ISSN 2229-5518

Simulation Based on Ion-Ion Plasma Techniques Of Electric Propulsion in Mars Mission Using Chlorine Gas

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Abstract*:* The recently(Nov-5/2013) launched Mankalyan by the Indian space Research Organization (ISRO) to Mars orbit with Mankalyan contained by small liquid engine(MMH+N_2O_4).This will take long time to reach the Mars orbit that is around the 10 Months. Bi-Propellant rocket system has good thrust but low specific impulse and velocity. In future we need a rocket with good high specific impulse and high velocity of rocket system, to reduce the trip time to Mars. Electric propulsion rocket system is expected to become popular with the development of ion-ion pair techniques because this needs low propellant, Design thrust range is 2 N with high efficiency. An ion - ion pair of Electric propulsion rocket system is proposed in this work. Ion–Ion (positive ion- negative ion) Based Rocket system consists of three parts 1.The negative ionization stage with electro negative propellant 2. Ion-Ion plasma formation and ion accelerator 3.Exhaust of Nozzle. The Negative ions from electro negative gas are produced by adding up the gas, such as chlorine with electron emitted from an Electron gun ionization chamber. The formulate of large stable negative ion is achievable in chlorine gas with respect to electron affinity (ΔE). When a neutral chlorine (chlorine act as Electro negativity gas) atom in the gaseous form picks up an electron to form a Cl^- ion, it releases energy of 3.6eV. The negative ion density becomes several orders of magnitude larger than that of the electrons, hence forming ion-ion (positive ion – negative ion) plasma at the periphery of the discharge. The distance between ion-ions is important for the evaluate the rocket thrust and it also that the distance is determined by the exhaust velocity of the propellant. Accelerate the ion-ion plasma to a high velocity in the thrust vector direction via grids and the exhaust of ions through Nozzle. The simulation of the ion propulsion system has been carried out by MATLAB. By comparing the simulation results with the theoretical and previous results, we found that the proposed method is achieved of thrust value with high efficiency for simulating the ion propulsion rocket system.

Index Terms : Chlorine gas, Electron Affinity, Ion propulsion rocket, MATLAB ,Negative ion, positive ion, Plasma dynamic,

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1. INTRODUCTION

Electric thruster propels the Mars mission (long interplanetary mission) using the same basic principle as chemical rockets- accelerating mass and ejecting it from the vehicle. The ejected mass from electric thruster , however ,is primarily in the form of energetic particles. This changes the performance of the propulsion system compared to other types of thruster and modifies the conventional way of calculating some of the thruster parameter, such as specific impulse and velocity. The operation of this rocket system is based on the principle of Newton's third law "For every action there is an equal and opposite reaction".Ion propulsion systems use only 1/10 of the fuel used in chemical rockets .The thrust given by ion propulsion is relatively low (so they cannot, be used to leave earth), however, they provide the large velocity needed for long interplanetary Mission. The ion propulsion rocket system will take a lead role in the future rocket system. It reduces the total mass of the rocket and reaches the far-off targets at low thrust. This ion propulsion has three main parts namely 1.Ionization chamber 2.Ion acceleration 3.Exhaust Nozzle. The ionization chamber produces the ions with the help of RF power. While producing Ion, the internal temperature and pressure of the chamber is also increasing rapidly. The high pressured ions are ejected through ion acceleration chamber. The ion acceleration chamber

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enhances the thrust of the ions. The required thrust (mN) is produced with high RF power and Electric power for this propulsion Method and also the recombination between ions and electron is a rather slow process and the presence of electrons downstream adds to the ionization in this region. Hence, even if charge neutrality is insured a downstream plasma with charged particles exits outside of the thruster body, this plasma is known as the plasma plume. one of the major problems with the plasma plume is that the accelerated ions might undergo charge exchange collision with the slow neutrals, which then produces slow ions that can backscatter and deposit on the thruster body, solar panels, scientific instruments etc. The reaching of Mars orbit consumes a longer period of time approximately 10 months for the present's methods. The present methods are used to Bi-propellant ($MMH+N_2O_2$) techniques in mars mission. To overcome the above both difficulty the base is needed on the Ion-Ion pair techniques of ion propulsion rocket system. The new Ion propulsion rocket system is now intensively studied of based on Negative ion pair with using chlorine Gas. In addition, chlorine atoms can gain electrons through plasma cathode electron gun (PCE) is heated to form negatively charged ions. A plasma cathode electron gun has capabilities for generating high current, broad and focused beams for plasma assisted microwave sources. The knowledge of the mean free path, λ is useful to evaluate the distance from which negative ions can be extracted and to understand the relative importance of collision with positive ions but the collision process is very high range for this process and it will possible highly for the attractive force between the ion - ion plasma. Calculated the distance (λ) between ion-ion plasma, Its main determined factor (λ) divided by time taken is calculated for the exhaust ion velocity of propellant. The Mass flow rate is calculated with the help of ion particle mass in terms of proton mass. The required thrust is produced with high exhaust velocity. The proposed method is to reach the Mars orbit less than 10 Months.

