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CARBONIC CELL

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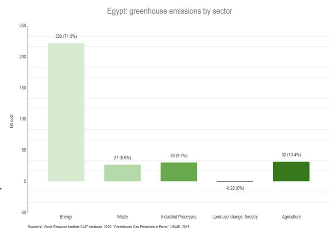
Abstract

Climate change and global warming are well-known global issues, with greenhouse gas emissions as the primary cause. The only solution is for each country to reduce its contribution to these issues. Egypt's main concern is energy, as the country is heavily reliant on hydrocarbon-based fossil fuels to generate electricity. According to studies, manufacturing and industrial operations emitted 30 million tons of CO_2 in 2016, accounting for 9.7% of Egypt's total CO_2 emissions. To assist Egypt in overcoming these challenges, a system should be built at industrial complexes to generate energy and hydrogen fuel while also reducing CO_2 emissions from factories, and the electrochemical cell was chosen as method to implement that system. This cell must meet some design requirements as follow; generating not less than 1.5 volts and producing hydrogen while distinguished by efficiency not less than 90%, from these requirements, the idea of prototype was born. Anode is immersed in a container, which is filled with electrolyte solution, and A cathode is immersed in the other, which is filled with distilled water reacted with carbon dioxide gas. Finally, a U-shaped tube with two ends contain strong electrolyte solution works as salt bridge that facilitates the flow of ions between oxidation and reduction half-cells. After constructing the cell, the CO_2 which is produced from the reaction of baking soda and vinegar added to the cell, where it undergoes some reaction until results are obtained, and the test plan demonstrates how effective the cell is. Based on our findings, CO_2 emissions can be beneficial, providing you with energy rather than causing problems.

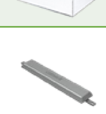
Introduction

Egypt faces numerous problems, which are referred to as Egypt grand challenges. Climate change and global warming are without a doubt the two most critical challenges facing not only Egypt but the entire world. And as Egyptians, the contribution of Egypt to this problem must be solved. In Egypt, the main cause of global warming is greenhouse gases which are emitted from burning of fossil fuels to produce energy.



The most available greenhouse gas in the atmosphere is carbon dioxide. Its emission rate is exponentially increasing and as a proof manufacturing and industrial operations emitted 30 million tons of CO_2 in 2016, accounting for 9.7% of Egypt's total CO_2 emissions (as shown in Graph (1)) as Egypt is heavily dependent on hydrocarbon-based fossil fuels to generate energy.
This extreme increase in greenhouse gases emission led to an uncontrollable change in the climate. Climate change leads to long-term repercussions like ice melting, sea-level rising, and ocean acidification. This series of problems generated from one specific problem which is greenhouse gas emission due to generating energy. For these reasons, A lot of searches had done to find other solutions that have already been tried attempting to solve such a problem. For example, Petra nova project which is considered as a clean-energy project that aims to reduce carbon emissions of the boilers of a coal-fired power plant. One of its strengths is its ability to boost the oil production at the site. However, it does have weaknesses, one of which is high cost as the installation of the Petra Nova carbon emission reduction system cost around $1 billion. Another solution is Al/CO_2 electrochemical cell, this cell depends on the electrochemical conversion of CO_2 to huge amount of electrical energy. The brightest strengths point in this project that it generates valuable products like O_2 and C_2 compounds in addition to electricity. It also has weaknesses like Sensitivity to moisture as it will not work if water is present in the mixture of gases it draws in. Following are the design requirements after the problem and other solutions have been identified. The project will be consisted of two nonconductive electrical containers containing solutions which through chemical reactions, produce pure hydrogen gas as well as electrical energy through voltage difference not less than 1.5 volt when 0.83 moles of CO_2 is added. The voltmeter will measure the electricity flowing through the circuit as the water reacts with CO_2 produced by the vinegar-backing soda reaction. After much consideration of the best suitable and applicable solutions for the problem of greenhouse gas emissions due to energy production, we found that building a cell that can use CO_2 emissions to generate electricity is the most effective. The cell will be consisted of two container one for anode and electrolyte solution and the other for cathode and carbonic acid solution that results from the reaction between CO_2 and water. Finally, this cell must be made of safe materials and connected by scientific methods which discussed in the next part.

