addition to insulation, these liners also provide a cooling effect.

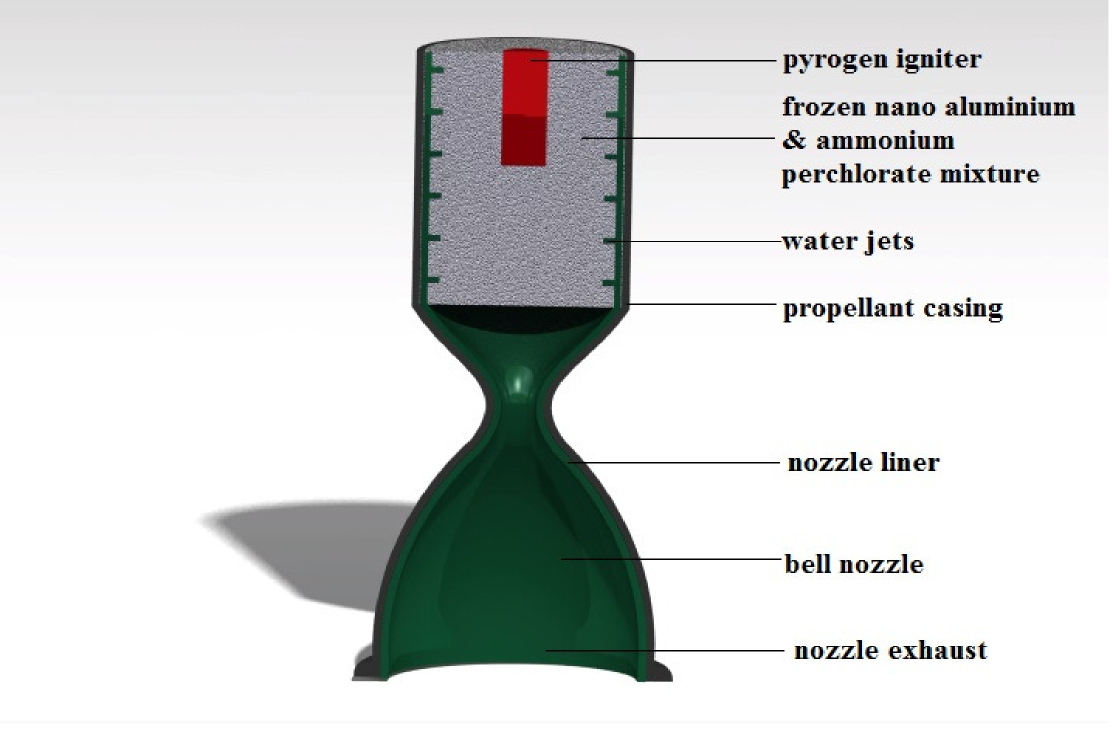


Figure 3.Cross sectional view of the convergent-divergent thruster

2.4 Ignition

The motor case of the rocket envelopes the nano-aluminium perchlorate mixture, similar to the process of setting up a conventional solid propellant. It is then ignited by a pyrogen igniter, which is a miniature rocket mechanism used for effectively igniting the propellant. It consists of a burnable mixture of potassium nitrate with charcoal powder and sulphur called as the 'black powder' in the ratio 0.75:0.15:0.10. Iron oxide thermite is additionally used to produce high temperatures and molten material crucial for ignition. Water jets are present internally for intensifying the ignition. Moreover the steam formed provides a cooling effect. The plume from the small rocket produces local ignition followed by a flame spread, which results in an overall ignition area, caausing overall burning leading to high amount of pressure producing thrust. The rocket is additionally accelerated by spinning it about its axis causing a centrifugal force which then pushes the flames to the outside, in order to increase its burn rate.

