Jurnal Penelitian Medan Agama Volume 16, Nomor 02, 2025 | ISSN : 1693-0673, e-ISSN : 2655-2663

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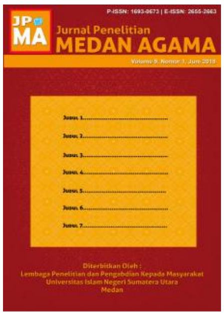

Neon Fluid Tree: Bio-Artificial Trees in Urban Landscape and Weather Detecting Systems

Neon Fluid Tree: Pohon Bio-Artifisial dalam Lanskap Perkotaan dan Sistem Pendeteksi Cuaca

Bunga Shafira Muthmainah[1*], Disha As Syifa Maharani[2], Siti Chairun Nabila[3], Hendri [4], Afryansyah[5]

[1,2,3,4,5] *MAN Insan Cendekia OKI, Ogan Komering Ilir, Indonesia;*
[1]shashaframthmnh@gmail.com, [2]dishasifa6@gmail.com, [3]sitichairunnabila16@gmail.com, [4]hendri.j7prime@gmail.com, [5]afryansyah@manicoki.sch.id

[*]Correspondence: shashaframthmnh@gmail.com

Abstract

Urban air pollution continues to intensify due to high vehicle emissions, limited green spaces, and the declining capacity of vegetation to absorb carbon dioxide. To address this challenge, this study proposes the Neon Fluid Tree, a portable bio-artificial system that utilizes Chlorella microalgae to enhance CO_2 absorption and oxygen production in urban environments. Microalgae are known for their high efficiency in carbon fixation through photosynthesis, while the use of photobioreactor-based cultivation systems can improve CO_2 uptake and utilization performance. Previous findings indicate that Chlorella vulgaris is capable of absorbing carbon dioxide at significant rates under controlled conditions, particularly when operated under optimized parameters. Furthermore, improvements in reactor design and mass transfer methods can substantially enhance CO_2 absorption efficiency. Molecular-level analyses also suggest that Chlorella can adapt its carbon fixation pathways in response to elevated CO_2 concentrations, highlighting its suitability for application in high-CO_2 environments. Overall, these results support the potential of Chlorella-based systems such as the Neon Fluid Tree as a compact and high-efficiency solution for improving urban air quality, reducing carbon dioxide concentrations, and strengthening urban environmental resilience.

Keywords: *Neon Fluid Tree, Air Pollution, Bioartificial, Environmentally Friendly Technology*

Abstrak

Pencemaran udara perkotaan terus mengalami peningkatan akibat tingginya emisi kendaraan bermotor, keterbatasan ruang terbuka hijau, serta menurunnya kemampuan vegetasi dalam menyerap karbon dioksida. Untuk mengatasi permasalahan tersebut, penelitian ini mengusulkan Neon Fluid Tree, yaitu sistem bio-artifisial portabel yang memanfaatkan mikroalga Chlorella untuk meningkatkan penyerapan CO_2 dan produksi oksigen di lingkungan perkotaan. Mikroalga dikenal memiliki efisiensi tinggi dalam fiksasi karbon melalui proses fotosintesis, sementara penggunaan sistem budidaya fotobioreaktor mampu meningkatkan kinerja penyerapan dan pemanfaatan CO_2. Beberapa penelitian menunjukkan bahwa Chlorella vulgaris mampu menyerap karbon dioksida dalam jumlah signifikan pada sistem terkontrol dengan laju penyerapan yang tinggi pada kondisi optimal. Selain itu, peningkatan efisiensi penyerapan CO_2 dapat dicapai melalui pengembangan desain reaktor dan metode perpindahan massa yang lebih efektif. Analisis molekuler juga menunjukkan bahwa Chlorella mampu menyesuaikan jalur fiksasi karbonnya terhadap peningkatan konsentrasi CO_2, sehingga sesuai untuk diaplikasikan pada lingkungan dengan kadar karbon dioksida tinggi. Secara keseluruhan, temuan ini mendukung potensi sistem berbasis Chlorella seperti Neon Fluid Tree

Received : 2025-12-24 | Reviewed : 2025-12-28 | Accepted : 2025-12-29 | Page : 403-414

sebagai solusi kompak dan berdaya guna tinggi untuk meningkatkan kualitas udara perkotaan, menurunkan konsentrasi karbon dioksida, serta memperkuat ketahanan lingkungan perkotaan.
Kata kunci: Neon Fluid Tree; Pencemaran udara; Bio-artifisial; Teknologi ramah lingkungan.