Materials & Methods

Item	Description	Quantity	Picture
Container	The container is made of plastic and was used to store water, solutions, cathode, anode, and so on.	Two	
Aluminum Anode	The anode is a charged positive plate immersed in NaCl solution where the oxidation undergoes.	One	
Copper Cathode	It is immersed in distilled water, and the cathode is the electron acceptor where the reduction undergoes.	One	
Salt bridge	It is a U-shaped tube contains salt solution.	One	
Distilled water	It is a type of water that is evaporated and condensed to ensure its purity.	600 ml.	
Sodium chloride solution.	It is a solution contain Na+ ions and Cl- ions.	500 ml.	

Methods

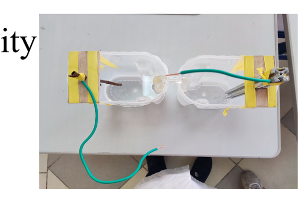


Figure (1): Prototype strucutre

The prototype is consisting of two containers of a capacity 2 L and each one containing electrode immersed in an electrolyte solution while two solutions are connected electrically through a U-shaped tube called Salt bridge containing electrolyte solution as shown in figure (1).
First: Container was filled with 600ml of distilled water and the other container was filled with sodium chloride solution composed of 29.22 grams of sodium chloride dissolved in 500ml of water these specific quantities aim to achieve balance in concentration at the two containers.
Second: Aluminum anode was immersed in a NaCl solution which connected through copper wires to a copper cathode which was immersed in a distilled water that react with carbon dioxide gas.
Third: A Potassium chloride solution is prepared and poured in a U-shaped tube which closed at its two ends by a piece of cotton that immersed in two solutions.
Fourth: 50 grams of backing soda reacts with a liter vinegar shown in figure (3) to produce a 0.83 moles of carbon dioxide gas, which go through hose to react with water in the container this specific amount required to achieve the design requirement with consideration that some carbon dioxide gases don't react.

Test plan

Testing of prototype followed some steps, represented in:

- First, connect the aluminum anode with positive part of a multimeter (**AVO Digital Multimeter, DT-9205A**) and the copper cathode with negative part by using wires
- Adding 1 liter of vinegar to 50 grams of baking soda in a bottle connected to a hose to produce 0.83 mole of carbon dioxide gas in a try to balance the concentration of the solutions in the two half-cell parts.
- Putting the hose at the bottom of water container, making the rection between the evolved carbon dioxide and water.
- Recording the volt and ampere measurements, to be sure of achieving the design requirement of producing not less than 1.5 volt and to calculate the electrical power of the cell.

Results

Negative results

Our first test plan obtained negative results, as the cell produced 0.5 volts which didn't met the design requirement.
During research we found that there is critical point required in our design related to cell potential which is the concentration of ions in two solutions. The Nernst equation can be used to describe the dependence of the cell potential on concentration as shown in Fig (2).

$$E_{cell} = E^0 - \left(\frac{0.0592\ V}{n}\right)\log Q$$

Figure (2): Nernst Equation

Positive results

By making some modification according to what we learned during search, the positive results appeared:
The carbonic cell produced a voltage of 1.52 volts. And this meets the design requirements. The cell also produced 19 microamperes.
The electric power that the cell produced could be calculated by the law shown in Fig (3), the electric power = 1.52 × (19 × 10-6) = 2.888 × 10-5 watt.

Watts = Volts x Amps

Figure (3): ampere to Watt conversion

The actual work of the cell is -879943.2 while the maximum work is under the standard condition is -960990.6, thus the efficiency of the cell equal the actual work divide the maximum work times one hundred percent ((-879943.2) / (-960990.6)×100%) = 91.6%.

Analysis

Starting with the container that is used, the isolation of the container was considered, the container must be a bad conductor of electricity.
So plastic container was used because plastic is a good insulator. The insulators have atoms that are tighter to each other than conductors as shown in figure (4). This prevents the electrons from flowing forming an electric current as electricity is the flow of electrons.

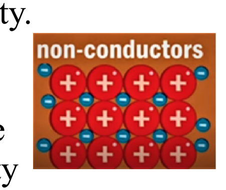


Figure (4): distribution of atoms in non-conductors

When it comes to the electrolyte in the container, sodium chloride was used because it is a strong electrolyte. Electrolytes are divided into strong, weak, and non-ionization degrees. The ionization degree of NaCl is 100%. This means that NaCl ionizes to positive sodium ions and negatively charged chlorine ions completely in water at Standard temperature and pressure (STP).
The continuity equation in fluid dynamics is an equation that describes the flow of some quantity of fluid throw a cross-section area. The continuity equation is shown in figure (5).