3. CALCULATIONS

Calculations were done with the following values in order to quantify the proposal

Table 1.values used for calculations

Quantity	Value
Chamber pressure (p_c)	15 Mpa
Specific heat coefficient(γ)	1.2
Coefficient of thrust	C_F
Characteristic velocity	C^*
Exit pressure (at 30Km)	0.00529Mpa
Molecular mass (m)	20 kg/kmole
Temperature	2500K
Gas constant	$8.314 JK^{-1}mol^{-1}$
Thrust	T
Area of throat (A_t)	$0.1\ m^2$
Area of exit (A_t)	$5\ m^2$

$$C_F = \sqrt{\frac{2\gamma^2}{\gamma-1}\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma+1}{\gamma-1}}\left(1-\left(\frac{p_e}{p_c}\right)^{\frac{\gamma-1}{\gamma}}\right)} + \left(\frac{p_e - p_a}{p_c}\right)\left(\frac{A_e}{A_t}\right) \quad (1)$$

= 1.3601 + 0.01365 = 1.3737.

$$C^* = \frac{1}{\tau}\sqrt{\frac{R_0 T}{m}}\ where\ \tau = \sqrt{\gamma}\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma+1}{2(\gamma-1)}} \quad (2)$$

= 1393.5677 m/s

$I_{sp} = C^* \times C_F$ (3)

=1914.3439 Ns/Kg

$T = C_F\, p_c\, A_t$ (4)

= 2.0605 MN.

Mass flow rate of the propellant

$= \frac{T}{I_{sp}}$ = 1076.3478 kg/s (5)

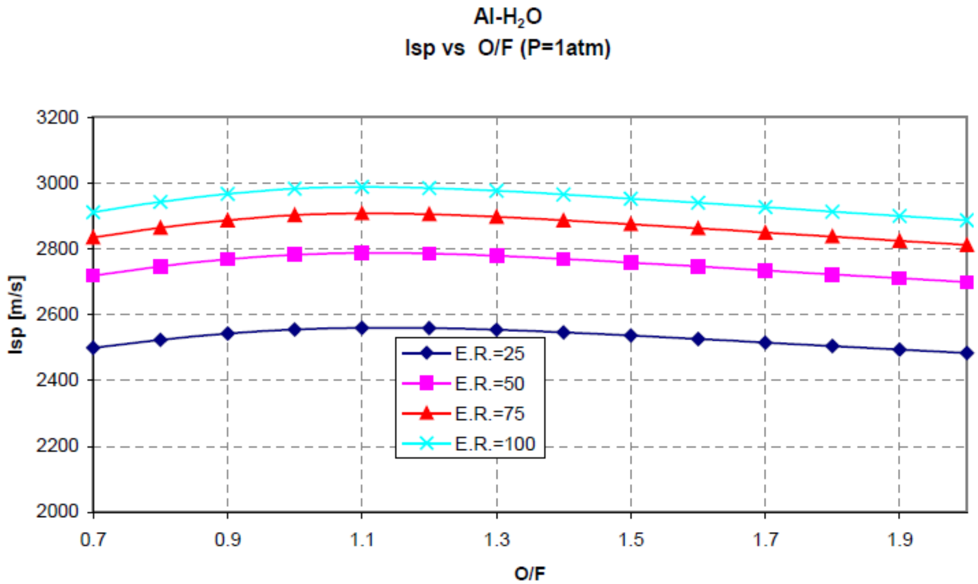


Figure 4.Specific Impulse VS Mixture ratio

A graph is plotted between different values of specific impulse with respect to the mixture ratios of aluminium and water and different expansion ratios at a pressure of 1atm. A peak value of specific impulse of about 3000m/s is attained with a mixture ratio of 1.1

4. CONCLUSIONS

The theoretical values calculated by using various formulae show that the thrust is in the order of Mega Newton as the specific impulse is high, affirming the fact that a thruster based on the exothermic reaction of nano aluminium powder and water with a bell nozzle could be used in rockets for better performance [5]. It is environmentally benign as it emits lesser amounts of pollutants with an added advantage of noise reduction, Therefore, could potentially serve as a '*green'* for future space applications.

The theoretical results should be verified experimentally, so as to be implemented as the propulsion system for rockets.

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