Conceptual study of Variable Specific Impulse Magneto-Plasma Engine On-Board Vessels

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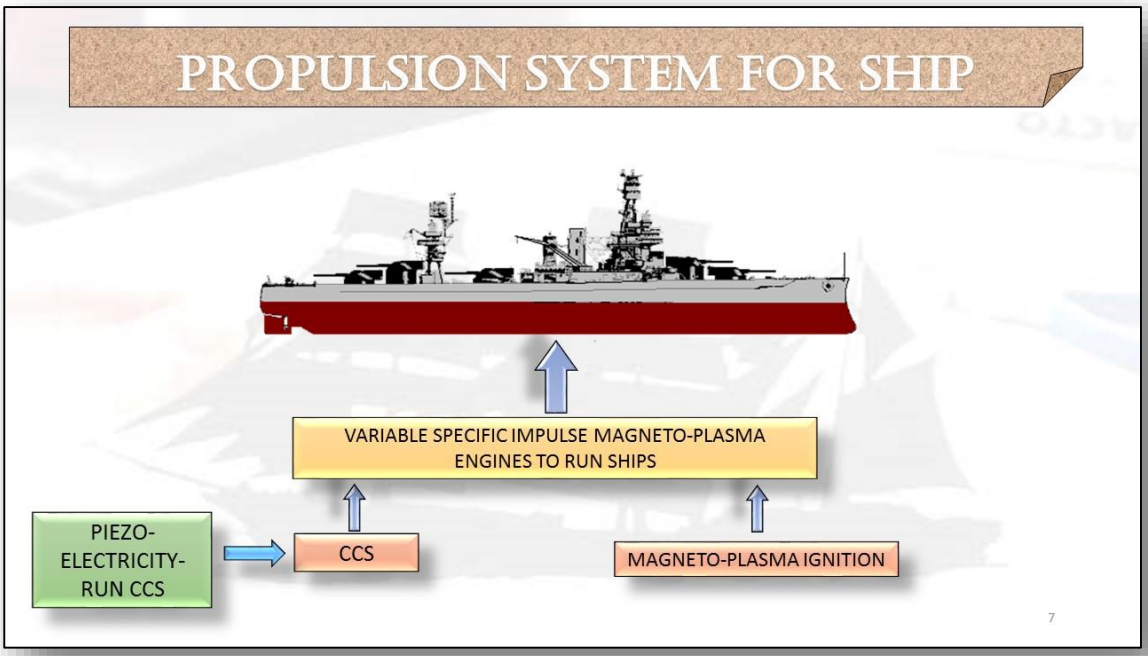
Abstract: This paper deals with the conceptual study of Variable Specific Impulse Magneto-Plasma Engines for propulsion of merchant vessels. The optimum performance for Variable Specific Impulse Magneto-Plasma Enginesis obtained with LH2 and LOX fuels which will be efficiently produced using CCS technology.It will help in reducing oil-bunkering, overall cost, fuel consumption as well as emissions. In addition, the innovative concept of piezo-electricity generation and its application have been discussed with respect to vessels. These technologies and design has the potential to be very sustainable in the long-term.
Keywords: Variable Specific Impulse Magneto-Plasma Engines, CCS, Ion Cyclotron Heating (ICH), Electro-Chemical Acidification Cell, Piezo-Electricity

1. Introduction

In this modern era, imports and exports play pivotal role in our day to day life. Majority or we may say 90 percent of these imports and exports are carried out by shipping industry. This transportation of goods involves huge running cost and heavy emissions to the environment. With the alarming rate of increase in emissions from shipping vessels and growing inflation it's necessary to have a technology cut out or a change to both reduce emissions as well as to meet the investments. Keeping this concern in the mind we propose an idea to use Variable Specific Impulse Magneto-Plasma Engines in future vessels. Variable Specific Impulse Magneto-Plasma Engines are modern rocket engines that utilises liquid hydrogen and liquid oxygen as fuel or oxidiser to create thrust. Variable Specific Impulse Magneto-Plasma Engines are far more efficient and advantageous over modern Internal Combustion engines. With the use of Variable Specific Impulse Magneto-Plasma Engines emissions can be minimised to the minimal level. This engine runs on clean fuel because of which the only combustion product is H2O. However, here rises an issue of bunkering clean fuel that is LOX and LH2 on board vessels. This can be resolved by producing clean fuel on-board using Carbon Capture Skid (CCS). This technology produces sufficient amount of liquid hydrogen and oxygen which is in abundance as required. The CCS

