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Helium-3: A Futuristic Step Towards Sustainable Energy Source

Nehal A. Vyawhare **Jitendra R. Sawant** **Vipul M. Raut**

Abstract- **As the world's natural energy supply diminishes, researchers have been looking for new source of clean energy. Helium-3 seems to be the answer. The substance is almost foreign to Earth; however the Sun produces it in large quantities in a natural fusion reaction. The Helium-3 could be transported to Earth and used in a nuclear reaction that produces no radiation or radioactive waste. The only byproduct is oxygen and water. The technology is not advanced enough to make Helium-3 acceptable alternative yet, but new techniques are improving its efficiency every year. Once the technology has developed into a sustaining energy producer, many see Helium-3 as the perfect answer to the world's future energy needs.**

Keywords- **Deuterium, Fusion Reactor, Helium-3, Power Generation.**

I. INTRODUCTION

Helium-3 (^{3}He) is the gas that has the potential to be used as a fuel in future nuclear fusion power plant. There is very little helium-3 available on the Earth. However, there are thought to be significant supplies on the Moon. Several governments have subsequently signaled their intention to go to the Moon to mine helium-3 as a fuel supply. Such plans may come to execution within the next two to three decades and trigger a new Space Race.

Helium-3 fusion reactions represent the most advanced form of energy that is currently within our grasp. Helium-3 fuels are the most energy dense out of any currently in use or under experimentation, and have the highest electrical conversion efficiency of any form of electricity, making them unparalleled as an energy source. This is due to the fact that reactions using helium-3 are largely aneutronic. This means that instead of yielding neutrons, which deliver their energy as heat, and must be sent through a steam cycle to generate electricity, helium-3 reactions generate charged particles which can be converted into electricity directly. This difference represents a doubling in electrical conversion efficiency. In addition, they are an ideal fuel source for propulsion, providing fuel efficiency advantages superior to any chemical, nuclear or even other potential fusion rockets, thus opening up mankind's access to previously unreachable regions of the cosmos. It is, in all respects, the ideal fuel of the future. And the future must begin now.

II. INTRODUCTION TO HELIUM

Helium-3 (^{3}He) is a light, non-radioactive isotope of helium with two protons and one neutron, in contrast with two neutrons in common helium. The abundance of helium-3 is thought to be greater on the Moon than on Earth, having been set in in the upper layer of regolith by the solar wind over billions of years. Its hypothetical existence was first proposed in 1934 by the Australian nuclear physicist Mark Oliphant while he was working at the University of Cambridge Cavendish Laboratory. Oliphant had performed experiments in which fast deuterons collided with deuteron targets. Helium-3 was thought to be a radioactive isotope until hellions were also found in samples of natural helium, which is mostly helium-4, taken both from the terrestrial atmosphere and from natural gas wells. Other than protium, helium-3 is the only stable isotope of any element with more protons and neutrons.

Name	Helium-3, ^{3}He
Neutrons	1
Protons	2
Natural Availability on Earth	0.000137 %
Half-life	Stable
Molecular Weight	3.016 g/mole
Standard state	Gas at 298 K
Group in Periodic Table	18
Group Name	Noble gas

III. PROPERTIES OF HELIUM-3

- Colorless.
- Odorless.
- Non-toxic gas.
- It is less soluble in water than any other gas.

- It is less reactive.
- The density and viscosity of helium vapour are very low.
- The thermal conductivity and caloric content are exceptionally high.
- Chemically inert.
- Highest ionization potential.

Because of its lower atomic mass of 3.02 atomic mass units, helium-3 has some physical properties different from those of helium-4, with a mass of 4.00 atomic mass units. Because of the weak, induced dipole–dipole interaction between helium atoms, their macroscopic physical properties are mainly determined by their zero-point energy. Also, the microscopic properties of helium-3 cause it to have a higher zero-point energy than helium-4. This implies that helium-3 can overcome dipole–dipole interactions with less thermal energy than helium-4 can.

The quantum mechanical effects on helium-3 and helium-4 are significantly different because with two protons, two neutrons, and two electrons, helium-4 has an overall spin of zero, making it a boson, but with one fewer neutron, helium-3 has an overall spin of one half, making it a fermion.

Helium-3 boils at 3.19 K compared with helium-4 at 4.23 K, and its critical point is also lower at 3.35 K, compared with helium-4 at 5.2 K. Helium-3 has less than one-half of the density when it is at its boiling point: 59 gram per liter compared to the 125 gram per liter of helium-4—at a pressure of one atmosphere. Its latent heat of vaporization is also considerably lower at 0.026 kilojoules per mole compared with the 0.0829 kilojoules per mole of helium-4.

