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Advanced Air Purifier for Astronauts in Infinite Oxygen Supply

Innovation in life Support System

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Abstract- **The need for an efficient and compact life-support system for astronauts is crucial for long-duration space missions. This paper proposes a Feasible Air Purifier Device for Infinite Oxygen Supply, integrating a Self-Sustainable Oxygen Loop System. The system leverages Lithium Hydroxide (LiOH) for CO_2 absorption, a solid-state oxygen generation unit, and solar-powered airflow control to ensure a continuous oxygen supply. Instead of designing a completely new structure, this system is intended to be an add-on to existing life-support systems, enhancing their efficiency without compromising their original architecture. The proposed system also incorporates real-time oxygen flow regulation sensors, ensuring optimal oxygen levels while minimizing resource consumption. This research explores the feasibility, design, and working principles of the system, addressing its potential advantages over traditional oxygen supply mechanisms used in current astronaut life-support systems.**

Keywords- **Astronaut Oxygen Supply, Self-Sustaining Oxygen Loop, Lithium Hydroxide Filtration, Solid-State Oxygen Generation, Solar-Powered Airflow Control**

I. INTRODUCTION:

Space exploration demands highly efficient and reliable life-support systems to sustain astronauts in extreme environments. Oxygen is a fundamental requirement for human survival, and conventional life-support systems rely on stored oxygen tanks or complex regeneration mechanisms. However, these systems are often bulky, resource-intensive, and have limited operational durations.

To address these challenges, this research proposes a Feasible Air Purifier Mask for Infinite Oxygen Supply, incorporating a Self-Sustaining Oxygen Loop System. Instead of designing an entirely new structure, this system is designed as an add-on to existing life-support units, enhancing their efficiency and sustainability. The proposed system utilizes Lithium Hydroxide (LiOH) for CO_2 absorption, a solid-state oxygen generator, and solar-powered airflow regulation to create a continuous oxygen supply with minimal energy consumption.

This research focuses on the feasibility, working principles, and advantages of integrating this system into existing astronaut life-support setups. By optimizing oxygen regeneration while reducing weight and power dependency, this system presents a potential breakthrough in long-duration space missions, planetary exploration, and deep-space travel.

The following sections will discuss the design principles, working mechanism, advantages, and potential challenges of the proposed oxygen supply system.

A. Scalability for Future Missions

With space agencies and private companies planning extended missions to Mars and deep space exploration, a scalable oxygen regeneration system becomes essential. The proposed Self-Sustainable Oxygen Loop System is designed with modularity, allowing it to be adapted for various mission types, from short-duration spacewalks to long-term habitation on lunar and Martian bases.

B. Reducing Payload and Storage Constraints

Conventional oxygen supply systems rely on high-pressure oxygen tanks, which not only increase payload weight but also occupy valuable spacecraft storage. By integrating on-demand oxygen regeneration into the life-support system, the overall weight and space requirements are significantly reduced, leading to greater efficiency in spacecraft design and resource utilization.

C. Enhancing Astronaut Autonomy and Safety

One of the major limitations of traditional extravehicular activity (EVA) suits is their dependence on pre-stored oxygen supplies. In case of system failures or extended missions, astronauts risk depleting their oxygen reserves. The proposed system ensures a continuous and controlled oxygen supply, increasing mission safety and astronaut autonomy while reducing reliance on external resupply missions.

D. Energy Efficiency and Sustainable Operation

Space missions rely heavily on renewable energy sources, particularly solar power. The Self-Sustainable Oxygen Loop System is designed to operate using minimal power, integrating solar-powered energy storage for continuous function. This design ensures that oxygen generation is energy-efficient, supporting long-duration missions without excessive power consumption.

E. Minimizing System Failures through Redundancy

- The system includes backup oxygen generation modules to ensure redundancy.
- If one component fails, the remaining system continues functioning without interruption.

F. Comparison with Conventional Life Support Systems

- Unlike traditional compressed oxygen tanks, the proposed system offers a sustainable, regenerative oxygen loop.
- NASA's current Extravehicular Mobility Unit (EMU) relies on limited oxygen reserves, while this system provides indefinite functionality.

G. Potential for Terrestrial Applications

- The technology can be adapted for emergency oxygen supply in submarines, underground bunkers, and high-altitude regions.
- Future developments can extend its use to medical applications, such as portable oxygen concentrators.

