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Review Article

Medical Oxygen a Vital in Covid 19 Pandemic: Production Techniques from Natural to Man-made

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Oxygen is the most important source for the survival of all living organisms. Our daily activities require energy and it comes from the food we consume when the oxygen present in our blood burns that food. The deficiency of oxygen disturbs the entire functioning of organs in the body. Around 50-80% of the natural oxygen production on Earth comes from the ocean. The oxygen production from ocean is the result of drifting plants, algae, and some bacteria that can photosynthesize. Oxygen has many applications like chemical processing, medical application, and many more. Different types of methods are available to produce oxygen at a considerable scale, *e.g.*, cryogenic, pressure swing, electrochemical. In this article, we discuss the stepwise process of various methods to produce oxygen and the challenges associated with details.

Keywords: Photosynthesis; Electrolysis; Cryogenic; Adsorption

1 Introduction

Whenever we think about life sustainability, the essential thing that comes first in our mind is oxygen, as today's world is facing critical challenges to the availability of oxygen in this pandemic. People are trying to find out any possible way to get that lifesaver oxygen. The atmospheric air contains only 20% oxygen, rest is nitrogen and other gases. It is well known that 90 percent of our biochemical and metabolic activities require oxygen. We inhale oxygen and exhale carbon dioxide. The inhaled oxygen travel firstly through the lungs, blood, and then every cell in the body. Plants are known as autotrophs means they can produce their food via light, water and carbon dioxide (CO_2). Plants use sunlight, water, and the gases in the air to make glucose, which is a form of sugar that plants need to survive. This process is called photosynthesis. All plants, algae, and even some microorganisms follow this process. The conversion of unusable sunlight energy into usable chemical energy is associated with the actions of the green pigment chlorophyll. Chlorophyll is a pigment based on a tetrapyrrole ring contains magnesium. It absorbs blue and red light, and transmits to the green. Most of the time, the photosynthetic process uses water and releases oxygen that requires for human survival.

A schematic representation of photosynthesis has been depicted in Fig. 1. for a better understanding.

Oxygen constitutes around 65% of our body mass and is the key to regulating most body functions. If someone is not getting recommended amount of oxygen, one can opt for breathing substitution oxygen through an oxygen cylinder. In the current scenario, due to pandemics in India and worldwide, oxygen

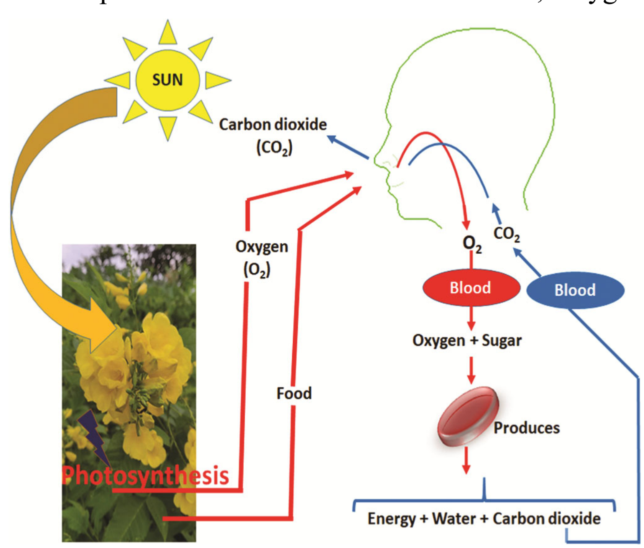

Fig. 1 — Photosynthesis respiration cycle.

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crises have become the biggest challenge. There are various types of methods to produce oxygen at a small as well as industrial scale. Commonly used commercial methods for oxygen production include either cryogenic separation of air or a vacuum swing adsorption process. The production of oxygen can be done from a chemical process, which releases oxygen and a chemical compound formation in gaseous state. Small-scale production of oxygen can be possible by this method and it can also apply for life support on submarines, aircraft, and spacecraft.

There are various types of methods for oxygen production, as shown in the schematic diagram of Fig. 2.

When the electricity is passed through the water molecules, it splits into two gaseous phases- oxygen and hydrogen. Liberation of hydrogen gas occurs at the negative electrode surface, whereas oxygen evolution can be seen at positive surface. This combined process is named electrolysis, and using such a method, very pure hydrogen and oxygen can be obtained. But such type of method is preferable for the large-scale production of oxygen as it uses a large amount of electrical energy.