also produces 200 gal/day of hydrocarbon fuel which can be used to power generators as well as other auxiliary machines and pumps. Variable Specific Impulse Magneto-Plasma Engines prove to be icing on the cake. When compared to old conventional Cryogenic Engines, it proves to be much faster and safer. Efficiency of engine increases with mere use of radio waves to ionise and heat the propellant. Researches on these have also proved them to be efficient for lighting fuel such as LOX and LH2.



Electricity for CCS plant can be assisted with the use of piezo-ceramic pads. These pads are capable of producing fairly high amount of electricity with low as well as high frequencies. These pads can be installed beneath bed-plates or machineries with heavy weights and vibrations, ships flooring, bulbous bow and other such parts which are under some load or face vibrations.

2. Principles Involved

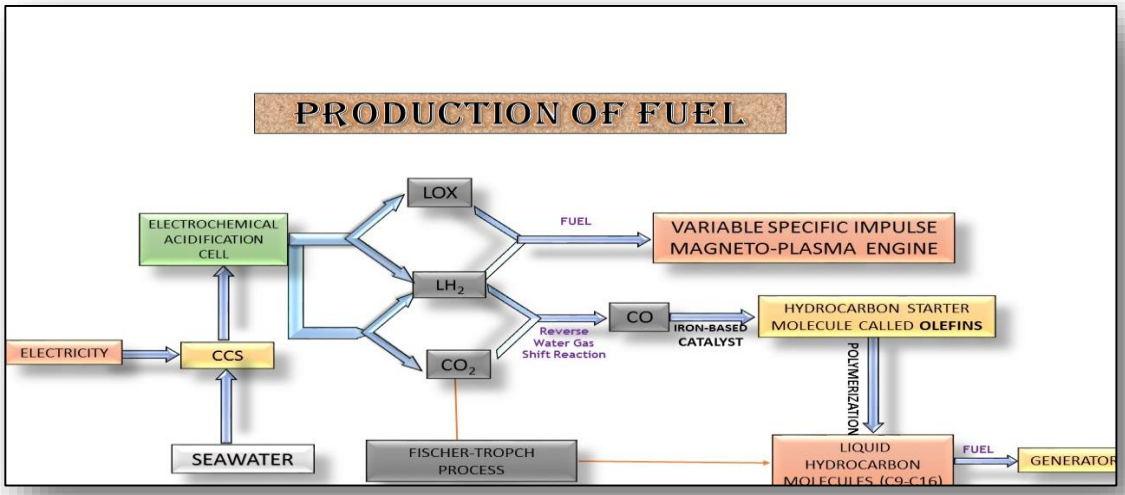
Variable Specific Impulse Magneto-Plasma Engines:-
The Variable Specific Impulse Magneto-Plasma Engineis a newly developed electromagnetic thruster for spacecraft propulsion. It makes use of radio waves to ionize and heat a propellant, and Magnetic field to accelerate the resulting plasma which generates thrust. It is a type of engine which is electrodeless belongs to the same electric propulsion family as electrodeless plasma thruster, the microwave arc jet, or the pulsed inductive thruster class.

Carbon Capture Skid (CCS):-
This technology is used to extract liquefiedHydrogen (H2) with a concomitant production of liquefied Oxygen (O2) and removal of Carbon dioxide (CO2) from seawater. This extracted LH2 and LOX can serves as fuel for cryogenic-engine. This is achieved through the use of Electrochemical Acidification Cells. Simultaneously

Fischer-Tropsch reaction with extracted CO2 and H2 produces Hydrocarbon fuels that can be used to run generators and boilers.