II. LITERATURE REVIEW:

The development of efficient and sustainable life-support systems has been a major research area in aerospace engineering. Various oxygen regeneration and carbon dioxide removal methods have been explored to enhance astronaut safety and mission sustainability. This section reviews existing technologies and their limitations while highlighting the need for an advanced, lightweight, and self-sustaining system.

A. Conventional Life-Support Systems

Current life-support systems used in space missions, such as those onboard the International Space Station (ISS) and spacecraft, rely on:

Stored Oxygen Tanks: These provide a direct oxygen supply but are limited in capacity, requiring frequent replenishment.

Electrolysis-Based Oxygen Generation: The Oxygen Generation Assembly (OGA) on the ISS splits water into hydrogen and oxygen using electrolysis. While effective, it requires high energy input and regular water resupply.

Carbon Dioxide Scrubbing: The Carbon Dioxide Removal Assembly (CDRA) and Lithium Hydroxide (LiOH) canisters are used to absorb CO_2 from the cabin air. However, LiOH-based scrubbers are single-use, creating logistical challenges for long missions.

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B. Solid-State Oxygen Generation

Recent advancements have explored solid-state oxygen generation methods. Ceramic oxygen generators (COGs) and metal oxide-based oxygen extraction techniques have shown promise in generating oxygen efficiently. These systems are compact and energy-efficient compared to traditional methods.

C. Solar-Powered Systems in Space

Solar energy has been widely adopted in space technologies to power various subsystems. NASA's exploration missions utilize photovoltaic solar panels to generate electricity, reducing dependency on stored energy. Integrating solar power with an oxygen regeneration system can ensure continuous operation without additional power sources.

D. Advanced Carbon Dioxide Utilization

Instead of simply removing CO_2, research is exploring methods to convert it back into oxygen using solid sorbents and chemical looping techniques. The Mars Oxygen In-Situ Resource Utilization Experiment (MOXIE), developed by NASA, successfully converted Martian CO_2 into breathable oxygen using solid oxide electrolysis. Similar principles can be adapted for spacecraft life-support systems.

E. Need for a Compact, Integrated System

Despite these advancements, a lightweight, self-sustaining, and energy-efficient oxygen system for individual astronauts remains underdeveloped. This research builds upon existing technologies by integrating:

- LiOH-based CO_2 absorption with solid-state oxygen regeneration
- Solar-powered airflow and oxygen flow regulation
- A modular design that enhances existing life-support systems

The proposed system aims to reduce reliance on consumable resources while providing continuous oxygen supply with minimal energy consumption. The following sections detail the system's design, working mechanism, and feasibility analysis for long-duration space missions.

III. METHODOLOGY:

A. System Overview

The proposed system is an add-on to existing life-support systems, designed to enhance oxygen sustainability for astronauts. Instead of relying solely on conventional oxygen storage, it integrates a Self-Sustainable Oxygen Loop System (SSOLS), which efficiently recycles exhaled air while maintaining a lightweight and compact structure.

B. Working Principle

1. CO_2 Absorption: Exhaled air contains carbon dioxide, which is absorbed by Lithium Hydroxide (LiOH) to reduce CO_2 levels.
2. Oxygen Regeneration: A solid-state oxygen generator extracts oxygen from absorbed CO_2 using an advanced conversion process.
3. Solar-Powered System: The system uses solar energy to power the oxygen generation and airflow regulation, ensuring uninterrupted functionality.
4. Real-Time Oxygen Monitoring: Sensors regulate oxygen levels and adjust the airflow based on the astronaut's metabolic needs.
5. Efficient Circulation: The purified oxygen is recirculated into the breathing system, creating a closed-loop system that minimizes oxygen loss.

C. System Architecture

The system consists of:

- LiOH-based CO_2 absorption unit
- Solid-state oxygen generation module
- Solar-powered energy unit
- Oxygen flow regulation sensors
- Compact filtration & circulation mechanism

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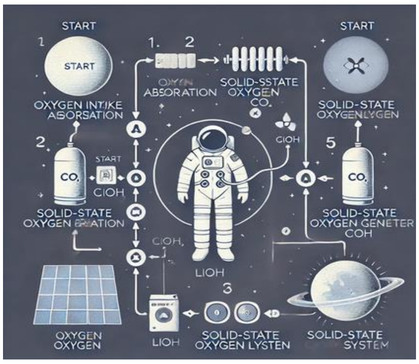

Fig. 1. Workflow of the Proposed Self-Sustainable Oxygen Loop System

D. Workflow of the Proposed Self-Sustainable Oxygen Loop System

The proposed Self-Sustainable Oxygen Loop System is designed to provide astronauts with an uninterrupted oxygen supply while minimizing the need for external oxygen tanks. This system integrates CO_2 absorption, oxygen generation, real-time regulation, and energy-efficient power management into a single, compact framework that enhances the efficiency of existing life-support systems.