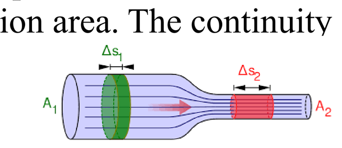


Figure (5): carbon emissions by sectors

It states that the area of the cross-section multiplied by the velocity of the fluid is constant at any given time. This means that the relation between the cross-section area of the pipe or the hose is inversely proportional to the velocity of the fluid. Based on this equation, the hose which was used as a path to the carbon dioxide has a small diameter, to accelerate the velocity of the gas to the distilled water to obtain faster and more effective results.
Moving to the salt bridge, it was used because during the process of flowing the electron from the oxidation site to the reduction site, The percentage of electric charge increased in the reduction site, while the percentage of positive charge increased in the oxidation site. This issue was solved by constructing a salt bridge. A salt bridge is a U-shaped tube filled with KCl that has been fully ionized in water to produce both positive and negative ions. That is why it balances the solutions; positive ions are pulled to the concentrated negative charge, while negative ions are pulled to the positive concentered charge. KCl was used because ions have a property known as mobility, and the mobility of an ion depends on its size. Smaller ions have higher mobility than larger ions. That means that the ideal species for a salt bridge should have a cation and an anion of the same size and charge. Potassium chloride is the ideal species for incorporation into a salt bridge, as K^+ and Cl^- have the same number of electrons and are approximately the same size.

Chemical reaction analysis

First, carbon dioxide is prepared by adding vinegar to baking soda which is stated in this balanced equation $\mathbf{NaHCO_3(s) + CH_3COOH(l) \rightarrow CO_2(g) + H_2O(l) + Na^+(a) + CH_3COO^-(aq)}$ (as learnt in CH.1.10). Although Carbon dioxide is polar (has a slight negative charge near the oxygen molecule and a slight positive charge near the carbon molecule), water gets attracted to it, thus, it dissolves in water (as learnt in CH.1.12) which is put on the cathode side (Copper side). Cold water is a better solvent than hot water because the solubility is inversely proportional to the temperature of the solvent (CH.1.08). This reaction between cold water and carbon dioxide produces carbonic acid which is stated in this equation $\mathbf{CO_2 + H_2O \rightarrow H_2CO_3}$. Because of the weakness of the bond between hydrogen ion and the hydrogen carbonate ion, the hydrogen ion will dissociate from the carbonic acid producing the two spectator ions separately which is written as $\mathbf{H_2CO_3 \rightarrow H^+ + HCO_3^-}$. On the anode side (Aluminum side), sodium chloride is dissolved in water into spectator ions which could be written as $\mathbf{NaCl + H_2O \rightarrow Na^+(as) + Cl^-(aq) + H_2O(l)}$. As the aluminum anode has high oxidation potential, it undergoes oxidation as stated in this equation $\mathbf{2Al \rightarrow 2Al^{+3} + 6e^-}$.
The aluminum ions precipitate in the container and the electrons are attracted to the hydrogen ions and passes through the wires and the cathode producing Hydrogen gas written in a chemical equation as $6H^+ + 6e^- \rightarrow 3H_2(g)$ and thus, producing electric current by passing through wires. The net redox reaction (as learnt in CH.1.12) is shown in Fig (6).

$$\underbrace{2Al(s) + 6H^+(aq) \rightarrow 2Al^{+3}(aq) + 3H_2(g)}_{\text{Oxidation / Reduction}}$$

Oxidation
Reduction
Figure (6): Net redox reaction

The salt bridge is the reason of the sustainability of this project as it completes the circuit allowing current to flow. The salt used in the salt bridge is KCl Anions (Cl^-) in the salt bridge flow toward the anode (Al) and cations (K^+) in the salt bridge flow toward the cathode (Cu). The movement of these ions completes the circuit and keeps each half-cell electrically neutral.