Let's discuss each method with some schematic of how they will produce oxygen at different stages.

Water Electrolysis for oxygen production

In water electrolysis, electrical power supply is used to break water into hydrogen, and oxygen gaseous molecules. Water electrolysis in the chemical reaction form is described as

$$H_2O \rightarrow \frac{1}{2}\, O_2 + H_2 \qquad \ldots (1)$$

Water is supplied to an electrochemical cell where the evolution of hydrogen and oxygen takes place at cathode and anode electrode, respectively in the presence of electricity (Smolinka et al. 2009). The fundamental principle for electrolysis cell is shown in Fig. 3.

A diaphragm/membrane does not separate the anode and cathode. The evolution of the two gases that is oxygen and hydrogen, occurs at the top of the electrolysis cell.

To convert 1 mole of water molecules into hydrogen and oxygen gases requires the standard state free energy change (ΔG°) of +237.2 kJ mol^{-1} and +286 kJ mol^{-1} of enthalpy change (ΔH°). The current density and potential measure the activity of the electrocatalyst. A cell voltage of 1.23 V, 0V for hydrogen evolution, and 1.23 V for oxygen evolution is needed from the thermodynamic perspective.

The potential higher than the equilibrium potential is known as overpotential (η) is a decisive parameter for evaluating electrocatalysts' performance. For high electrochemical performance smaller value of overpotential is favourable.

2 Classification of Water Electrolysis

Water electrolysis categorized in different categories based on the use of energy source as shown in Fig. 4.

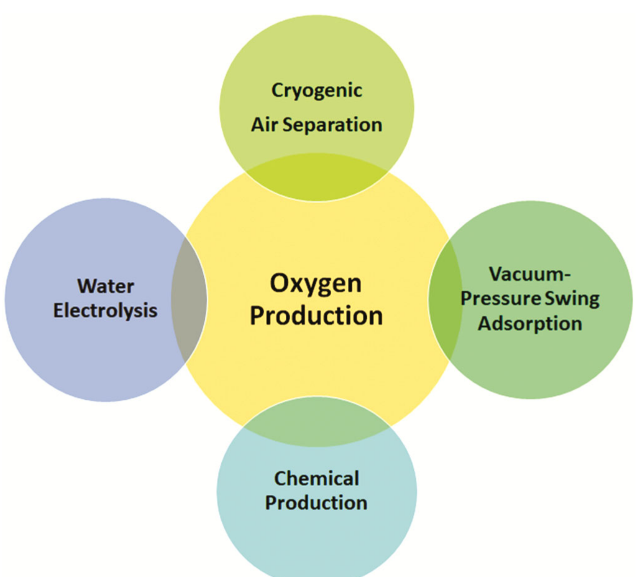

Fig. 2 Classification of oxygen production methods.

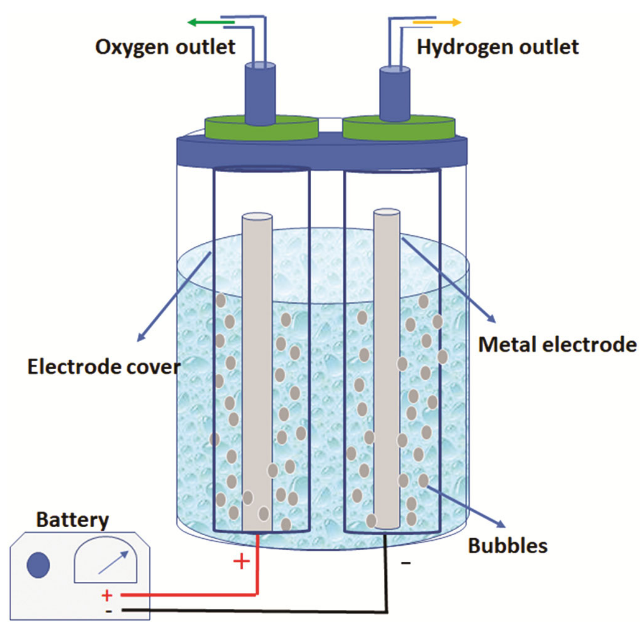

Fig. 3 — Simple water electrolysis cell setup.

