Green Oxygen Production via Alkaline Electrolysis: Efficient Generation, Transport, and Industrial Utilization

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***Abstract*—Oxygen produced from alkaline electrolysis of water is a pure form of oxygen, also known as "Green Oxygen". Oxygen is a gas whose demand is never ending in various Industrial sectors like healthcare, Pressure Swing Adsorption (PSA) plants, food, chemical, wastewater treatment plants, steel manufacturing industries, etc.**

The amount of oxygen produced on a daily basis from a green hydrogen production plant with a capacity of producing more than 50TPD of hydrogen is, around 480TPD of oxygen.

This paper provides the production of oxygen and hydrogen on molecular basis and detailed financial analysis of the CAPEX & OPEX required to transport produced oxygen from plant to the desired consumers by pipelines, especially to the waste water treatment plants with a capacity of treating (70 million liters per day) and in exchange buying the treated waste water from these plants as a feedstock & coolant at very cheaper cost.

This treated waste water after purification and deionization becomes a very good source for the electrolysis process and in Compressor-cooling (Heat Exchanger), eliminating the need of seawater or any nearby freshwater sources and reusing the waste water which otherwise would have been discharged into the environment.

***Index Terms*—Green Oxygen, PSA plants, Wastewater Treatment Plants, 480TPD of oxygen, Alkaline Electrolysis of water, Compressor-cooling, financial analysis.**

I. INTRODUCTION

Alkaline electrolysis is a sustainable method for producing hydrogen and oxygen, governed by the reaction:

$$2H_2O \longrightarrow 2H_2 + O_2$$

While hydrogen is widely recognized as a clean energy carrier, the oxygen produced is often overlooked despite its industrial applications.

This research examines the feasibility and economics of utilizing oxygen from alkaline electrolysis in wastewater treatment plants. With a daily output of 480,000 kg at 18 bar and 70°C, this high-purity (99%-99.5%) oxygen serves industries like steel manufacturing, chemical processing, and wastewater treatment.

A key aspect is transporting oxygen via a 10,000-meter 316 stainless steel pipeline, ensuring optimal pressure and flow. The report evaluates pipeline material selection, cost estimation, and safety measures for high-pressure transport.

Furthermore, integrating wastewater treatment with electrolysis enhances sustainability by using treated water as a feedstock. The financial analysis covers pipeline infrastructure costs, maintenance, and potential revenue from oxygen sales, presenting a viable industrial model.

This study bridges green hydrogen production with industrial oxygen use, promoting a holistic approach to sustainable energy and resource management.

II. LITERATURE REVIEW

The production of hydrogen and oxygen through alkaline electrolysis has been widely studied as a sustainable alternative for industrial applications. Several studies have highlighted the efficiency of alkaline electrolysers, especially in large-scale industrial setups. According to Buttler and Spliethoff (2018), alkaline electrolysis remains one of the most mature and cost-effective water-splitting technologies for hydrogen production. Similarly, Carmo et al. (2013) discuss that alkaline electrolysis offers a significant advantage in terms of lower capital costs compared to proton exchange membrane (PEM) electrolysis, making it a viable option for large-scale applications.

Another key aspect of oxygen production in electrolysis is its utilization in various industries. Research by IRENA (2019) suggests that industrial oxygen demand is expected to rise due to its applications in wastewater treatment, steel manufacturing, and chemical processing. In wastewater treatment, oxygen acts as a powerful oxidizing agent, improving the efficiency of aerobic treatment processes (Zhou et al., 2020). Studies have shown that utilizing electrolytically produced oxygen in wastewater treatment plants can improve efficiency while reducing reliance on conventionally produced oxygen (Gan et al., 2021).

Pipeline transportation of oxygen at high pressure also requires careful material selection and safety considerations. Research conducted by EIGA (European Industrial Gases Association, 2021) provides comprehensive guidelines on materials suitable for oxygen transport, emphasizing the importance of corrosion-resistant materials like stainless steel (grades 304 and 316). Additionally, studies by McClaine et al. (2019) indicate that material degradation due to oxygen exposure at high pressures can be mitigated using advanced pipeline coatings and regular maintenance protocols.

