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Producing the most significant vital gas for humanity's survival during colonization of other planets by using the available chemical resources

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SUMMARY

In the near future, the next generation of space travels will be revealed and humanity is going to live on multiple planets and moons. There are a lot of important elements that need to be considered such as body requirements to stay alive, Anyway, the most significant parts are food, water, clothing, and breathable air. In addition, any group of scientists who are working on these challenges must pay attention to the facilities because we have some limitations like energy which makes the problems more complicated. As a result, in this article, we are going to find a way to produce oxygen by considering the accessible resources.

INTRODUCTION

In recent years, there were a lot of experiments to find out the best way to produce O_2 in the near future, although some of the experiments achieved the goal of producing O_2 and they were successful, unfortunately, some big challenges remained unsolved. For instance, some of them need a lot of energy or they need catalysts to perform their determined reactions, but carrying anything into another planet from earth, increases the costs so much! Even carrying a bottle of water to the international space station which is in low earth orbit can cost something around $9,100 to $43,180! As a result, it can be concluded that we have to find a chemical reaction that can be executed on another planet.

Not only the costs are important, but also a simple evaluation from different aspects shows that delivering a lot of rockets and manufacturing a high number of payloads for the colonies, can be really dangerous because our planet will be destroyed and bring up several issues! In the following, the author of this article tends to describe one of NASA's successful experiments which confirms the probability of oxygen production in other planets and its benefits and disadvantages will be measured. On February 18th, 2021, NASA's rover called: "Perseverance" landed on Mars successfully with a helicopter that joined in this mission which led humanity to fly on another planet for the first time (1)! Anyhow, this rover carries a device called MOXIE and a separate section is dedicated to this because of its importance in this research paper.

MOXIE

MOXIE stands for: "The Mars Oxygen In-Situ Resource Utilization Experiment", a technology for investigating the production of oxygen on Mars. This machine is embedded inside the rover (front, right side). In general, MOXIE works based on the conditions of the Martian atmosphere (2).

Carbon dioxide contains 95.32 percent of mars atmosphere and the remained amount consists of 2.7 percent nitrogen, 1.6 percentage argon, 0.13 percent of oxygen, and minor amounts of chemical mixtures like water, neon, krypton, xenon, and so on. Anyhow, it is intellectual to implement a way which can produce oxygen from Mars Carbon dioxide. It is the exact reason that MOXIE was built and sent to Mars. In fact, the net reaction is thus $2CO_2 \longrightarrow 2CO + O_2$ and MOXIE was a device to test how generating oxygen works. Approximately, this conversion requires the temperature of 800 °C (1,470 °F). A solid oxide electrolysis cell works in the core of that. In fact, at elevated temperatures, specific ceramic oxides,

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such as yttria-stabilized zirconia (YSZ) and doped ceria, become oxide ion (O^{2-}) conductors. A thin nonporous solid electrolyte like a disk of YSZ is placed between two porous electrodes. MOXIE sucks air in and CO_2 by a simple combination of thermal dissociation and electrocatalysis, converts to oxygen and Carbon monoxide (3). Finally in the first test, everything was normal and MOXIE was successful to make 5.37 grams of O_2 which shows producing oxygen in another planet is not a scene of a sci-fi movie anymore. As a simple illustration, it can be viewed as:

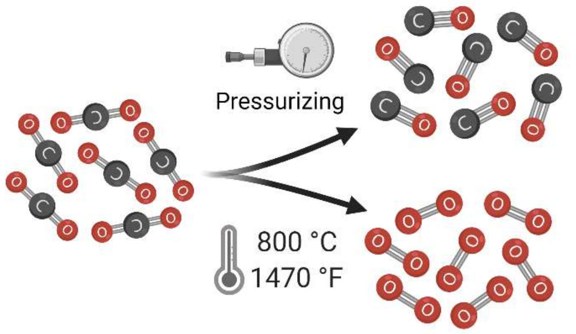

Figure 1. A simple Figure of MOXIE performance

In the above picture, there is an important tip. There is a step called "pressurizing". Destiny of the atmosphere of Mars is 3.93 g/cm³ but the earth's atmosphere has destiny of Earth is 5.51 g/cm³, so in order to provide enough oxygen for the astronauts, we have to pressurize it too because the situation must be like Earth. Anyway, MOXIE's oxygen Production Rate is up to 10 grams per hour so it means that we need to make a machine that performs like this on a larger scale because 10 grams of oxygen even is not adequate to keep a human alive for more than 10 minutes.