Piezo-Electricity:-
Some atomic lattice structures have as an essential unit (or "cell") a cubic or rhomboid cage made of atoms, and this cage holds a single semi-mobile ion which has several stable quantum position states inside the cell. The ion's post ion state can be caused to shift by either deforming the cage (applied strain) or by applying and electric field. The coupling between the central ion and the cage provides the basis for transformation of mechanical strain to internal electric field shifts and vice versa.

3. Main text



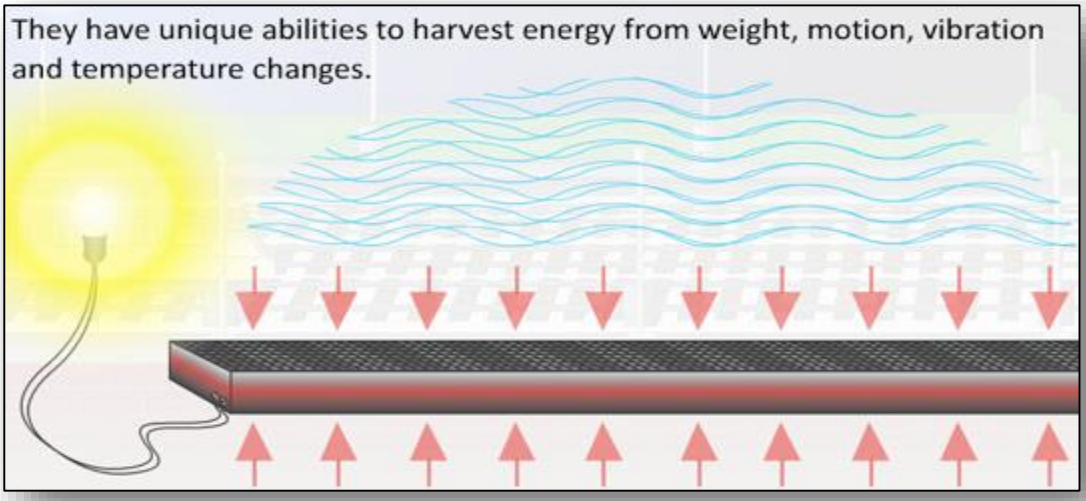
3.1 Variable *Specific Impulse Magneto-Plasma Engines:-*

3.1.1*Piezo-Electric pads to run CCS Plant to generate propellant for Variable Specific Impulse Magneto-Plasma Engine*

Squeeze certain crystals and we can make electricity flow through them. The reverse is true as well; if we pass electricity through the same crystal, they squeeze themselves by vibrating back and forth it is known as piezo electric effect.

- Stretching PSI-5A (1.5" x 2.5" x .0075") sheet to ±500 micro strains quasi statically at a frequency just below its fundamental longitudinal resonance of 15 KHz, and that we collect 100% of the stored electrical energy at its height twice per cycle we would get **approximately 9 watts** of electrical power from the sheet.

- On-board, the piezo electric pads can be installed in all pressure sensitive areas and areas with high vibrating forces such as bed plate of various machineries, beneath cargo hold, accommodation etc.



- The charges in the piezo electric crystal are exactly balanced even if they are not symmetrically arranged.
- The effect of charges exactly cancel out, leaving no net charge on crystal face.
- If we squeeze crystal charges are forced out of balance.
- Now dipole moments no longer cancel one another and net positive and net negative charges appear on opposite crystal faces.
- By squeezing the crystal, voltage across its opposite faces is produced-this is known as piezo electric effect and electricity generated is known as piezo-electricity.
- This electricity is feed to large batteries where it stored.
- Then it is utilised to run CCS Plant.