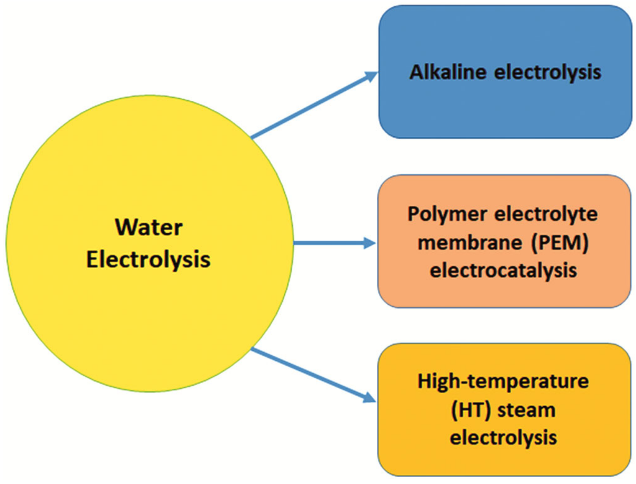

Fig. 4 — Types of water electrolysis.

Alkaline Electrolysis

Alkaline electrolyzers consist of an aqueous solution of KOH with 20-40 wt% as an electrolyte which circulates in the cell, as represented in Fig. 5.

The operating parameters for the alkaline electrolysis include operation temperature and pressure and their functioning values lies in the range of 343 and 363 K, 3 MPa, respectively for commercial purposes. The alkaline electrolysis is considered a fully-grown technology. Nowadays, almost all the hydrogen produced from the electrolysis process uses this technique.

Polymer electrolyte membrane (PEM) electrolysis

In the polymer electrolyte membrane (PEM) electrolysis, an acidic solid polymer is utilizing as the. Membrane performs the role of the gas separator as well as the solid electrolyte. Hence, the cell only contains deionized water, and there is no electrolytic additive cell. A membrane-electrode assembly (MEA) formed when the electrodes are directly coated on the membrane. A schematic representation of polymer membrane electrolytic cell setup is shown in Fig. 6.

The role of porous current collectors/distributors is to allow an electric current to pass in between the bipolar plates and electrodes together; it also evacuates the evolved gas bubbles via electrodes surface. In majority of the PEM fuel cells consist of electrically conductive bipolar plates with flow-field structures like parallel channels for moving water to the anode electrode and gases O_2 and H_2 evolves form the cell setup.

High-Temperature Steam Electrolysis

Higher temperatures (HT) are favorable for the electrolysis process under the thermodynamic approach. It is an endothermic process in which heat assists the decomposition of the water molecules. Thus, more will be the temperature, the lesser amount of electricity will be needed for decomposition. Fig. 7 depicts the schematic of high-temperature steam electrolysis.

The Electrical energy needed to split water is lessened by 25% at a temperature range of 1073-1273 K. The use of HT heat generated form the waste materials by the fossil, geothermal, solar, or nuclear origin, makes the electrolysis more favorable. The disadvantage of high-temperature steam electrolysis its long launch times (Sapountzi et al. 2017).

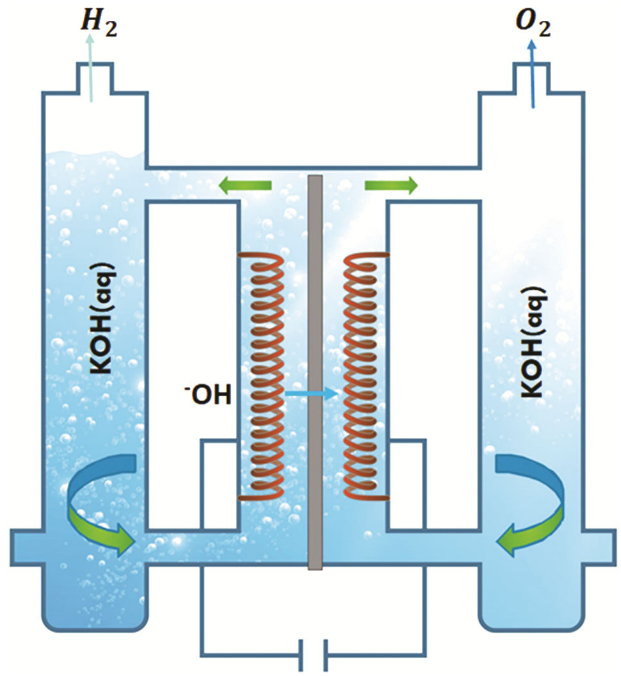

Fig. 5 — Conventional alkaline electrochemical setup.

