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Magnesio-Marine Thruster

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Abstract

Human endeavor in underwater has necessitated active research efforts aimed at better understanding of propulsion of the underwater vehicles (UV). The submarines form an integral part of a nation's security and play a vital role that cannot be reprised with operations ranging from highly technical weapons systems to sensors for distinctive intelligence on potential disasters. Although, much has been done but a perennial question in the development of submarines especially those that are volume limited, is how fast these vehicles can cruise in the paucity of adequate thrusters. To date, no comprehensive study has appeared in the open literature addressing this issue. The present work is an initial attempt to address this deficit by systematically analyzing a marine thruster and vehicle performance with magnesium as a potential fuel. Here, in this work a theoretical study had been conducted to gain physical insight into the use of magnesium in the thruster in submarines. The proposed thruster is driven by the exothermic reaction of burning magnesium powder with water resulting water jet exhausts. The calorific value of magnesium is comparable to that of modern day fossil fuels, additionally powdered magnesium has more surface area for reaction compared to strips, coils etc hence increasing the rate of reaction. The thruster has two steps of actuation; first magnesium powder in kerosene is pushed into fuel injectors by a valve mechanism, followed by opening of the conical divergent inlet to let a stream of flow pass through a duct and ignition of magnesium powder. Kerosene is used because it can be easily ignited, immiscible in water and ensures the smooth flow of magnesium into the fuel injector. The initial divergent section of the thruster reduces the speed of water flow, so as to ensure reaction to take place and the convergent section increase the exhaust velocity, thereby generating more thrust. It is worth noting that, the reaction of magnesium with water produces 1921 KJ/mol, which generates more thrust in submarines than the existing thrusters.

Keywords: Submarine; thrusters; magnesium; thrust; performance.

1. Introduction

In the current scenario, the submarines operate at low speeds, compromising speed for stealth, as a result of which they become easy victims of torpedo attacks when the stealth property is uncovered. The low speed also challenges the time with which a submarine can reach the site of operation. In this study, an attempt has been made to tackle these issues through the use of magnesium thruster which proposes to increase the speed and maneuverability of submarines. The thruster is based on the reaction of magnesium, an alkaline earth metal and the eighth most abundant element available in the earth's crust and water, the medium of the submarine's operation. The highly reactive magnesium is found in the form of ores and in sea water as salts. The hydration of magnesium is an exothermic reaction was proposed to be used to generate additional thrust in submarines. The extra thrust hence generated is to be used for speed augmentation and maneuvering in submarines, giving it an added advantage and opportunity to survive torpedo attacks when targeted. Feed mechanism of powdered magnesium proved to be challenging which was overcome in the course of this study. The study conducted is purely theoretical and assumes the efficiencies of the various parts to be unity with no friction losses.

2. Magnesio-marine thruster

2.1 Magnesium and its occurrence

Magnesium as mentioned earlier is the eighth most abundant element in the earth's crust. The highly reactive alkaline metal, occurs in deposits of magnesite ($MgCO_3$), dolomite ($CaMg(CO_3)_2$), brucite $Mg(OH)_2$, carnallite ($KMgCl_3.6(H_2O)$), talc ($Mg_3Si_4(OH)_2$), and olivine, and in mineral waters, where magnesium ion is soluble.

Sea water is a good source of magnesium as it is available in the form of $MgCl_2$. Mg^{2+} ions are the second most common.

$$MgCl_2 + Ca(OH)_2 \rightarrow Mg(OH)_2 + CaCl_2 \qquad (1)$$

Magnesium hydroxide (brucite) is insoluble in water so it can be filtered out, and reacted with hydrochloric acid to obtain concentrated magnesium chloride.

$$Mg(OH)_2 + HCl \rightarrow MgCl_2 + 2\ H_2O \qquad (2)$$

Electrolysis of $MgCl_2$ thus produced gives magnesium.