3.1.2*Extraction of Propellant (LH2, LOX AND CO2) by Electrochemical Acidification in CCS from seawater*

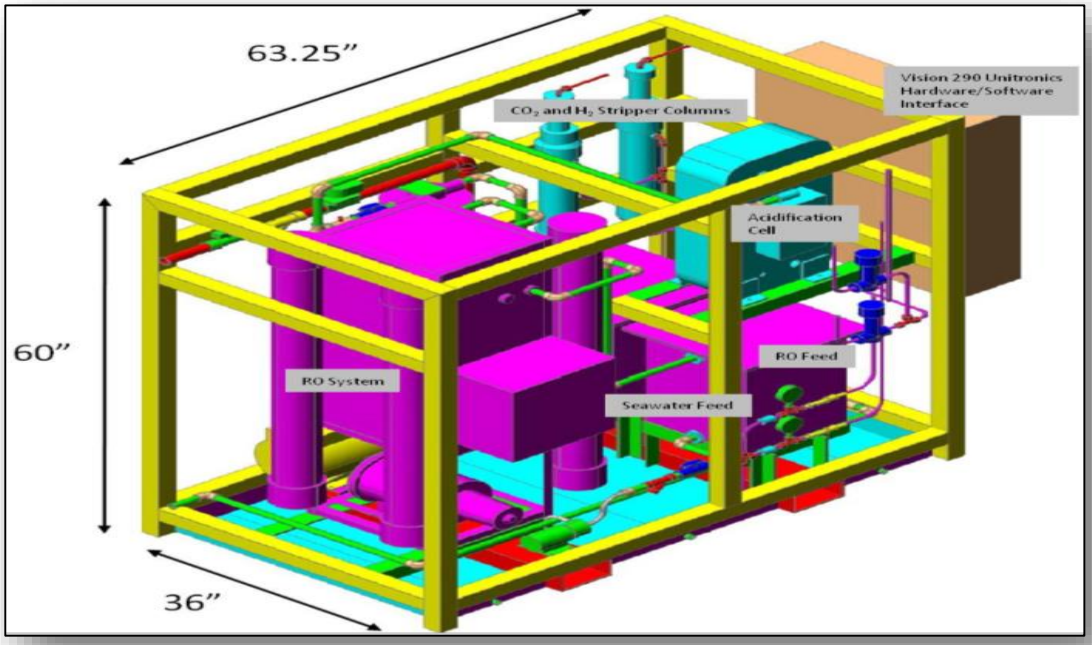
- Semipermeable membrane sandwiched between electrodes.
- H^+ and OH^- is generated by electrolysis,
- CO_2 bubbles off.

Cell Reaction:-

$\boldsymbol{Anode}$: $2H_2O \rightarrow 4H^+ + O_2 + 4e^-$ (1)

$\boldsymbol{IX}$ $4|\mathrm{NaCl}|\mathrm{seawater} + \mathrm{H}^+ \rightarrow 4\mathrm{Na}^+ +$ $4|\mathrm{HCl}|\mathit{acidic\ seawater}$ (2) $\boldsymbol{Cathode}$: $4\mathrm{H_2O} + 4\mathrm{Na}^+ + 4\mathrm{e}^- \rightarrow 4\mathrm{NaOH} + 2\mathrm{H_2}$ (3) $\boldsymbol{Overall}$: $6\mathrm{H_2O} + 4\mathrm{NaCl} \rightarrow 4|\mathrm{HCl}|_{\mathrm{IX}} + 4|\mathrm{NaOH}| + 2|\mathrm{H_2}|_{\mathrm{CATHODE}} + |\mathrm{O_2}|_{\mathrm{ANODE}}$