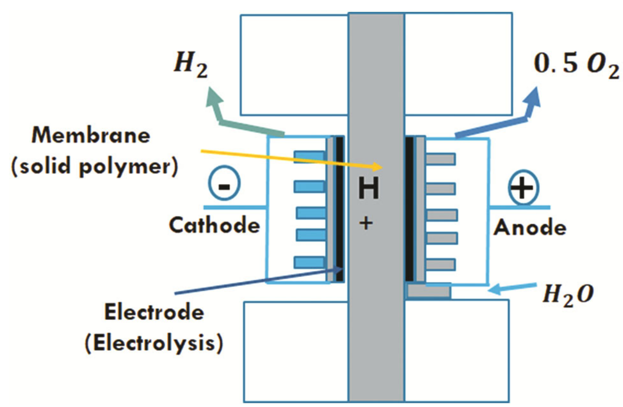

Fig. 6 — Polymer membrane electrolytic cell setup.

3 Cryogenic separation

Carl Von Linde was first developed this process in 1895, which George Claude further improved in the 1900s.

This cryogenic air separation method involves various stages like air compression, water vapor separation, cooling and adsorbing part, etc. (Kent et al. 1997, V N Reinhold 1990 and Allen er al. 1995). The method gives the highest purity grade oxygen compare to others routes.

- ✓ In the first stage, air is collected and compressed at 94 psi, followed by the condensation of water vapor through the cooling, and water is removed by water separator.
- ✓ The second stage involves the molecular sieve adsorption process. For the air adsorption, zeolite and silica gel-type adsorbents were used as adsorbing materials; they trap the carbon dioxide and other heavier traces. To maintain the process of impurity removal, two adsorbers are working in parallel to go on the process of airflow on the other adsorbing part the flushing activity is going on. Cryogenic oxygen production process is schematically shown in Fig. 8.
- ✓ The adsorb air stream is now divided, some of the portions of the air is passed through a compressor for its pressure booster and then cooled and expand to close to atmospheric pressure. This expanded air is now injected into the cryogenic section to give to cold temperatures for experimental operation.
- ✓ In next stage, major air goes via one side of a pair of plate-fin heat exchangers working in series; conversely, cold oxygen and Nitrogen from the cryogenic section flows through the other side. In the next part, the oxygen and Nitrogen are warmed, and the coming air is cooled. When the air temperature is down, and the oxygen has a maximum boiling point, and gas start to the liquid formation.

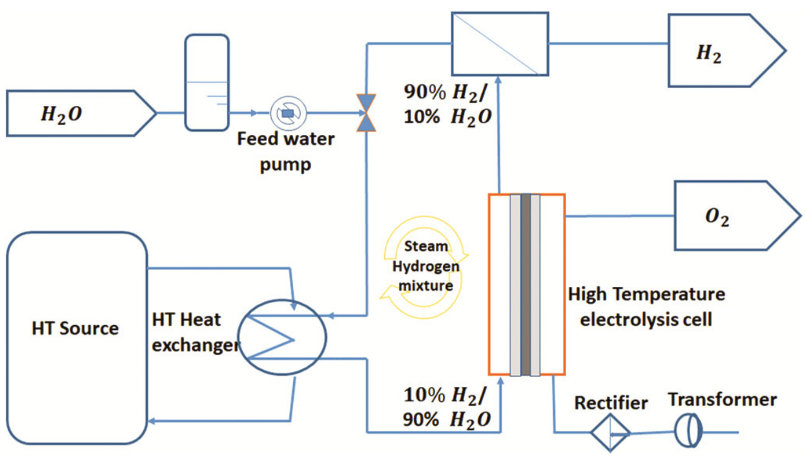

Fig. 7 — Schematic of high-temperature steam electrolysis.