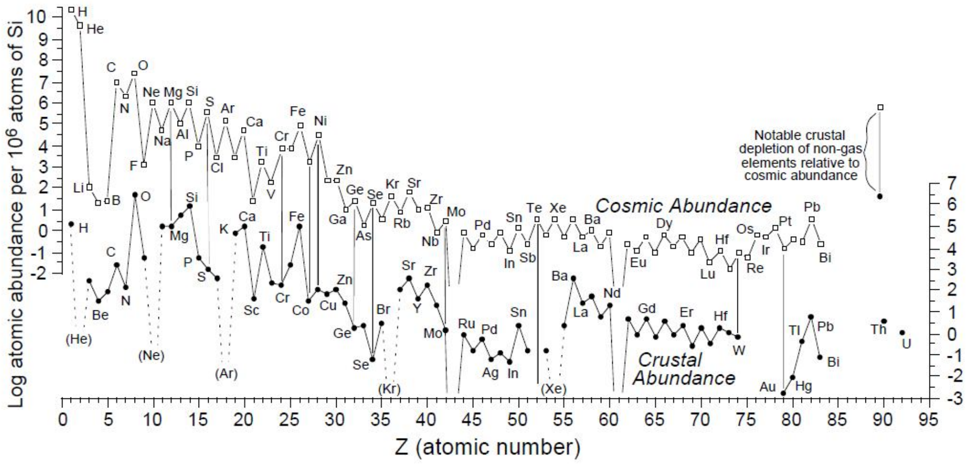

Figure 1: The diagram above shows the relative abundance of the elements in the cosmos and in Earth's crust. Note that the diagram has a logarithmic vertical scale, and in fact it has two vertical scales offset to separate the cosmic and crustal data.

2.2 Thruster:

A thruster is a device proposed to be used in submarines to increase the speed or to maneuver. The thruster is to be consisted primarily of a nacelle and an injector. The axis-symmetric nacelle made of inconel, a material used in the combustion chamber of jet engines, so as to withstand heat produced by the reaction, is of divergent-equiradial-convergent type, the divergent section is used to introduce some turbulence in the flow so that water could mix well with magnesium powder, the equiradial section is to act as a reaction chamber for the water flow, and the convergent section increases the exit velocity which in turn increases the thrust. The injectors are to be placed at the initial half of the equiradial section of the nozzle, so as to provide more room for the reaction. The section view of the proposed thruster is shown in figure 2.

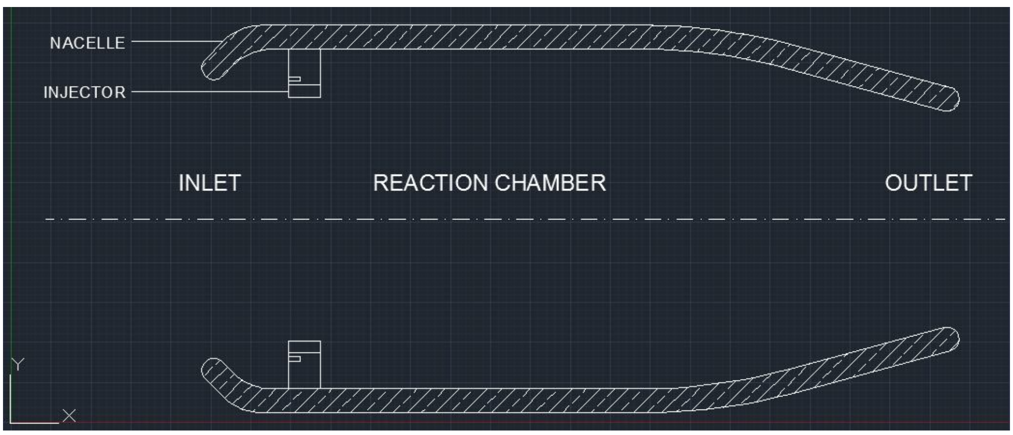

Figure 2: Cross Sectional View of Divergent-Convergent Thruster.

2.2.1 Injector: This component is to be used to inject burning magnesium powder in kerosene into the stream of water entering the thruster. The injector mechanism is similar to that of reciprocating piston used in IC engines. In the proposed mechanism, magnesium powder in kerosene is to enter the piston when the valve of injector is closed and the piston rod is at lowest position. As the piston rod moves towards top position, the inlet of the injector is to be closed. Further compression leads to rise in pressure and magnesium is burnt using Spark Igniter. In the subsequent step, the outlet valve of the injector is to be opened and burning magnesium powder is to be injected into the main stream. As soon as the piston looses the contact with highest point the outlet valve is to be closed, and when it reaches the lowest open inlet valve is to be set open. This procedure is repeated several times to get proper amount of thrust for working of a thruster. The working of injector is shown in figure 3.