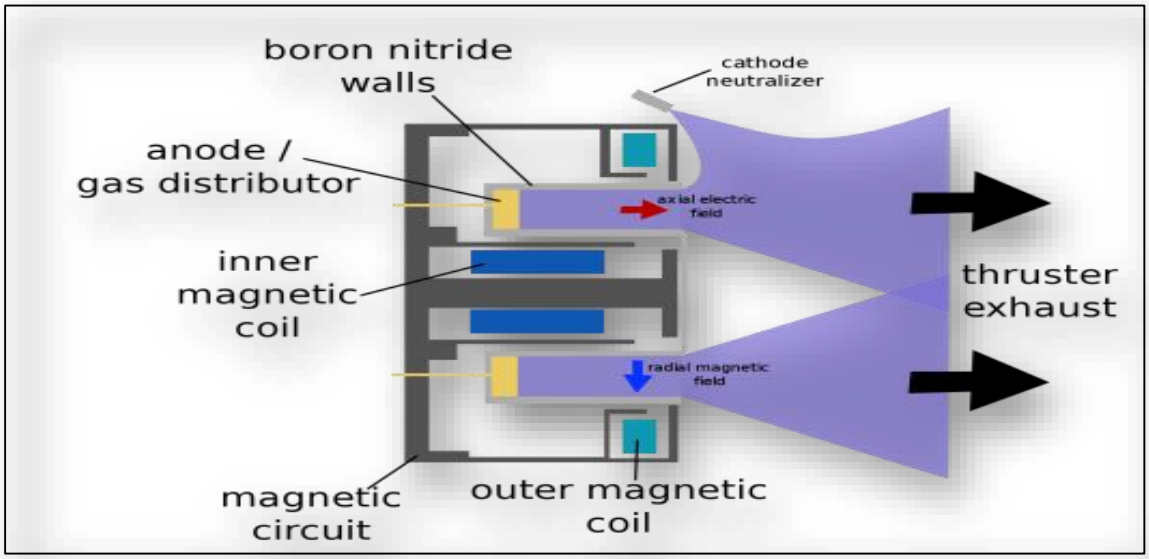
– (4)



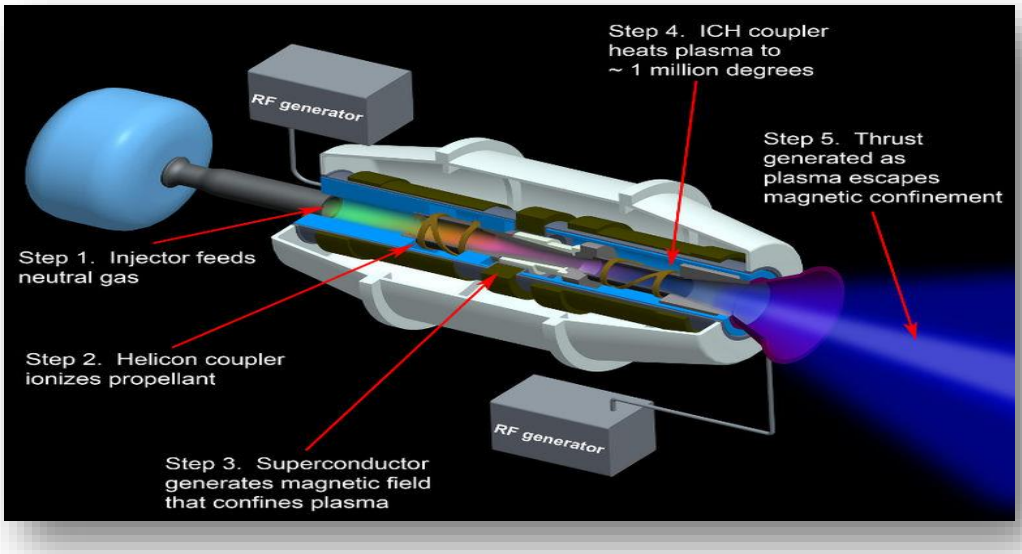
The production of hydrocarbons, which are compounds solely made up of hydrogen and carbon, from the recovered gases through the following process:-

- Extract liquefied Hydrogen (H2) with a concomitant production of liquefied Oxygen (O2) and removal of Carbon dioxide (CO2) from seawater. This is achieved through the use of **ELECTROCHEMICAL ACIDIFICATION CELLS.**
- Liquid hydrogen and Liquid oxygen produced are supplied to the two different tanks through two different pumps.
- Liquid H2 and Liquid O2 obtained is used as the fuel for the Variable Specific Impulse Magneto-Plasma Engine
- Further, the CO2 and part of H2 obtained are converted into unsaturated hydrocarbon starter molecules called **Olefins** using an iron-based catalyst.
- Then, these olefins are converted into a liquid containing larger hydrocarbon (C16-C19 range) molecules by polymerization.
- They are fed to ship’s generators as fuel.