2 Equations

Rocket equation: The mass ejected to provide thrust to the Interplanetary Mission (IM) is the propellant, which is **carried onboard the vehicle and expended during thrusting.** From conservation of momentum, the ejected propellant mass times its velocity is equal to the IM mass times its change in velocity. The "rocket equation" describing the relationship between the IM velocity & the mass of the system is derived as follows.

The force on a IM and thus the thrust on the vehicle, is equal to the mass of the IM, M, times it changes in velocity:

$$Force = T = M\frac{dv}{dt} \quad (1)$$

The thrust on the IM is equal and opposite to the time rate of change of the momentum of the propellant, which is the exhaust velocity of the propellant times the time rate of change of the propellant mass.

$$T = -\frac{d}{dt}(m_p\, v_{ex}) = -\, v_{ex}\frac{dm_p}{dt} \quad (2)$$

Where m_p is the propellant mass on the IM and v_{ex} is the propellant exhaust velocity in the IM of reference. The total mass of the IM at any time is the delivered mass, m_d plus the propellant mass, m_p

$$M(t) = m_d + m_p \quad (3)$$

The mass of the IM changes due to consumption of the propellant, so the time rate of changes of the total mass is

$$\frac{dM}{dt} = \frac{dM_p}{dt} \quad (4)$$

Substituting Eq.(4) into Eq.(2) and equating with Eq.(1) gives.

$$M\frac{dv}{dt} = -v_{ex}\frac{dM}{dt} \quad (5)$$

Which can be written as

$$dv = -v_{ex}\frac{dM}{M} \quad (6)$$

For motion In a straight line, this equation is solved by integrating from IM initial velocity v_i, to the final velocity v_f, during which the mass changes from its initial value, $m_d + m_p$, to its final delivered mass, m_d:

$$\int_{v_i}^{v_f} dv = -v_{ex} \int_{m_d+m_p}^{m_d} \frac{dM}{M} \quad (7)$$

The solution to equation (7) is

$$v_i\text{-}v_f = \Delta v = v_{ex} \ln\left(\frac{m_d}{m_d+m_p}\right) \quad (8)$$

The final mass of IM delivered after a given amount of propellant has been used to achieve the specified Δv *is*

$$m_d = (m_d + m_p)e^{-\Delta v/v_{ex}} \quad (9)$$

Thrust :The governing Newton's second law equation is simplified by making of thrust as per the assumptions given below.

Thrust is a force supplied by the Rocket engine to the IM. Since the IM mass changes with time due to the propellant consumption ,the thrust is given by the time rate of changes of the momentum ,which can be written as

$$T = \frac{dm_p v_{ex}}{dt} = \dot{m}_p v_{ex} \quad (10)$$

Where $\dot{m}_p$ *is* the propellant mass flow rate in is $\frac{Kg}{s}$, v_{ex} is the exhaust ion velocity of the propellant.

Mass flow rate ($\dot{m}_p$**):** For a cumulative period of days of operation, need for amount of chlorine propellant (m) is

$$m = \dot{m}_p t_p \quad (11)$$

$$(\, t_p = number\ of\ \ days\ X\ 24\ X\ 3600\,)$$

Calculation of propellant flow rate from equation (2) shown below

$$\dot{m}_p = \frac{m}{t_p} \quad (12)$$

Other Method of calculated, propellant flow rate of ion- ion plasma is related to the ion beam current (I_b) at acceleration process via Grids

$$\dot{m}_p = \frac{I_b M_i}{q} \quad (13)$$

Where M_i is the Mass of the ion particles in terms of Mass number, q is charge of electron

Exhaust velocity : The cross section around 10^{14} m² . When attachments of electron with chlorine gas to form a negative ions. The knowledge of the mean free path is useful to in order to evaluate the distance from which negative ions can be extracted and to understand the relative importance of collision. In these case of collision of negative ions with another heavy particle (a positive ion) the mfp, λ is defined as

$$\lambda = \frac{1}{n\sigma}\ at\ \Delta E \geq 3.6ev \quad (14)$$

n is the positive ion density, The electron affinity is calculated as per the following condition

$\Delta E =$ Delivering energy at Negative ions.