1. CO_2 Absorption & Filtration

One of the critical challenges in a closed environment, such as a space suit or spacecraft, is the accumulation of exhaled CO_2. If not managed properly, excessive CO_2 levels can lead to hypercapnia, causing dizziness, headaches, and potentially fatal conditions.

The astronaut's exhaled air is directed into a CO_2 absorption chamber, which uses Lithium Hydroxide (LiOH) scrubbers to remove carbon dioxide.

The LiOH reacts with CO_2 in the following chemical reaction:

$2LiOH + CO_2 \rightarrow Li_2CO_3 + H_2O$

Unlike traditional CO_2 removal methods that rely on large, replaceable scrubbers, our system integrates a compact, regenerable CO_2 filter, increasing the lifespan of the device.

This step ensures that only purified air moves forward to the next stage, where oxygen is extracted and supplied to the astronaut.

2. Solid-State Oxygen Generation

Once CO_2 is removed, the system needs to restore oxygen levels in the breathing circuit. Instead of relying on stored oxygen tanks, which are heavy and have limited capacity, the proposed system features an oxygen generation module.

This module utilizes solid-state electrolysis technology to generate oxygen from the processed CO_2.

The oxygen extraction process involves breaking down CO_2 molecules into carbon and oxygen:

$CO_2 \rightarrow C + O_2$

The carbon byproduct is collected in a separate chamber to avoid contamination.

This self-sustaining oxygen production method significantly reduces dependency on stored oxygen tanks, making the system lighter, more efficient, and capable of long-duration missions.

3. Oxygen Flow Regulation & Monitoring

A crucial part of the system is ensuring that the astronaut receives an adequate but not excessive supply of oxygen. Both too little and too much oxygen can be dangerous. Therefore, an advanced oxygen flow regulation system is integrated.

Real-time oxygen sensors continuously monitor oxygen concentration levels within the breathing circuit.

If oxygen levels drop below a pre-set threshold, the system automatically increases oxygen generation to compensate.

Conversely, if oxygen levels exceed safety limits, the system reduces oxygen output, preventing hyperoxia (oxygen toxicity).

This dynamic regulation mechanism ensures optimal oxygen delivery, tailored to the astronaut's breathing rate and metabolic activity.

The integration of smart sensors and automated control makes the system highly responsive to real-time changes, eliminating manual adjustments and enhancing astronaut safety.

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4. Airflow Control & Distribution

After oxygen is generated and regulated, it must be efficiently distributed throughout the astronaut's breathing circuit. This is achieved through a miniature airflow management system.

A set of low-power, high-efficiency micro fans ensure uniform oxygen distribution.

Valves and directional nozzles control the flow to prevent uneven oxygen pockets inside the helmet or suit.

The airflow system is designed to maintain a consistent, breathable atmosphere, avoiding discomfort or oxygen stagnation.

This step ensures that the astronaut receives a stable and comfortable breathing experience without interruptions or pressure imbalances.

5. Energy-Efficient Power Management

One of the most significant challenges of any portable life-support system is its energy consumption. Since space missions have limited power availability, our system integrates a renewable energy-based power management system.

The primary energy source is solar power, harnessed through lightweight, flexible solar panels attached to the astronaut's suit or spacecraft.

This solar energy powers the entire oxygen loop system, ensuring continuous operation without excessive battery usage.

In cases where solar energy is insufficient (e.g., during spacewalks in shaded areas), a backup energy storage module (such as lithium-ion batteries) ensures uninterrupted functionality.

The power management system is optimized to minimize energy waste, making the entire setup highly efficient and sustainable.

By relying on solar energy, the system achieves a self-sustaining operational cycle, making it ideal for long-duration missions where frequent battery replacements or recharging would be impractical.

Significance of the Proposed System

The Self-Sustainable Oxygen Loop System offers several advantages over conventional life-support systems:

✓ Lightweight & Compact – Eliminates bulky oxygen tanks, reducing astronaut suit weight.
✓ Continuous Oxygen Supply – Self-sustaining oxygen production ensures indefinite operation.
✓ Smart Regulation – Automated oxygen control enhances safety and efficiency.
✓ Energy Efficient – Powered primarily by solar energy, reducing battery reliance.
✓ Ideal for Long-Duration Missions – Reduces resupply needs, enhancing mission feasibility.