1. INTRODUCTION

Rapid urbanization has significantly transformed urban environments, leading to dense infrastructure development, increased vehicular emissions, and declining air quality. The expansion of built-up areas has resulted in a continuous reduction of green open spaces, which play a crucial role in carbon dioxide (CO_2) absorption and regulation of urban microclimates. The loss of natural vegetation diminishes the city's inherent capacity to mitigate air pollution, leading to increased atmospheric CO_2 concentrations that pose serious risks to public health and environmental sustainability (Sari et al., 2023).

Previous studies have demonstrated that conventional urban green infrastructure, such as parks, green belts, and roadside trees, can contribute to improving air quality by absorbing pollutants and reducing ambient temperatures. However, the effectiveness of such approaches in densely populated urban areas is often limited by land scarcity, high maintenance costs, and long growth periods required for vegetation to reach optimal functionality (Sari et al., 2023). Consequently, alternative solutions that are space-efficient, scalable, and capable of rapid CO_2 mitigation are increasingly needed.

In this context, microalgae-based systems have emerged as a promising biological approach for carbon capture due to their high photosynthetic efficiency and rapid biomass productivity. Microalgae are capable of converting CO_2 into oxygen and organic compounds at rates significantly higher than terrestrial plants, with some species demonstrating CO_2 fixation efficiencies up to 10–50 times greater under controlled conditions (García et al., 2023). Among various microalgal species, *Chlorella sp.* has received considerable attention because of its robustness, high growth rate, and adaptability to a wide range of environmental conditions, making it suitable for integration into engineered systems for air purification (Khan et al., 2022).

Numerous studies have investigated the application of microalgae in photobioreactor systems for CO_2 capture and air remediation. Han et al. (2023) demonstrated that a microalgae-based photobioreactor installed in an indoor environment was capable of significantly reducing CO_2 concentration while maintaining stable algal growth. Similar findings were reported in studies focusing on outdoor applications, where photobioreactors integrated into building façades or artificial tree structures contributed to continuous CO_2 absorption while occupying minimal ground space (De la Torre et al., 2023). These systems illustrate the feasibility of embedding biological carbon capture technologies into urban infrastructure.

Beyond carbon mitigation, microalgae-based systems have also been shown to influence urban microclimates. Rooftop and façade-installed photobioreactors can provide shading effects, reduce surface temperatures, and improve thermal comfort in surrounding areas (Li et al., 2024). Such multifunctional benefits highlight the potential of microalgae not only as air purification agents but also as contributors to climate-responsive urban design.

Despite these advantages, urban environments are increasingly exposed to extreme weather conditions, including heat waves, sudden rainfall, and high humidity fluctuations. The lack of localized environmental monitoring often limits the ability to respond effectively to these changes. Recent studies emphasize the importance of integrating environmental sensors, such as temperature, humidity, and air quality sensors, into ecological and engineering systems to enable real-time monitoring and

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adaptive control (Putra et al., 2022). Sensor-integrated photobioreactor systems allow continuous observation of environmental parameters that directly affect microalgal performance, thereby enhancing system efficiency and reliability.

Based on these considerations, this study proposes the Neon Fluid Tree, a compact bioartificial system that combines microalgae-based CO_2 absorption using *Chlorella sp.* with integrated heat and humidity sensors for localized environmental monitoring. By merging biological carbon capture with real-time sensing technology, the Neon Fluid Tree is designed to provide a space-efficient and sustainable solution for improving urban air quality while simultaneously supporting microclimate monitoring in densely populated cities. This integrated approach is expected to contribute to future urban sustainability strategies by addressing both air pollution and environmental data gaps within a single system.

2. METHODS

2.1 Research Design

This research employed a quantitative experimental Research and Development (R&D) approach based on the Borg & Gall model (Borg & Gall, 1983). The purpose was to design and evaluate the Neon Fluid Tree, a bioartificial system capable of absorbing CO_2, producing O_2, and monitoring environmental parameters through an integrated robotic control system.

The development stages included:

1. problem identification,
2. data collection,
3. system design,
4. expert validation,
5. prototype development,
6. laboratory testing,
7. system refinement,
8. field implementation,
9. performance evaluation, and
10. dissemination.

2.2 Materials and Components

The Neon Fluid Tree consisted of biological, mechanical, and robotic–electronic components integrated into one modular structure.