Incorporating treated wastewater as a feedstock for electrolysis is an emerging field of study. Research by IRENA (2020) and Anghilante et al. (2022) highlights that the integration of electrolysis with wastewater treatment facilities can enhance sustainability while reducing freshwater consumption in hydrogen and oxygen production. The use of treated wastewater in alkaline electrolysis has been demonstrated to be both technically feasible and economically advantageous, as it reduces the overall cost of water purification while ensuring an environmentally friendly production process (Guo et al., 2021).

These studies provide strong evidence supporting the feasibility and cost-effectiveness of alkaline electrolysis for industrial hydrogen and oxygen production. The integration of wastewater treatment plants into the supply chain further enhances the sustainability of the process, making it a viable solution for large-scale applications.

III. METHODOLOGY and CALCULATIONS

- In an alkaline electrolysis of water: -

$$2H_2O \longrightarrow 2H_2 + O_2$$

This means that for every two moles of water, two moles of H_2 gas is produced and one mole of O_2 gas is produced.

- The amount of Oxygen produced per day

1. Molar mass of hydrogen: - hydrogen has an atomic mass of 1g/mol

Therefore, the molar mass of H_2 is 2g/mol

2. Molar mass of oxygen: - oxygen has an atomic mass of 16g/mol

Therefore, the molar mass of O_2 is 32g/mol

3. Hydrogen produced per day = 60,000 kg = 6,00,00,000 g
4. Moles of H_2 produced: -

Moles of H_2 = Mass of H_2 / Molar mass of H_2 = 6,00,00,000 / 2g/mol

= 3,00,00,000 mol of H_2

5. Moles of oxygen produced: -

Moles of O_2 = 0.5* Moles of H_2

=0.5* 3,00,00,000 mol

= 1,50,00,000 mol of O_2

Moles of O_2 = (Mass of O_2 / Molar mass of O_2)

Mass of O_2 = Moles of O_2* Molar mass of O_2 = 1,50,00,000*32= 48,00,00,000g

Mass of O_2 = 4,80,000kg

The amount of Oxygen produced per day = 4,80,000 Kg.

- Alkaline Electrolysis of water produces O_2 and H_2 as the by-products.

Properties of O_2 produced by this method are: -

Pressure = 18 bar

Temperature = 70˚C

Purity = 99% to 99.5%

Flow rate = 21333.33 Kg/hr

Flow velocity = 15 m/s

- Applications of Oxygen gas on Industrial scale: -

Oxygen is a widely used Industrial gas in: -

1. Steel Making: This Industry is the largest consumer of Oxygen.
2. Chemical Manufacturing: Here Oxygen is used as raw material and as an oxidizing agent.
3. Mining: to blast rocks and is essential agent for the safety of miners.
4. Petrochemical Industries: Used for oxidation reaction, chemical synthesis and Waste water treatment.

5. Gas welding, cutting and flame working: used with fuel gases for these processes.
6. Waste water Treatment Plants: for treating the waste water collected from industries and less harmful water is discharged into the environment safely.

- Waste Water Treatment Plants: In a waste water treatment plant, the oxygen needed is generally supplied either as compressed gas, liquid oxygen or pure oxygen.

Waste water treatment plants are also one of the largest consumers of Oxygen gas. They require pure form of oxygen i.e. 99% to 99.5% pure.

The oxygen gas produced with the help of Alkaline Electrolysis of water is also a pure form of oxygen also called as “Green Oxygen”.

In a waste water treatment plant, the cost of oxygen supplied can vary widely depending on several factors:

a. Method of Oxygen delivery
b. Quantity required
c. Geographic Location

Large plants with Higher Oxygen demand will generally receive a lower cost per unit of oxygen due to bulk purchasing and more efficient delivery system.