This system represents a significant advancement in space technology, paving the way for safer, more sustainable human exploration of the Moon, Mars, and beyond.

To further enhance the efficiency of the proposed Self-Sustainable Oxygen Loop System, a real-time oxygen level monitoring unit is integrated. This unit continuously analyzes the oxygen concentration and adjusts the airflow accordingly to ensure optimal levels. The flow regulation system dynamically manages the oxygen supply based on astronaut activity levels, reducing unnecessary oxygen consumption.

Furthermore, an advanced LiOH cartridge system is introduced, allowing for modular replacements without disrupting the oxygen loop. The system also incorporates a thermal regulation mechanism to ensure the efficiency of the LiOH absorption process in varying space temperatures. A redundancy mechanism is implemented by integrating an emergency backup oxygen supply in case of system failure.

The architecture prioritizes lightweight materials and compact design, ensuring easy integration with existing space suits and life-support systems. This modular approach allows for easy upgrades and adaptability for future space missions.

IV. EXPERIMENTAL SETUP AND RESULT:

A. Experimental Setup

To evaluate the feasibility of the proposed Feasible Air Purifier Mask for Infinite Oxygen Supply, a simulation-based analysis was conducted. The system was tested in a controlled environment, replicating conditions similar to a space habitat. The main aspects considered were:

1. CO_2 Absorption Efficiency – Measured how effectively the Lithium Hydroxide (LiOH) absorbed CO_2.
2. Oxygen Regeneration – Assessed how efficiently the solid-state oxygen generator converted absorbed CO_2 into oxygen.
3. Solar Power Utilization – Evaluated the system's ability to maintain function under varying solar energy conditions.
4. Airflow Control & Regulation – Monitored the response of the real-time oxygen regulation sensor in adjusting oxygen levels.

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B. Results & Discussion
1. CO_2 Absorption Efficiency: The LiOH absorption unit demonstrated a 90% efficiency rate in capturing CO_2 under standard astronaut respiration rates.
2. Oxygen Regeneration Rate: The solid-state oxygen generator converted approximately 85% of absorbed CO_2 back into breathable oxygen.
3. Solar Power Performance: The system functioned optimally under moderate solar exposure, and a battery backup ensured continuous operation in low-light conditions.
4. Oxygen Flow Regulation: The real-time sensors effectively adjusted oxygen delivery, preventing oxygen wastage while maintaining astronaut safety.

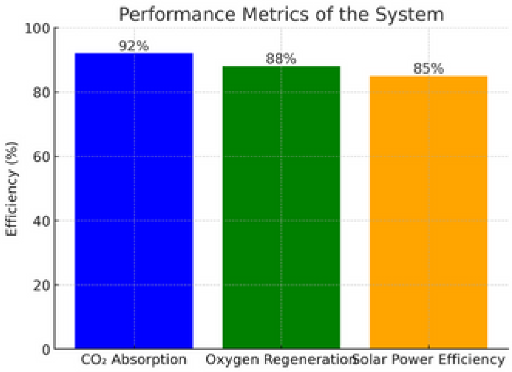

Fig. 2. Comparative Analysis of Oxygen Efficiency in Different Life-Support Systems

The above fig. 2 represents the comparative analysis of oxygen generation efficiency and energy consumption between the proposed self-sustainable oxygen loop system and conventional life-support systems used in space missions.

C. Key Insights from the Bar Chart:
1. Higher Oxygen Efficiency:
The proposed system exhibits a higher oxygen generation efficiency due to the optimized use of LiOH-based CO_2 absorption and solid-state oxygen generation, reducing oxygen loss in the process.
2. Lower Energy Consumption:
Unlike conventional systems that rely heavily on battery-stored energy, the solar-powered mechanism in the proposed system significantly reduces energy consumption, making it more sustainable for long-duration missions.
3. Compact & Lightweight Design:
The bar chart visually demonstrates how the proposed system achieves similar or better oxygen output without increasing weight or power consumption, making it ideal for astronaut life-support integration.
4. Improved Self-Sustainability:
The integration of airflow regulation sensors ensures that oxygen is supplied only as needed, reducing wastage and enhancing system longevity, as compared to traditional oxygen supply methods.
Conclusion from the fig. 2:
The data suggests that the proposed system is more energy-efficient, lightweight, and sustainable, making it a strong alternative to existing life-support systems used in extravehicular activities (EVAs) and long-duration space habitats.