The without collision process starts when $\Delta E < 3.6ev$. The time (τ_o) taken for the distance (λ) between collision with positive ion related to the Accelerating voltage is, by

$$\tau_o = \sqrt{\frac{M_i}{2ev}} \quad (15)$$

V is the net voltage through which the ion was accelerated. The exhaust ion velocities (v_{ex}) can be calculated from the equation of state.

$$v_{ex} = \frac{Distance\ betweem\ \ ion\ pair(\lambda)}{time\ taken\ between\ ion\ ions\ (\tau_o)} \quad (16)$$

The equation (13) and (16) is the substitute into equation (10), the final thrust equation is

$$T = \frac{I_b M_i}{q} \frac{\lambda}{\tau_o} \quad (17)$$

3 RESULTS & DISCUSSION

The rate coefficients calculated due to the velocity of electron were taken with slight variation in the energy level of electron beam. The simulation results shown in figure.1

ISSN 2229-5518

indicate a linear dependence of the operating rate co-

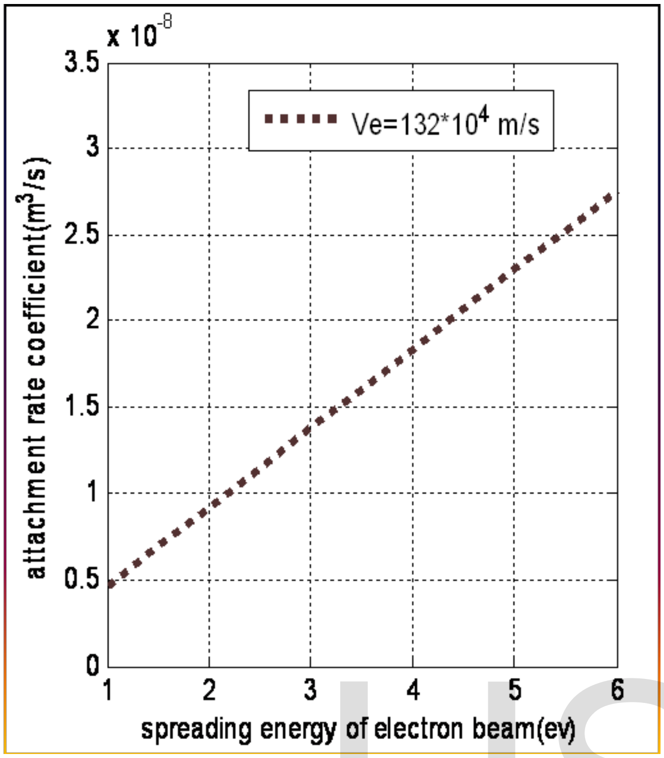
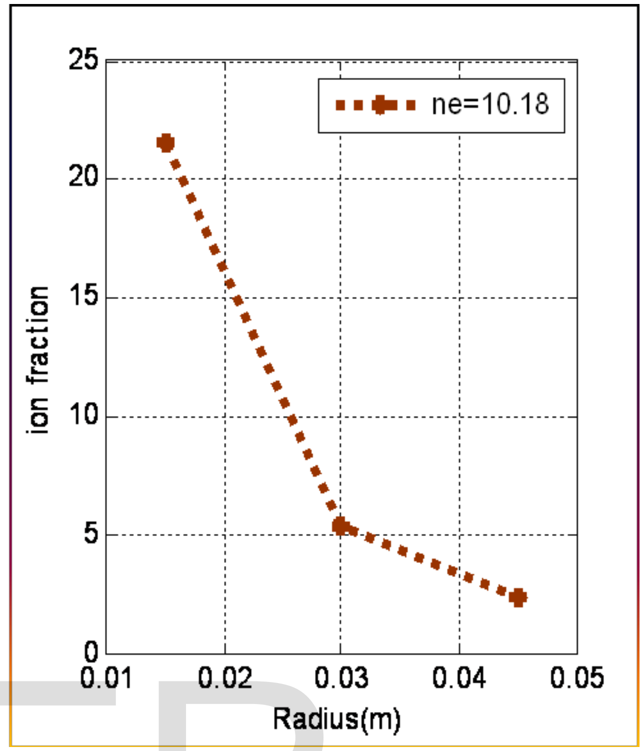


Figure 1.Attachment rate co-efficient as a function of energy of electron beam .