Anyhow, the main thing that we are really sensitive about, is energy usage. MOXIE consumes 300W which is all of the saved energy in Perseverance rovers' batteries. Scaled-up versions of the technology will consume much more energy, which means that we should dedicate hundreds of square meters of solar panels to oxygen production without considering other facilities like heaters, pressure optimizers, lights, rovers, and so on. Therefore, it is important to consider all factors. However, as NASA announced. MOXIE is just an experiment to demonstrate whether oxygen production on Mars is possible or not. Furthermore, in the near future, other groups of engineers and scientists will work on upgrading MOXIE for better performance. Anyway, the above information is necessary to get familiar with the logic behind oxygen production in space travels. In the coming section, the results of the author's research have expanded, by checking more information, another method of oxygen production has introduced and it will be indicated which one is a better choice.

RESULTS

According to the obtained information from multiple probes, we are going to evaluate condition of Mars from different aspects to find out what exists in this red planet that can be used as a resource for the production of oxygen.

Actually, one of the most recognizable elements about this planet is its thin atmosphere and high amount of Carbon dioxide. In the previous section, the author of this article clarified more about the way that we can produce oxygen from its atmosphere, but as it stated, there are a few problems in producing oxygen by using the Carbon dioxide of Mars atmosphere such as high energy consumption. Although other versions of MOXIE may have better performance with less energy in the near future, the author of this paper tends to discuss a new approach for producing oxygen that can be used during the colonization of Mars, and then, somehow, these methods can be generalized more and it can lead humanity to explore more methods which can be for effective. Anyhow, it can be demonstrated that producing oxygen on other planets is possible but just a few factors need to be changed if the destination planet changes because the abundance of particles that make up different planets is not the same so other chemical reactions should be considered for better efficiency. However, beside special features of

Mars like its atmosphere and its reddish appearance which refers to the effect of the iron oxide prevalent on Mars's surface, there is a “Wow factor” and that is the existence of water on mars. As time passed by, humanity, by sending rovers to the surface of Mars or satellites into space explored more, and obviously existence of water on mars approved. However, we have to pay attention to an important tip, liquid water cannot exist on the surface of Mars due to low atmospheric pressure, which is less than 1% that of Earth's. The amount of ice, is sufficient to cover the whole planet to a depth of 35 meters which is around 115 ft (4)! Anyway, as we mentioned, this “Wow factor” is H_2O which contains oxygen atoms. Therefore, it is intellectual to move the research based on this fantastic “Wow factor” and gain more information about what can be done with the solid water (ice) on Mars in order to produce oxygen for survival of the astronauts!

Discussion

Actually, H_2O needs to be divided into H_2 and O_2 which is breathable oxygen. Water electrolysis is one of the well-known operations which produce O_2 and H_2 and logically, O_2 is one of the products in this reaction which we had focused on it from the beginning of this research advancement. Anyway, we need to design a system which can take the Mars’s ice, convert it into liquid and then divide the achieved liquid water into its components (H_2 and O), in addition, as far as more water molecules join the reaction, more oxygen atoms (O) will be produced and all of these single atoms will be linked together and they will be converted into a determined amount of pure oxygen molecules (O_2). One of the reasons that attracts attentions in this method, is that beside producing oxygen, hydrogen exists! But why hydrogen is a factor that interests us?

To answer this question, a simple sentence can be defined as follows: “hydrogen is a key factor to recycle oxygen!”. In order to feel its importance, let’s take a look at following illustration to get familiar with the main cycle where H_2O comes from Mars and starts oxygen production:

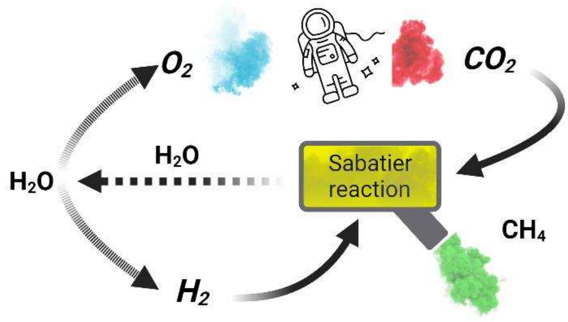

Figure 2. Some data regarding oxygen generator

As it can be seen in figure 2, water converts to H_2 and O_2, then oxygen goes into human lungs and converts into CO_2, in this step, carbon dioxide with the hydrogen that has been gained in the beginning of this cycle, goes into a reaction and not only recycles the air, but also provides water which can be added to the amount of ice that astronauts extract from the Mars’s underground ice. However, the gained methane gas is not useful because using it as a fuel, consumes a lot of oxygen so we release it in atmosphere. Additionally, after water electrolysis, hydrogen can have a similar reaction with carbon dioxide that exists in Mars’s atmosphere to produce more oxygen and also faster, but it needs to be considered that astronauts have produced CO_2 and it must be recycled. As a result, in first levels of colonizing Mars, it is better to recycle the carbon dioxide with Sabatier reaction as much as its possible and then because the efficiency is not 100%, the remained amount can be used by plants to bring us more amount of oxygen. Anyway, let’s check out that how the whole process works and get familiar with every reaction in this pattern.