Cell Potential, Electrical Work, and Free Energy analysis

We've only looked at electrochemical cells from a practical standpoint so far, with little theoretical knowledge. Now consider how the E° cell is related to thermodynamic quantities such as G° (free energy) and K° (equilibrium constant). Chemical energy is transformed to electric energy in a galvanic cell. The product of the cell potential and the total electric charge (in coulombs) that passes through the cell is the electric energy produced in a galvanic cell:

electric energy = volts × coulombs
= joules

The charge on 1 mole of electrons is a constant called the faraday (abbreviated F), which has the value 96,485 coulombs of charge per mole of electrons. Thus, q equals the number of moles of electrons times the charge per mole of electrons:

$$\mathbf{q = nF}$$

Now let's calculate the maximum possible work that this cell can do (the right-hand side's negative sign indicates that the system performs electrical work on the surroundings.):

$$\mathbf{w_{max} = w_{electrical} = -qE_{cell}^{o} = -nFE_{cell}^{o}}$$

And (as learnt in CH.1.10): The maximum possible useful work obtainable from a process at constant temperature and pressure is equal to the change in free energy: $\Delta G° = w_{max} = -nFE°$

Thus: $\Delta G° = -6 \times (96485\ C/(mol\ e^-)) \times (1.66\ J/C) = -960990.6\ J\backslash mol$
This relationship is significant because it allows for the experimental determination of Delta G for a reaction. It also proves that a galvanic cell will run in the direction that results in a positive cell value; a positive cell value corresponds to a negative Delta G value, which is the condition for spontaneity.
Equilibrium constant (K)
The quantitative relationship between ΔG° and E° allows for the calculation of redox reaction equilibrium constants. For an equilibrium cell,

$$E°_{cell} = 0.0592V / n \quad \log(K)$$

The equilibrium constant can help us understand whether the reaction tends to have a higher concentration of products or reactants at equilibrium.
When it comes to our cell, the equilibrium constant is $\mathbf{1.76 \times 10^{154}}$ which prove that our reactions are spontaneous as when equilibrium constant is greater 1 tend to be spontaneous and vice versa. The word spontaneous implies that a reaction happens as soon as the reactants are mixed.

Conncetions

- According to CH.LO 10, Learning the concept of Mole aided us in calculating the amount of used carbon dioxide.
- According to CH.LO 12, The concepts of electronegativity and polarity helped us to understand the dissolving of carbon dioxide on water and the attraction of lost electrons by the cathode
- According to MA.LO 8, the concept of logarithmic functions helped us in calculating the equilibruim constant of cell.
- According to ES.LO 9, This LO helped us to collect more data about general the energy resources in Egypt.

Conclusion

From the research and identification of the problem to the analysis and test plan, there had been a lot of work done. The results of the test plan showed how effective the cell is. It fulfilled the design requirements and solved the problem of both climate change and Energy, making Egypt's reliance on carbon-based fossil fuels in industry a benefit rather than a disadvantage, as it will produce electrical energy and hydrogen fuel while also avoiding carbon dioxide emissions from factories.

Recommendation

- It is recommended that if we make our prototype in the real life, it will be placed at the industrial complexes near the funnels of factories that depend mainly on the fossil fuel that emit carbon dioxide gas as the project will receive the gas through a pipeline and in this way, it will reduce the percentage of factories' contribution to climate crisis and global warming.

- It is recommended that Lithium anode (as shown in the Figure (7)) be used instead of Al anode because its standard reduction potential is high as ($Li_{(S)} \rightarrow Li^+ + e^-$) is about (-3.05 Volt), meaning that it is a strong reducing agent and thus easily undergoes oxidation, and it is also readily available in Egypt.


Figure (8): carbon emissions by sectors

- It is recommended to use multiple lithium anodes in the electrolyte solution to generate more voltage and ampere. Furthermore, lithium superionic conductors (LISICON) (shown in Fig (8)) are preferred over salt bridges because they act as a positive ion membrane, allowing Li ions to flow only to the required side
- It is recommended that the hydrogen produced by the reactions be transported via pipeline with safety considerations to hydrogen refueling stations and used not only in cars, but also in much heavier trains and ships instead of gasoline to fulfil hydrogen's longstanding potential as a clean energy solution.

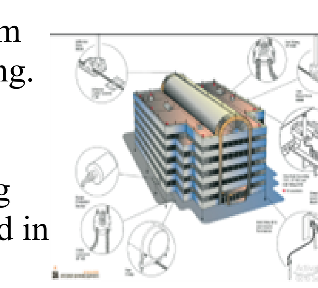


Figure (9): carbon emissions by sectors

- It is recommended to install a lightening protective system as the project can conduct electricity by exposure to lightening. Included in the system rooftop air terminals, also known as lightning rods, but they are only one part of the puzzle. The system includes a lightning conductor network that extending down a building and connects to ground electrodes embedded in the earth outside the structure's foundations, as well as other materials that aims to avoid the danger (as shown in Figure (9)).

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