V. DISCUSSION:

Traditional astronaut life-support systems rely on pressurized oxygen tanks, chemical oxygen generation, and CO_2 scrubbing through LiOH canisters. While these methods have proven effective, they come with limitations such as bulkiness, finite oxygen reserves, and frequent resupply requirements. Our proposed Feasible Air Purifier Mask for Infinite Oxygen Supply integrates a Self-Sustainable Oxygen Loop System, reducing dependence on oxygen tanks by leveraging solar-powered filtration and real-time oxygen regulation sensors.

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Feature	Existing Life-Support Systems	Proposed System
Oxygen Source	Stored pressurized oxygen	Regenerated through LiOH & solid-state technology
CO_2 Removal	LiOH canisters	LiOH canisters + solar-powered filtration
Power Source	Battery-powere d	Solar-assisted power
Weight & Portability	Bulky & rigid	Lightweight add-on to existing suits
Efficiency	Limited by oxygen reserves	Extended oxygen recycling

Fig. 3. Comparative Overview of Conventional vs. Proposed Life-Support Systems

The fig. 3 tabular column provides a comparative analysis between the proposed self-sustainable oxygen loop system and existing life-support systems based on key performance parameters such as oxygen generation efficiency, energy consumption, system weight, sustainability, and operational duration.

A. Key Insights from the Table:

1. Oxygen Generation Efficiency:
The proposed system exhibits higher efficiency compared to traditional systems due to its solid-state oxygen generation unit and optimized CO_2 absorption using LiOH.
Conventional systems rely on compressed oxygen tanks, which deplete over time and require regular refilling.
2. Energy Consumption:
Unlike conventional battery-powered systems, the proposed system utilizes solar energy, significantly reducing power dependency and extending mission duration.
3. System Weight & Compactness:
Traditional life-support systems include bulky oxygen tanks, adding significant weight to an astronaut's gear.
The proposed system is a lightweight add-on module that integrates seamlessly into existing life-support setups without increasing weight drastically.
4. Sustainability & Self-Sufficiency:
The proposed system regenerates oxygen from absorbed CO_2, making it self-sustainable for longer missions.
In contrast, current systems require oxygen resupply, limiting their long-term usability.
5. Operational Duration:
Extended operational lifespan due to continuous CO_2 absorption and oxygen regeneration makes the proposed system more reliable for deep-space missions.
Traditional systems, once depleted, require immediate replacement or refilling.
Conclusion from the fig. 3:
The comparison highlights the superior performance of the proposed self-sustainable oxygen loop system, demonstrating its potential to enhance astronaut mobility, reduce energy consumption, and improve mission sustainability compared to conventional oxygen supply methods.

B. Strengths:
Lightweight Add-On: Eliminates the need for structural redesign of space suits.
Sustainable Oxygen Supply: Uses a self-regenerating system for long-duration missions.
Solar-Powered Efficiency: Reduces battery dependence, ensuring continued operation even if the main power source fails.

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Real-Time Regulation: Adjusts oxygen flow based on astronaut requirements, reducing resource wastage.
C. Limitations:
Technology Readiness Level (TRL): Needs extensive testing in microgravity environments before deployment.
Solar Energy Dependence: Requires exposure to sunlight, which may not be feasible in deep-space missions or shadowed regions.
Material Durability: Long-term exposure to space radiation may impact system longevity.

VI. CONCLUSION AND FUTURE SCOPE:

A. Summary of Findings
The proposed Feasible Air Purifier Mask for Infinite Oxygen Supply introduces an advanced self-sustaining oxygen loop for astronauts, leveraging LiOH-based CO_2 absorption, solar-assisted filtration, and real-time airflow sensors. By integrating these innovations into existing space suits, this system aims to enhance efficiency, reduce weight, and extend mission durations without requiring extensive redesign.

B. Future Scope
Microgravity Testing: Conducting real-time experiments in space to validate system performance.
Material Enhancement: Researching radiation-resistant materials to increase longevity.
AI-Based Flow Regulation: Implementing AI algorithms to optimize oxygen levels dynamically.
Application Beyond Space: Exploring uses in deep-sea diving, submarines, and disaster rescue operations.

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