- Oxygen Transportation through pipelines: -

By Alkaline electrolysis of water, oxygen is produced at an outlet pressure of 18 bar.

The standard Operating pressure of most of the industrial oxygen pipelines is between 6-10 bar. Since in our case the pressure is 18 bar i.e. at quite higher end, few key considerations are to be taken while setting up the pipeline.

- Key Considerations for transportation of O_2 at 18 bar pressure are: -

1. Pipeline Pressure Compatibility: Components such as valves compressors and regulators are rated for pressure higher than 18 bar to handle the operating pressure safely.

The amount of pressure drop depends upon the diameter of the pipeline and the flowrate of Oxygen gas.

2. Safety Concerns: O_2 is highly reactive (especially under pressure).

It is important that the pipeline is specifically designed for O_2 transportation.

3. Pressure Regulation: If pipeline is designed for lower pressure than we are producing then we need to regulate the pressure before transporting. Instead of that we should design a pipeline which can easily sustain the required pressure.

For pressure regulation we can use Pressure Regulation Valve at entry point. The Pressure regulation valves are used to maintain consistency and safety.

4. Pipeline Material and Design: Material used for the pipeline should be Corrosion Resistance and designed for high pressure O_2 transport.

Steel, Aluminium and special Composites are the different types of materials used widely.

If the pipeline has large diameter, pressure loss will be lower.

5. Flow rate and Distance: If transporting O_2 to a longer distances it can need the use of compressor or booster to maintain the pressure and flow rate over the period of time. As the flow rate and flow velocity of the O_2 can be affected due to the walls of the pipeline causing friction and resistance to the flow, hindering the efficiency of transport.

The flow rate also depends on the distance to be travelled.

6. Losses**:** Various kinds of losses can take place while transporting O_2 to a longer distance through pipelines i.e. losses due to friction, pressure loss, flow velocity loss, etc.

- Selection of material for the pipelines: -

A study was conducted by EIGA (EUROPEAN INDUSTRIAL GASES ASSOCIATION AISBL) regarding the types of materials and their properties and specifications which can be used for oxygen transportation. After several studies and research, the scientist of this department introduced a method named Oxygen Hazards Analysis and Risk Assessment.

This method consists of:

a. Cleaning and maintaining Cleanliness of piping and equipment.
b. Use of compatible Metal or Non-Metal if appropriate lubricants are used.
c. Use of Burn resistant Metals.

An oxygen hazards analysis is a method used to evaluate risk of fire in an oxygen system, Evaluate flammability of materials in application pressure and thickness.

The material used should be safe, efficient, long-term durability, compatible with oxygen, able to handle high pressures and resistant to corrosion and erosion.

1. Stainless Steel (Austenitic Stainless Steels, such as 304 or 316)

Pros:

Corrosion-resistant: Stainless steel is highly resistant to oxidation and corrosion, making it ideal for handling oxygen, which can cause other metals to corrode.

Strength and Durability: Stainless steel can handle high-pressure conditions like 18 bar without significant deformation or failure.

Oxygen compatibility: Stainless steel is non-reactive with oxygen, which is crucial because oxygen is a highly reactive gas, especially at high pressures.

Good for both low and high temperatures: Stainless steel remains stable at a wide range of temperatures, making it suitable for various operational conditions.

Widely used: It is commonly used in the oil, gas, and chemical industries for transporting gases, including oxygen.

Cons:

Cost: Stainless steel is relatively expensive compared to some other materials.

Requires cleaning: The pipeline must be properly cleaned and degreased before use, as impurities can cause reactions with oxygen (this is an important safety consideration).

Recommended Grades:

304 stainless steels: Good general-purpose material that is resistant to corrosion and works well in oxygen transport.

316 stainless steels: Offers enhanced resistance to corrosion (especially against chlorides) and is used in more demanding applications.