IV. NUCLEAR POWER

First Generation Fusion Reaction:

A first-generation fusion reaction involves two isotopes of hydrogen—deuterium and tritium (DT). When these isotopes fuse, the reaction generates neutrons, photons, and charged helium nuclei (alpha particles). Eighty percent of the energy from this reaction is released in the form of kinetic energy from the motion of the high-energy neutrons. Although the energy released per unit mass of this fusion fuel is higher than in fission reactions, the same physical process is at play. Because neutrons are neutrally charged they do not respond to a magnetic field, and are thus very hard to control. Therefore, the only way to extract energy from them is to use them to power a steam cycle. Because neutronic forms of fusion such as DT would use a steam cycle, which is the same method by which we extract energy from almost all of our fuels, its electrical conversion efficiency is roughly the same.

Second Generation Fusion Reaction:

A second generation reaction, using helium-3 and deuterium, generates very different fusion products. A reaction between a helium-3 and deuterium ion will yield a proton and an alpha particle helium-4 nucleus). But these ions do not always pair up perfectly, and sometimes there are reactions between two deuterium ions, which yield a neutron and a helium-3 ion. Reactions yielding neutrons may be suppressed by controlling the plasma temperature and by keeping a lower ratio of deuterium ions compared to helium-3 ions in the fuel. Through these measures, very few neutrons may be produced (15% of energy).Thus; the majority of the products will be in the form of charged particles (protons and alpha particles) and photons. Because charged particles—as opposed to neutrons—respond to a magnetic field, they can be controlled and directed. Instead of having to convert the heat generated from neutrons into electricity, the charged particles and electromagnetic radiation may be directly converted to electricity. Direct conversion methods yield efficiencies of 60-70%.

Third Generation Fusion Reaction:

A third generation fusion reaction uses helium-3 as both agents in the reaction. In an electrostatic device, 99% of the resulting energy is in the form of charged particles, which can be directly converted into electricity, yielding an electrical conversion efficiency of 70-80%. A 3He–3He reaction yields a 4He ion and 2 protons. There are no neutrons or radioactivity produced in a 3He–3He reaction.

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a) FUSION REACTIONS:-

Reactants		Products	Q	n/MeV
First-generation fusion fuels				
${}^{2}_{1}H + {}^{2}_{1}H$ (D-D)	→	${}^{3}_{2}He + {}^{1}_{0}n$	3.268 MeV	0.306
${}^{2}_{1}H + {}^{2}_{1}H$ (D-D)	→	${}^{3}_{1}H + {}^{1}_{1}p$	4.032 MeV	0
${}^{2}_{1}H + {}^{3}_{1}H$ (D-T)	→	${}^{4}_{2}He + {}^{1}_{0}n$	17.571 MeV	0.057
Second-generation fusion fuel				
${}^{2}_{1}H + {}^{3}_{2}He$ (D-^{3}He)	→	${}^{4}_{2}He + {}^{1}_{1}p$	18.354 MeV	0
Third-generation fusion fuels				
${}^{3}_{2}He + {}^{3}_{2}He$	→	${}^{4}_{2}He + 2\,{}^{1}_{1}p$	12.86 MeV	0
${}^{11}_{5}B + {}^{1}_{1}p$	→	$3\,{}^{4}_{2}He$	8.68 MeV	0
Net result of D burning (sum of first 4 rows)				
6D	→	2(^{4}He + n + p)	43.225 MeV	0.046
Current nuclear fuel				
${}^{235}U + n$	→	2 FP+ 2.5n	~200 MeV	0.001

TABLE I
VARIOUS FUSION REACTIONS

V. POWER GENERATION USING HELIUM-3

(2ND GENERATION FUSION REACTION)

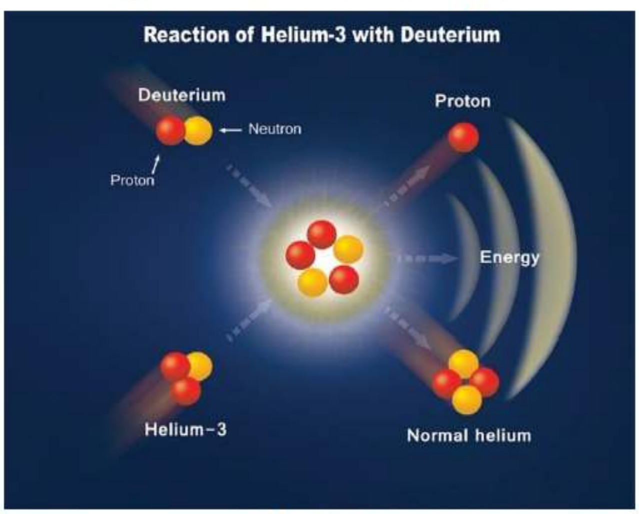

FIGURE I
DEUTERIUM-HELIUM-3 REACTION

^{3}He is used in a reaction with deuterium to produce energy:

$$D + {}^{3}He \longrightarrow p(14.7\,MeV) + {}^{4}He\,(3.7\,MeV) + 18.4\,MeV$$

This is a nuclear fusion reaction. The deuterium and helium-3 atoms come together to give off a proton and helium-4. The products weigh less than the initial components; the missing mass is converted to energy. 1 kg of helium-3 burned with 0.67 kg of deuterium gives us about 19 megawatt-years of energy output.