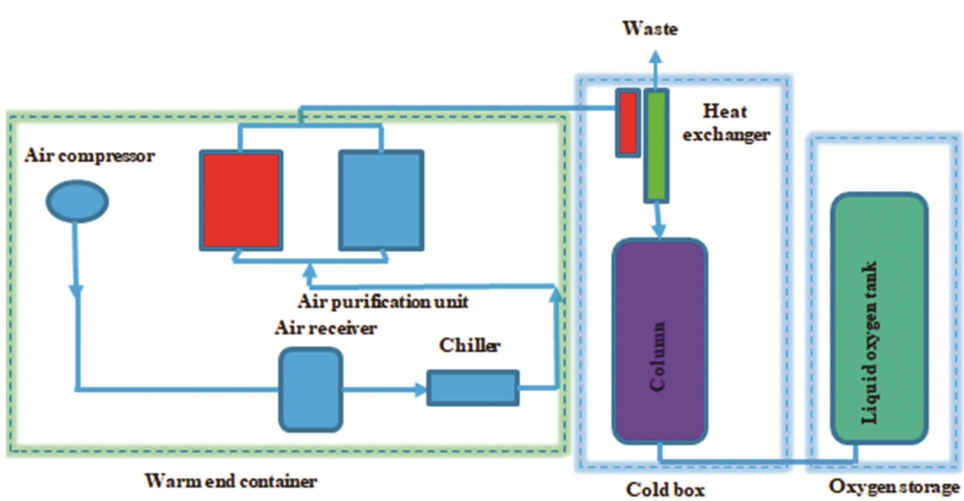

Fig. 8 — Cryogenic oxygen production process.

- ✓ Now air is in the liquid part enters through the bottom part of the high-pressure and once go up, it releases the extra heat. The Liquefaction process of oxygen continues in this way, resulting in a formation of more oxygen containing mixture in the base of the column while top part of the column flow with the vapors of nitrogen and argon (Smit et al. 2001).
- ✓ In last, the liquid oxygen mixture, also known as crude liquid oxygen, is taken out from the base and further cooled into the sub-cooler. Then expansion of oxygen gas started nearly at atmospheric pressure, this mixture is then fed to the low-pressure fractionating column. In this stage, most of the left Nitrogen and argon were removed and pure oxygen (99%) was received at the base of the column.

4 Oxygen by Vacuum-Pressure Swing Adsorption

It is a newer technology concerning cryogenic air separation. The vacuum-pressure swing adsorption (VPSA) method consists of adsorption units used to produce high purity of oxygen between 90 and 94% (Debnath et al. 2019). There are approximately 5% impurities like argon and Nitrogen typically present. In the VPSA method, only a few psig (about 0.2 atmospheres, gauge) produces oxygen. An additional oxygen booster compressor or blower is combined to the unit when it requires higher oxygen delivery pressure. Combined VPSA units are costlier to build but consume less energy than PSA units. Fig. 9 schematically shows the vacuum pressure swing adsorption.

In VPSA units are fully regenerated, the sieve material under the influence of vacuum that is selective over other PSA units and as results the higher percentage of oxygen recovery, less air utilization. Another advantage is the air compressor power is less than PSA because of less airflow and lower compressor discharge pressure. There are some more advantages of VPSA like:

- ✓ The use of air compression power mechanism to operate the vacuum-generation machinery.
- ✓ It is more cost effective over oxygen PSA units on higher production of demanded oxygen eg 20 tons per day.
- ✓ The combination of two VPSA plants can be the replacement of cryogenic plants for the production of same amount of oxygen production.
- ✓ The power utilization in VPSA is one third of other PSA units which comparable to cryogenic plants.

5 Chemical production of oxygen

In the early 1900s, chemical production and delivery are well known in several forms. In this method, oxygen stored in form is different from gaseous diatomic oxygen produced by chemical reaction, the best-known example of chemical method for oxygen production is hydrogen peroxide (H_2O_2). H_2O_2 is used in the pharmaceutical as a disinfectant, and it also finds its application in food industries. Our body also released H_2O_2 a metabolic product in the form of reactive oxygen species.

The exothermic reaction takes place during the H_2O_2 decomposition to water and oxygen gas as follows:

$$2H_2O_2 \rightarrow 2H_2O + O_2 \quad \text{... (2)}$$

It is a spontaneous process. However, rate of the reaction is slow and it can be enhanced by the catalyst addition (e.g., catalase, peroxidases, manganese dioxide, iron, and many others) (Ward et al. 2012). The fundamental calculation of how much oxygen produces during the reaction and as output 11.4 mL of oxygen produced from 1 mL of 3% H_2O_2 at 37°C and