Methods

After extracting ice and converting it into water, the net reaction of water electrolysis can be defined as: $2H_2O \longrightarrow 2H_2 + O_2$ and it needs catalyst and electric potential difference to perform. Actually, in standard conditions (STP) according to a simple experiment, it requires a theoretical minimum of 237 kJ of electrical energy input to dissociate each mole of water and if no heat or energy is added, the reaction won't proceed less than 286 kJ per mol. Furthermore, nickel-based hydroxide (Nickel (II) Hydroxide) are among best catalyst but it has some disadvantages, for instance, it is not accessible easily on earth, on the other hand, this substance exists on the red planet amazingly!

However, researchers form university of Houston have reported a promising oxygen-evolving catalyst with superior catalytic performance. Not only it is highly active and stable, but also it increases the speed and efficiency, also, by using this electrocatalyst, the amount of electric potential difference can be reduced and it is the best catalyst that can be used in electrolysis of water in large scales, for gaining more information regarding this 3D foam of $Fe(PO_3)_2/Ni_2P$, it has been widely studied in (5). One of the most important tips that needs to be remarked again, is that 2mol of water needs $2 \times 237 = 474\, kJ$ energy in order to be converted into its components, as a result, by a simple stoichiometry it can be concluded that it gives us 1mol oxygen molecule (16 grams!)

Anyhow, although solar panels are able to provide remarkable electric energy in Mars, Mars is far from Sun so it is highly recommended that we dedicate solar energy to other facilities that are really important but they consume less energy, systems like pressure optimizers or rovers' batteries are good examples. The author of this article, tends to announce that using nuclear energy is a perfect way to have energy because not only it helps humanity to create oxygen from Mars, but also by splitting uranium atoms to produce energy, the heat released by fission can be used to create steam that spins a turbine to generate a high volume of electricity (7).

Using substances like Uranium-235 in primary periods of colonizing another planet is really necessary because enough equipment is not available on Mars. In contrast with high costs of this method, it needs to be considered that we only need to do this a few times not forever.

Anyway, let's analyze how recycling oxygen can be possible. As it mentioned before, electrolysis of water divides water into its components, therefore, beside oxygen, a certain amount of hydrogen spreads out, this hydrogen can be used to filter the carbon monoxide that has been produced by astronauts' lungs and then it gives oxygen in products, as a result, let's find out more about the equation which offers H_2O again.

Sabatier reaction produces methane and water from a reaction of hydrogen with carbon dioxide at elevated temperatures of 300–400 °C optimally. Also, it needs pressure of perhaps 30 bar. In addition, in the presence of a nickel catalyst this reaction will moves forward. It can be viewed as:

$$CO_2 + 4H_2 \longrightarrow CO_4 + H_2O \quad \Delta H = -165\frac{KJ}{mol}$$

The above reaction, was discovered by the French chemists Paul Sabatier and Jean-Baptiste Senderens at the end of 19^{th} century, aluminum oxide can make a more efficient catalyst. (6)

A remarkable point in this reaction is its enthalpy, its enthalpy is smaller than zero! It means that when this reaction completed its job, it releases a certain amount of energy. The reason that why this is really considerable, gets back to the electrolysis of water. As it can be observed in figure 2, the cycle after Sabatier reaction, return to its first step where water needs to be electrolyzed again, therefore, this 165 $\frac{KJ}{mol}$ can help here! A small part of the required energy can be obtained from this reaction. In the beginning of this section, a significant element announced as:

"If no heat or energy is added during electrolysis of water, the electrolysis of water won't proceed with any energy rate less than 286 kJ per mol."

As a result, Sabatier reaction enthalpy cooperates with life support systems and decreases oxygen generators energy consumption. However, Sabatier reaction efficiency varies based on the condition. Currently, international space station recycles more than 90 percent of its water, but recycles just 40 percent of the oxygen astronauts breathe. As a result, the rest needs to come up on resupply missions (8), and as it mentioned in the first section of this research, sending payloads into space costs a lot. Nowadays international space station receives payloads including essential materials for astronauts to survive like food or water that converts to oxygen, but sending a lot of rockets into another planet can costs more than even what can be imagined.

Damaging the environment in exchange for sending different payloads to another planet is never acceptable. So, a stable cycle with the highest efficiency is required and it is the exact reason that why the author of this article suggests using plants to recycle the remained amount of carbon dioxide. Because not only we need plants to breath, but also, we need them to have a sustainable life cycle. Even in the primary levels of thinking about colonizing mars, plants are among the most remarkable points, not only for oxygen, but also for its other impacts like fruits, so using plants and Sabatier reaction together, is a great way to have a sustainable cycle.

Definitely, the discussed methods would have disadvantages beside their benefits, but as time passes by, science move forward so even if something seems impossible, can be solved soon, and these methods can be generalized in different manners more for any future colony in any planet.

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