efficient on the energy level of electron beam. The linear dependence typical to velocity of electron with a mass of electron (9.1×10^{-31}) is opposite to the supply of voltage dependence in a spreading energy of electron beam(eV). Furthermore, a electron beam is in interaction with a chlorine atom in the rate of co-efficient is extremely large and inversely proportional to the mean free path. In this case most electrons created are converted to negative ions, hence forming ion-ion plasmas. Figure 2 shows the radial negative ion fraction (α) due to magnetic fields and confirms that for high magnetic field (500 G), the plasma presents the usual stratified structure with an electronegative (α *is large*) at radius of 0.015m.the plasma appears electro negativity along the whole radius. In addition, for $r > 0.12\ m$ the negative ion density becomes several orders of magnitude larger than that of the electron. The reducing of ion fraction value at high radius because of negative ion density is larger than electron, hence forming



FiFigure.2. shows the ion fraction as a function of radius. The sy System is a function of cylinder with 0.05 m long.

Ion- ion plasma. The figure 3 shows negative ion densities and electron densities as a function of radius for the magnetic field case. The ion fraction increases and negative ion density becomes of lowest order of the electron density. At a radius $\geq 0.015m$, the ion – ion plasma formed with an negative ion density of the order of 10^{19} m^3.The positive ion-negative ion charge amount of ions is created at underneath range of electron affinity ($\Delta E \geq 3.6eV$).Its range is should be around > 4eV which is proposed for this technique. The thrust force depends only on the ion -ion charged particles and must be of the different "sign" if the two ions are of the different charge ,they will move in the same direction .Table.1 is calculated to have the parameter of mean free path due to density of ion per volume. The final energy of ion- ion plasma depends on temperature, distance between collision ions dependence on the attachment of cross section. The cross section along with the attachment of electron beam to atom under the Initial

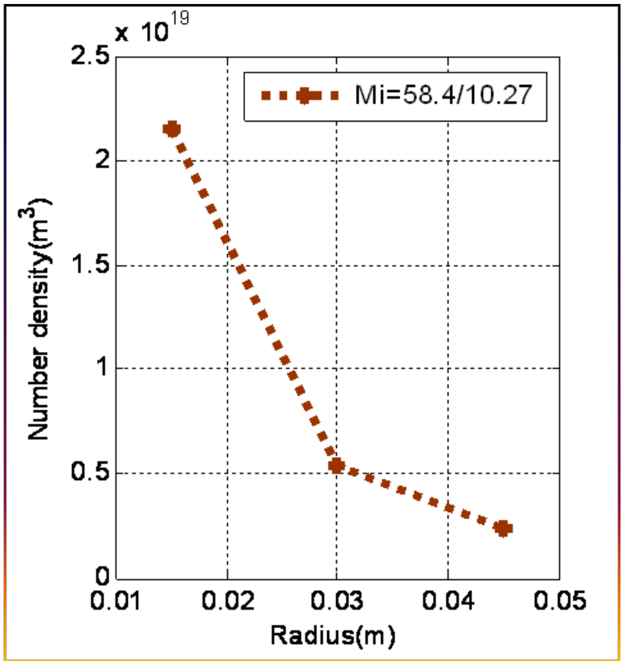


Figure.3. The negative ion densities as a function of radius.

TABLE.1
CALCULATED THE DISTANCE (MFP) BETWEEN ION-ION PLASMAS.

Radius(m)	Density/m^3	Distance(m)
0.015	10^{20}	$1.3*10^{-3}$
0.200	10^{19}	$1.2*10^{-2}$
0.300	10^{17}	$2.5*10^{-1}$

energy of spreading electron. The cross section area around $0.1x10^{-9}$ m² at the temperature value 34815K and distance between ion-ion plasma value is $1.2x10^{-2}$ m. The figure 4 shows the time taken is calculated due to accelerating voltage taken with slight variation in the distance between ion- ion plasma. The ion- ion plasma is formed on a longer time scale in the order of 10^{-7} second.