The fusion reaction time for the D-He3 reaction becomes significant at a temperature of about 10 KeV, and peaks about 200 KeV. A 100 KeV (or so) reactor looks about optimum.

A reactor built to use the D-3He reaction would be inherently safe. The worst-case failure scenario would not result in any civilian fatalities or significant exposures to radiation.

The total amount of energy produced in the D + 3He reaction is 18.4 MeV, which corresponds to some 493megawatt-hours (4.93×108 Wh) per three grams (one mole) of ^{3}He. If the total amount of energy could be converted to electrical power with 100% efficiency (a physical impossibility), it would correspond to about 30 minutes of output of a Gigawatt electrical plant per mole of ^{3}He.

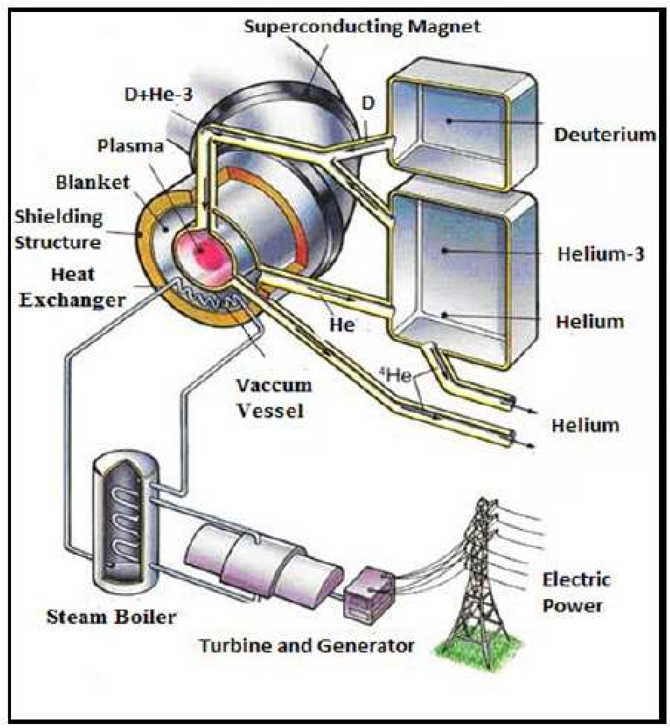

FIGURE II
SAMPLE MODEL FOR FUSION REACTOR

VI. HELIUM-3 SUPPLY

At present, helium-3 is only produced as a byproduct of the manufacture and purification of tritium for use in nuclear weapons. The supply of helium-3 therefore derives mostly, perhaps entirely, from two sources: the U.S. and Russian governments. Other potential sources of helium-3 do exist, but using these sources would present varying degrees of technical and policy challenges.

The main source of helium-3 in the United States is the federal government's nuclear weapons program. For many years, the National Nuclear Security Administration (NNSA) and its predecessor agencies have produced tritium for use in nuclear warheads.16 Over time, tritium decays into helium-3 and must be replaced to maintain warhead effectiveness. The NNSA recycles the mixture of tritium and helium-3 that results from this decay process and reuses the resulting pure tritium. From the perspective of the weapons program, the extracted helium-3 is a byproduct of maintaining the purity of the tritium supply. This means that the tritium needs of the weapons program, not the demand for helium-3 itself, determine the amount of helium-3 produced.

We have very little helium-3 on Earth. But studies have indicated there are upwards of 5 million tons of helium-3 on the Moon, and that has been said to be enough to power the entire planet Earth for 10,000 years.

VII. ADVANTAGES

- Higher conversion efficiency up to 70% by using direct energy conversion.
- No harmful radiations
- Less technical complexity
- No air and water pollution
- Only low-level radioactive waste disposal requirements as there are no harmful byproducts obtained.
- Direct energy conversion can be possible by using inertial electrostatic confinement or magnetic confinement.
- Clean source of energy

VIII. FUTURE SCOPE

Helium-3 Fusion Rockets:

Helium-3 will change our relationship to the Cosmos. Helium-3 will greatly facilitate our development of the Moon itself as a base of operations. The development of helium-3 fusion reactors on the Moon would give us a unique power for industrial and agricultural applications that could take advantage of the low gravity, near vacuum, extreme temperature changes, and other conditions. This is an ideal fuel for use on the Moon and other space applications, because it is available on site, and because the direct conversion to electricity mitigates thermal losses.

IX. CONCLUSION

Helium-3 (^{3}He) is gas that has the potential to be used as fuel in future nuclear fusion power plants. When helium-3 and deuterium are fused, it creates normal helium and a proton, which wastes less energy and is easier to contain. Nuclear fusion reactors using helium-3 could therefore provide a highly efficient form of nuclear power with virtually no waste and no radiation. Efficient D- 3He fusion energy would benefit terrestrial electricity, space power and space impulsion.

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