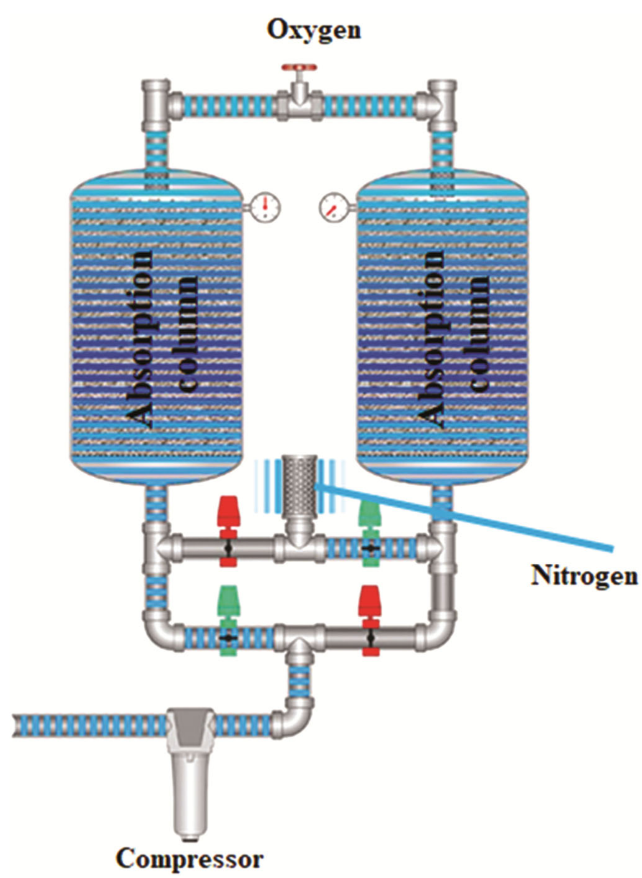

Fig. 9 — Vacuum pressure swing adsorption.

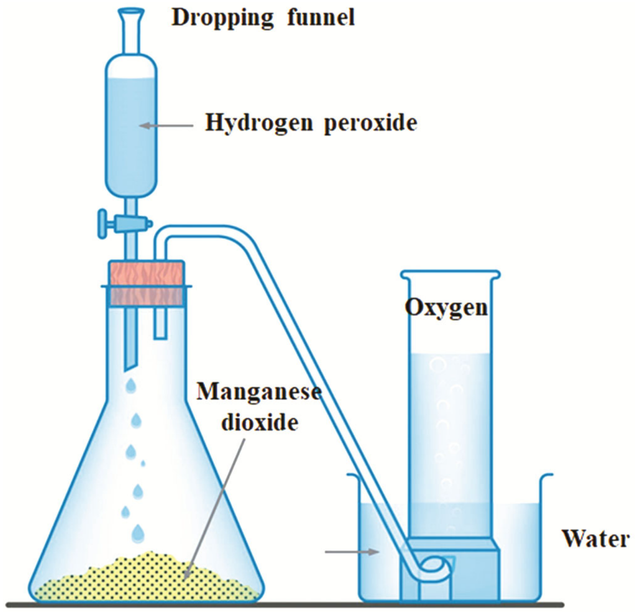

Fig. 10 — Chemical production of oxygen using Hydrogen peroxide and manganese dioxide.

Table 1 — Characteristics of oxygen production methods

S. No	Methods	Advantage/Disadvantage	Amount of Pure Oxygen
1	Cryogenic	High-capacity oxygen production/Long startup time	99%
2	Adsorption	Fast startup time/High energy uses for production	95%
3	Membrane	Fast startup time/Low purity grade of oxygen	40%
4	Chemical	Very less or no energy uses/Slow rate of production	99%

1 atmosphere per second. Fig. 10 shows the schematic of chemical production of oxygen using Hydrogen peroxide and manganese dioxide.

During the decomposition of H_2O_2 to H_2O and O_2, 46,880 cal/mol O_2 or about 1.94 cal/mL medical needed oxygen was produced during the reaction.

A brief summary of characteristics of all the possible oxygen production methods represented in a Table 1.

6 Conclusions

The literature on possible methods to produce oxygen concerning its production at a large scale is reviewed. This review discusses four methods to produce oxygen at a significant level: electrochemical water splitting, cryogenic air separation, vacuum pressure swing absorption, and chemical method for producing oxygen from hydrogen peroxide. It is being observed that these methods have different selection criteria, which depend on various factors. For example, the selection criteria for PSA and cryogenic include factors like volume, purity, and installation time. PSA is best suited if there is a requirement for low volumes and low purity oxygen, whereas cryogenic air separation works better when high oxygen purity is required. Similarly, the oxygen obtained from polymer membranes is of low quality compared to the one obtained from the other techniques. Oxygen shares several applications may it be in the industrial field, medical field, in a chemical laboratory, or on a commercial scale. Thus, it becomes imperative to study its production for proper utilization of available resources in nature.

Conflict of Interest

The authors declare no competing interests.

Data Availability Statement

All the data have been included in the manuscript. No supplementary data is available.

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