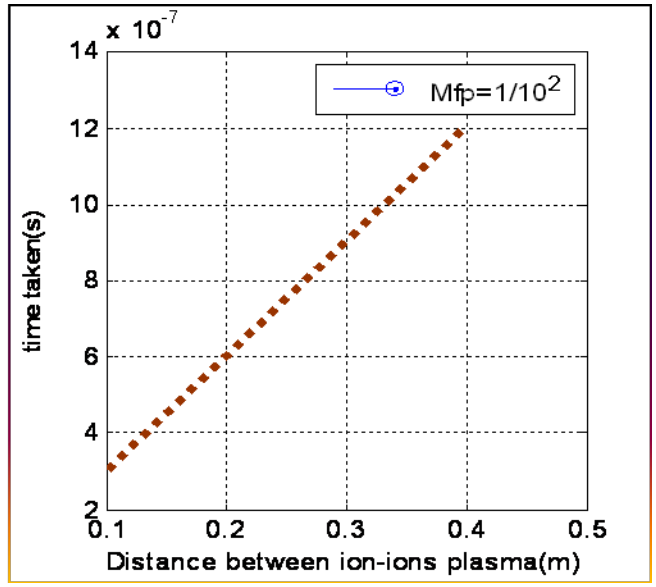


Figure.4.Time taken is calculated as a function of distance between same ions

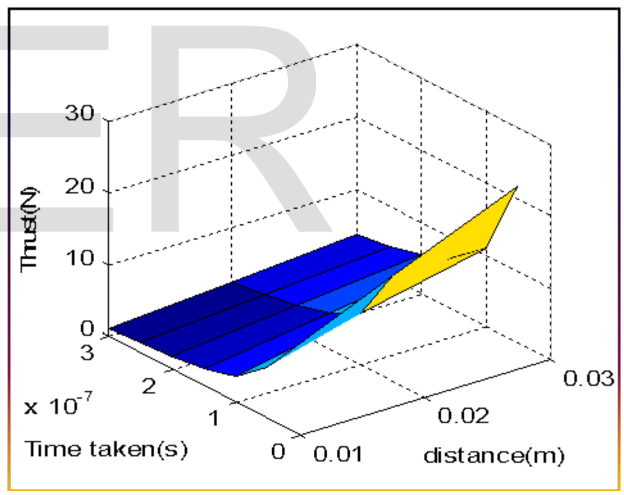


Figure.5. Thrust of the ion propulsion rocket system as a Function of distance to time.

For data presented in Figure.5, The ion propulsion rocket system used a total ion bean Current is from 20A to 100A, Accelerating ions via grids, after acceleration process, Electron is filtering with using Magnetic fields .Time scale in the order from 10^{-6} to 10^{-7} seconds ,the value of distance between ion-ion plasma 10^{-2} to 10^{-1} m, which yields simulated results that show a total thrust of 2 N at velocity of 28000 m/s.

4 COMPARING RESULTS

The previous technique is developed to the ion propulsion rocket system (generally is called electric propulsion) with using mostly ion-electron pair method. The large amount of electric power is needed for the developing of the thrust because of the range of ionization energy 1170KJ/mol (or) 12eV is involved for removing electron from atom to form positive ion with Electron. The reduction in collision

TABLE: 2
PREVIOUS METHOD IS COMPARING WITH PROPOSED METHOD.

Parameter	Ion–electron pair	Negative ion pair
Engine	**Ion engine(Hall thruster, Magneto plasma dynamic)**	**ion propulsion with ion-ion pair**
Thrust	**67.2 mN**	**2 N**
propellant	**Xenon(Xe)**	**Chlorine(cl)**

Process is possible at high electric power, then in the production of good thrust in electric propulsion. Operating this scheme only high temperature. The electrical mobility value records approximately 1.4cm^3 / V, for positive small ions. The proposed method is the low electric power which is needed to develop the thrust because of the range of electron affinity 349 KJ/mol or 3.6eV is involving for attachment of electron from atom to form negative ions. Its ion - ion plasma process occur at the range of $\Delta E \geq 3.6eV$ and operation only at low temperature. The electrical mobility value is approximately 1.9cm^3/V, for negative small ions.

5 CONCLUSION

The Electro negativity gas thruster is a new concept of plasma propulsion where ion- ion Pairs are used for thrust. Initially plasma production is achieved with Negative ion by using gain electrons to chlorine atom through plasma cathode electric Gun is heated to form negatively charged ions. The negative ion densities is larger than electron densities as a function of radius, then forming of ion-ion pair at $r \geq 0.12m$ with a ion density of the order of 10^{19} m^3.it will reaction rate coefficient and cross section increases due to function Energy level. The attractive force will be forceful when the two ions are different and provides for an accelerating thrust. At low electric power and different charges negative ion-positive ion is formed on a longer time scale in the order of 10^{-6} to 10^{-7} . The finally achieved thrust value reaches as 2 N.

ACKNOWLEDGEMENTS

This work is supported by the Dr.D.Ravikumar,Professor, Department of English, PSN college of Engineering & Technolgy.

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