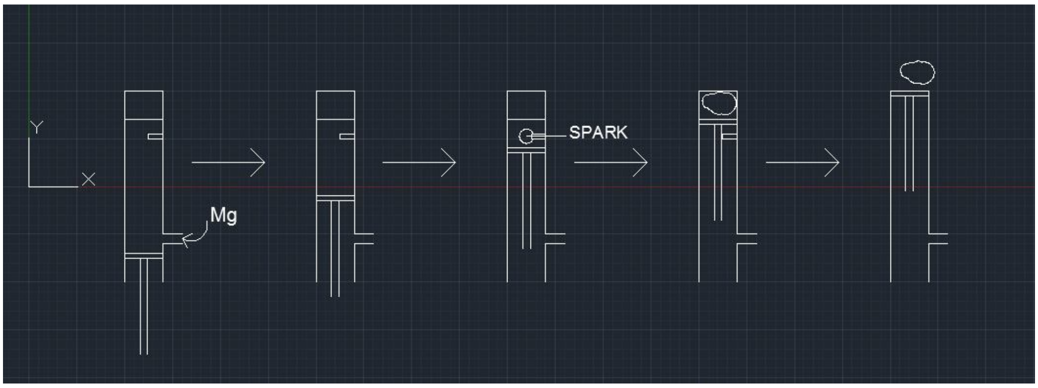

Figure 3: Mechanism of Injector using Spark Ignition.

2.3 Calculations:

Based on the following assumptions calculations were done, in order to quantify our attempt to propose magnesium thrusters for submarines.

$$Mg + H_2O \rightarrow MgO + H_2 \quad (3)$$

$$MgO + H_2O \rightarrow Mg(OH)_2 \quad (4)$$

Table 1: Values used during the Calculation.

Variable	Value
Inlet Pressure (P01)	13 bar (13 x 105 Pa)
Inlet Temperature (T01)	295 K
Velocity (vw)	12.8 m/sec (25 Knot)
Specific Heat of Water at Constant Pressure (cp)	4.186 KJ/kg K
Hydration Enthalpy (Q)	1921 KJ/mol (80KJ/gram)
Reaction Chamber Outlet Temperature	T02

Static Temperature	T
Velocity Outlet from Reaction Chamber	c
Area Ratio of nozzle	a
Fuel Ratio	f

Reaction Chamber- $c_pT_{01}+fQ = c_pT_{02}$
$T_{02} = (fQ/c_p) + T_{01}$
$T_{02} = (80*10^3/4.186) + 295$ K
$c = (2c_p(T_0-T))^{1/2}$
For maximum velocity at the point static conditions must be zero.
Therefore, $c = (2c_pT_0)^{1/2} = (2469.74 + 159997.292f)^{1/2}$