2. Carbon Steel (with proper treatment and coatings)

Pros:

Cost-effective: Carbon steel is typically less expensive than stainless steel and may be a cost-effective solution when treated properly.

High strength: Carbon steel can handle high pressures, and with appropriate thickness, it can be used for oxygen transport.

Cons:

Oxygen reactivity: Carbon steel can react with oxygen and form rust or scales, which makes it less ideal for direct oxygen transport unless the steel is properly coated and cleaned.

Corrosion: It is more susceptible to corrosion than stainless steel, especially in environments with high oxygen content.

Solution:

Galvanized or coated carbon steel: To enhance oxygen compatibility, carbon steel can be treated or coated with a non-reactive layer (e.g., epoxy coatings) to prevent corrosion and reactivity.

3. Aluminium (for smaller-scale or low-pressure systems)

Pros:

Lightweight: Aluminium is lighter than stainless steel, which can reduce installation costs, especially for long pipelines.

Corrosion-resistant: It forms a protective oxide layer that makes it resistant to corrosion, though it is not as robust as stainless steel.

Cons:

Pressure limitations: While aluminium can handle pressures up to about 18 bar, it is generally more suitable for lower-pressure applications.

Strength concerns: Aluminium has a lower tensile strength than stainless steel, so it may require thicker walls to handle high pressure safely.

Oxygen reactivity: Aluminium can react with oxygen under certain conditions (e.g., at high temperatures), which can create risks for fire or explosive reactions if the aluminium is not properly treated.

4. Copper Alloys (e.g., Copper-Nickel):

Pros:

Good corrosion resistance: Copper alloys are resistant to corrosion, especially in saline and oxygen-rich environments.

Ductility: Copper alloys can withstand mechanical stresses, and they are flexible enough to handle minor vibrations and thermal expansion.

Cons:

Cost: Copper alloys can be expensive, although they are cheaper than stainless steel in some cases.

Limited pressure handling: Copper alloys are generally not as strong as stainless steel and may not be suitable for very high-pressure applications unless used in thicker-walled pipes.

5. Nickel Alloys (e.g., Inconel)

Pros:

High strength and resistance: Nickel alloys, such as Inconel, are highly resistant to both corrosion and oxidation, especially in high-pressure and high-temperature environments.

Oxygen compatibility: They have excellent resistance to reactive oxygen and can perform well under extreme conditions.

Cons:

Cost: Nickel alloys are very expensive compared to stainless steel and other materials.

- Best Material Choice for Oxygen Pipelines at 18 bar Pressure

Given the high pressure (18 bar) and the need to handle oxygen transport safely, the best material would be:

Stainless Steel (Grade 304 or 316):

316 stainless steels would be the most recommended material for transporting oxygen at high pressure because it has the best balance of strength, corrosion resistance, and oxygen compatibility. It is widely used for oxygen pipelines, especially in chemical processing, industrial gas transport, and medical oxygen systems.

For applications that involve highly reactive conditions or extremely high pressure, 316L stainless steel (low-carbon variant) may be preferred to prevent sensitization during welding, which can reduce corrosion resistance.

- Costing of Material (316- Stainless Steel):-

Price per Kg = Rs.240/Kg

The outer diameter of pipe = 0.29m

The inner diameter of pipe = 0.29-(2*0.01) = 0.27m

The wall thickness = 0.01m

The Length of pipeline(L) = 10,000m

1. To calculate volume of stainless-steel pipeline: -

V = π*($Dout^2$- $Dinner^2$)*L

V=3.14*(0.29^2-0.27^2)*10,000

V = 351.68 m^3

2. To calculate mass of stainless steel: -

Mass = Volume*Density

(Density of 316-stainless steel = 8000Kg/m^3)

Mass= 351.68 m^3 * 8000Kg/m^3

Mass = 28,13,440 Kg _ Mass of stainless-steel pipe

3. To calculate material cost: -

Stainless steel price = Rs.240/ Kg

Material cost = 28,13,440*240 = Rs67,52,25,600 = 67.5 CR

4. Installation cost: -

The installation cost includes cost of fabrication, testing, etc which = Rs.2500/m