3.1.2 Working of Variable Specific Impulse Magneto- Plasma Engine



- Variable Specific Impulse Magneto-Plasma is a convergent-divergent nozzle for ions and electrons.
- The LOX and LH2 stored in CCS tanks is first injected into a hollow cylinder surfaced with electromagnets.
- Upon entry into the engine, the gas is first heated to a “cold plasma” by a coupler which bombards the gas with electromagnetic waves, stripping electrons off the propellant atoms and leaving plasma consisting of ions and loose electrons to continue down the engine compartment.
- Depending on the RF heating value Variable Specific Impulse Magneto-Plasma is capable of generating either low-thrust, high–specific impulse exhaust or relatively high-thrust, low–specific impulse exhaust.



- A second coupler, known as the **Ion Cyclotron Heating (ICH)** section, emits electromagnetic waves in resonance with the orbits of ions and electrons as they travel through the engine.
- Resonance of the waves and plasma is achieved through a reduction of the magnetic field in this portion of the engine which slows down the orbital motion of the plasma particles.
- This section further heats the plasma to temperatures upwards of 1,000,000 kelvin—about 173 times the temperature of the Sun's surface.
- Motion of ions and electrons through the engine can be approximated by lines parallel to the engine walls, however particles actually orbit those lines at the same time that they are traveling linearly through the engine.
- The final, diverging, section of the engine contains a steadily expanding magnetic field which forces the ions and electrons into steadily lengthening spiral orbits in order to eject from the engine parallel and opposite to the direction of motion at speeds of up to 50,000 m/s.
- Furthermore, since every part of a Variable Specific Impulse Magneto-Plasma Engine is magnetically shielded and doesn't comes in direct contact with plasma, the potential durability of this engine design is greater than other ion/plasma engine designs.

4. Benefits

- Variable Specific Impulse Magneto-Plasma Engines uses clean fuel (LH2 and LOX) and gives H2O after combustion in contrast to conventional engines.
- High Energy per unit mass
- Independency on fossil fuels make Variable Specific Impulse Magneto-Plasma Engine eco-friendly.
- Zero emission fuel.
- Variable Specific Impulse Magneto-Plasma Engines does not use electrodes; instead, it magnetically shields plasma from most of the hardware parts, thus eliminating electrode erosion—a major source of wear and tear in ion engines.
- No SOX and NOX emission from engine.
- Highly cost-effective.
- High Thermal thrust.
- Variable Specific Impulse Magneto-Plasma Enginesconsumes $1/10^{th}$ of fuel in comparison to Conventional Engines.
- Small in size in comparison to Conventional Engines
- CCS technology removes CO2, LOX and LH2 at 92% efficiency.
- Hydrocarbons fuel formed is utilised to run various machines on-board.
- For re-poling 5H material, an electric field of 40 - 60 volts/mil will restore nearly all lost polarization. For 5A, use 50 - 100 volts/mil.
- Ships need not stop for refuelling during voyages, as a continuous production of fuel takes place on board.

5. Conclusion

- This paper presents a concept study for the use of Variable Specific Impulse Magneto-Plasma Engine Propulsion. The paper puts forward the reasons why

such a study is welcomed at this moment. With the vast growth in shipping industry, the fuel consumption has increased manifold. Thus Alternate Eco-Friendly Technologies are the need of the hour and as the proverb goes" Necessity is the Mother of Invention" ,a new coupled technology can be developed in which renewable and non-pollutant LH2 and LOX can be utilised as cryogenic fuel and oxidisers .

- The Electrical Energy thus produced using piezoelectric concept can be used to meet electric requirement for CCS Plant.

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