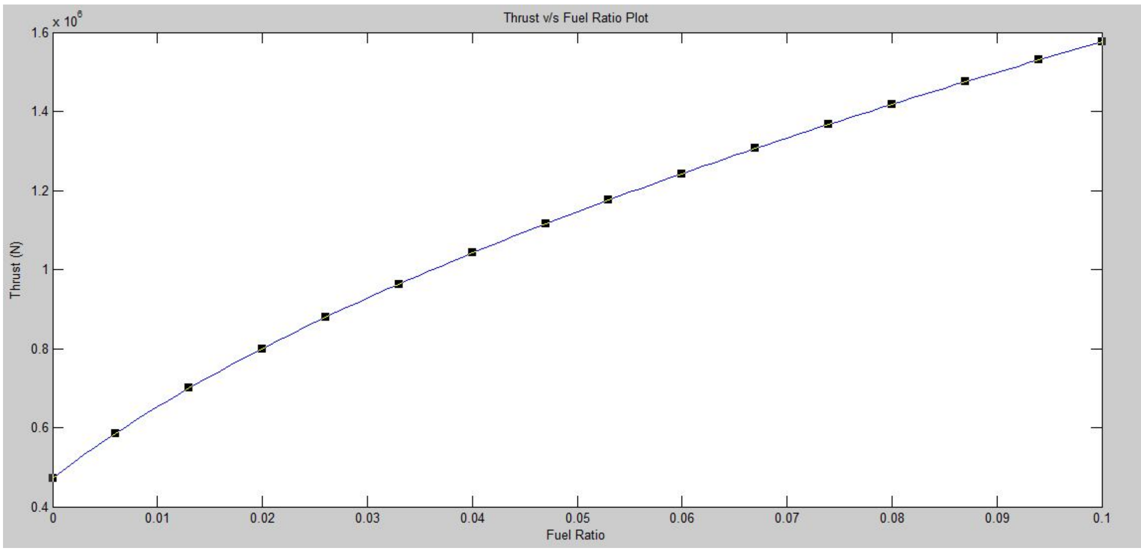

Figure 4: Thrust vs Fuel Ratio graph.

With fuel ratio varying from 0 to 0.1, a graph of thrust vs fuel ratio was plotted using Matlab.
Thrust= (mass flow rate)*$(c-v_w)$ = 12800 * (c-12.8) N
Th = 12800 * $((2469.74 + 159997.292*f)^{1/2} - 12.8)$ N
Assuming f=0.01, Th=12800*(c*a-12.8)

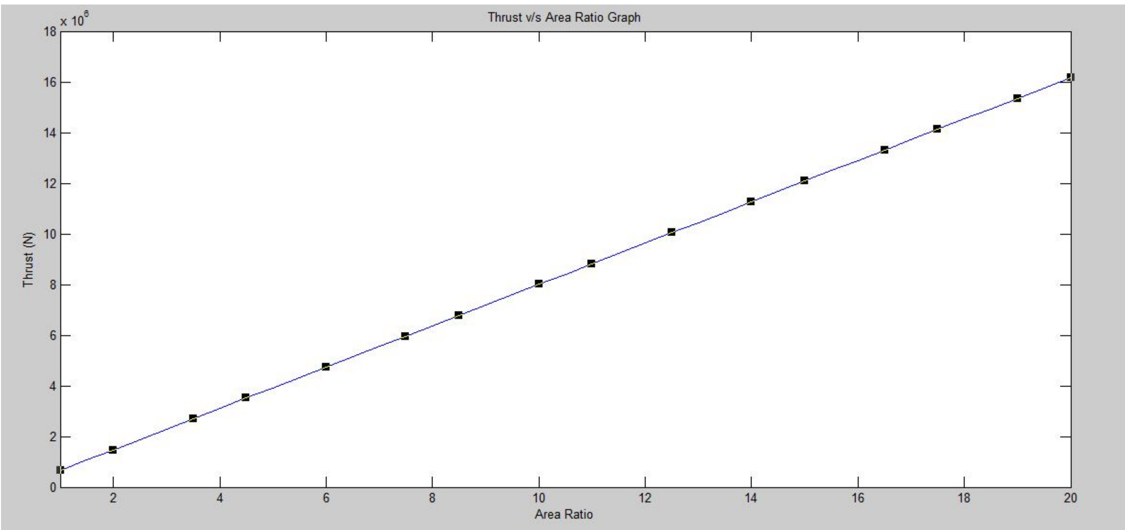

Figure 5: Thrust vs Areal Ratio of nozzle graph.

2.4 Theoretical Results

From both the graphs plotted, thrust of the order 6 was computed for fuel ratio more than 0.03. The graph between the thrust and fuel ratio was found to be quadratic and that between thrust and area ratio was linear.

3. Conclusions

The theoretical results obtained on various assumptions showed that the thrust produced is of the order of Mega Newton, affirming the argument that a thruster based the hydration of magnesium, could be potentially used in submarines for better speed and stealth properties.

The speed and maneuverability is to be improved by the usage of a jet of water, whereas stealth property is an added advantage as the noise produced is lesser in the case of water jet thrusters. The theoretical results should be verified experimentally so as to be implemented in modern submarines for increased performance.

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