Installation cost = Distance*2500 = 10,000*2500 = 2,50,00,000 = 2.5 CR

5. Total Pipeline cost (Capital cost): -

Total cost = Material cost + Installation cost = 67,52,25,600 + 2,50,00,000

Total Pipeline cost = Rs.70,02,25,600 = 70.02CR

6. Annual Maintenance cost = 3% of the capital cost

Maintenance cost = 0.03*70,02,25,600 = Rs.2,10,06,768/year

- COSTING OF PURE OXYGEN

Oxygen is delivered to the waste water treatment plant through the pipeline.

The cost of Oxygen on weight basis is around Rs.50/ Kg of O_2

Selling Cost of oxygen = Rs.50*4,80,000 Kg of O_2 = Rs.2,40,00,000/day

The Potential Revenue from selling O_2 = Rs.2,40,00,000/day.

- Why We Chose Wastewater Treatment Plants for Electrolysis?

Wastewater treatment plants provide a continuous supply of treated water, which, after purification and deionization, can be efficiently used in alkaline electrolysis for hydrogen and oxygen production.

The nearest plant, with a 70 million liters per day capacity, ensures reliable sourcing. These plants require oxygen as an oxidizing agent to improve water quality before discharge. By integrating electrolysis, we establish a mutually beneficial system:

- Our electrolysis plant gains a cost-effective, sustainable water source.
- The treatment plant receives high-purity oxygen (99–99.5%), reducing its reliance on external suppliers.
- Both entities profit, as we sell oxygen from electrolysis at competitive rates.

Using treated wastewater eliminates the need for costly seawater desalination, which is energy-intensive and produces excessive brine waste.

Challenges & Risks

Despite its advantages, treated wastewater poses challenges for electrolysis:

- Impurities: Trace heavy metals, organics, and salts can degrade electrode efficiency.
- Scaling & Deposition: Dissolved calcium, magnesium, and silica cause electrode fouling, increasing maintenance.
- Corrosion: Residual contaminants accelerate electrode wear and reduce equipment lifespan.
- Pre-Treatment Costs: Reverse osmosis, ion exchange, and ultrafiltration are required, increasing operational expenses.
- Water Quality Variability: Industrial discharges fluctuate daily, requiring continuous monitoring.
- Regulatory Compliance: Environmental approvals may be necessary for wastewater utilization.

Mitigation Strategies

- Advanced Filtration: Multi-stage purification (RO, UV, ion exchange) removes contaminants.
- Real-Time Monitoring: Ensures consistent water quality for electrolysis.
- Electrode Protection: Corrosion-resistant materials (nickel, iridium oxide) enhance durability.
- Selective Sourcing: Prioritizing industries with cleaner effluents minimize purification efforts.

IV. CONCLUSION

For transporting oxygen at 18 bar pressure and 21,333.33 kg/hr flow rate, 316 stainless steel is the optimal pipeline material due to its high strength, superior corrosion resistance, and excellent compatibility with oxygen. It is the industry standard for high-pressure oxygen transport, ensuring safety and durability. While 304 stainless steel is a more cost-effective alternative, 316 SS offers better resistance to oxidation and aggressive environments, making it the preferred choice for long-term reliability.

The pure oxygen produced through the process of alkaline electrolysis of water is used widely and has several applications in various sectors like steel making, gas welding, food processing, chemical industries and also in Hospitals and health care industries, etc.

Additionally, utilizing treated wastewater for electrolysis is a sustainable and cost-efficient approach, reducing reliance on freshwater while maximizing resource efficiency. However, advanced water treatment and strict quality control are crucial to ensure electrolyser longevity, process efficiency, and regulatory compliance. With the right mitigation strategies, this approach can contribute to a greener, more economical hydrogen production system.

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