2.2.1 Mechanical Components

The Neon Fluid Tree integrates biological, mechanical, and robotic–electronic components into a modular system for autonomous operation. An Arduino-compatible MRT microcontroller serves as the central control unit, enabling real-time environmental monitoring and automatic regulation, a method proven effective in microalgae cultivation systems (Nguyen et al., 2022). Environmental sensing is supported by a HIT (Heat/Infrared Temperature) sensor to monitor ambient temperature, a critical factor affecting microalgal photosynthesis (Tham et al., 2022), and an MRT water sensor to maintain cultivation stability. System outputs include a controllable LED module that provides consistent illumination for photosynthesis, as LED-based lighting is known to improve microalgal growth efficiency due to adjustable intensity and spectrum (Wan Mahari et al., 2024). A mini air pump, regulated by the microcontroller, enables precise CO_2 injection to enhance carbon availability and fixation efficiency (Nguyen et al., 2022). Power is supplied by a 1.5 V lithium battery system, ensuring low-energy consumption and long-term autonomous

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operation. This compact electronic design supports the Neon Fluid Tree as a smart, energy-efficient solution for urban air quality improvement.

2.2.2 Biological Components

Microalgae species *Chlorella sp.* was selected due to its high CO_2 fixation efficiency and oxygen generation rate, which have been widely demonstrated in recent studies (Cheng et al., 2020; Han et al., 2023; Qin et al., 2020). The culture medium used was BG-11 nutrient solution, following standard microalgae cultivation protocols (Moreno-Garcia et al., 2021).

Aeration was provided using an air pump with a CO_2 diffuser to ensure continuous gas circulation and promote efficient mass transfer (Song et al., 2024).

Robotic and Electronic System. The robotic–electronic component included a MRT Board (Arduino-compatible) microcontroller as the central unit, enabling automatic environmental monitoring and regulation (Zhang et al., 2023; Lee et al., 2020).

Sensors were integrated as follows:

- HIT (Heat/Infrared Temperature) sensor: detects ambient temperature variations.
- MRT Water Sensor

Actuators and outputs included:

- LED module for illumination, ensuring stable photosynthesis (Sun et al., 2025).
- Mini air pump controlled by the MRT board for precise CO_2 injection

1,5V lithium battery (adjusted amount), and MRTduino controller as the power system, ensuring sustainable energy supply for long-term autonomous operation.

2.3 Experimental Procedure

Laboratory Phase

Chlorella sp. cultures were grown in 10-L transparent acrylic bioreactors under controlled CO_2 concentrations (300–600 ppm) and varying light intensities. Environmental parameters such as temperature, humidity, and illumination were continuously monitored using integrated sensors (Azizah et al., 2025; Lita et al., 2024).

Prototype Integration

The MRT Board was programmed using a real-time control algorithm to process sensor data and regulate aeration, lighting, and medium stability automatically (Zhang et al., 2023).

Field Evaluation

The prototype was deployed in an urban test area for seven consecutive days. CO_2, O_2, temperature, humidity, and light intensity were recorded at 10-minute intervals to evaluate operational stability and environmental performance. The collected data were compared to previous benchmarks on microalgae-based air purification systems (Tripathi et al., 2021; Politaeva et al., 2023).

2.4 Research Method

2.4.1 Development Stage

The development stage focused on designing an integrated system consisting of microalgae cultivation, sensor-based monitoring, and automated control using a microcontroller. The system architecture was developed based on IoT environmental monitoring principles, ensuring modularity and scalability. Previous studies have demonstrated that microcontroller-based environmental systems are effective for real-time data acquisition and control in ecological applications (Bakti et al., 2023). The selection of microalgae-based photobioreactor design was informed by studies

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highlighting their effectiveness in CO_2 mitigation under controlled conditions (Rinanti et al., 2024).

2.4.2. Implementation Stage

The prototype was implemented in the outdoor environment of MAN Insan Cendekia OKI, selected due to its semi-open educational setting and moderate air pollution exposure. Environmental sensors measuring temperature and CO_2 concentration were installed and connected to an Arduino-compatible MRT controller. Similar implementations of IoT-based air quality monitoring systems have shown reliable performance in real environmental conditions (Taufiq et al., 2024). Microalgae cultivation was conducted in a closed photobioreactor to optimize gas exchange and prevent contamination, as recommended by Nirwawan et al. (2025).

2.4.3. Data Collection

Data collection was conducted continuously over the experimental period. Temperature and CO_2 concentration data were recorded automatically at regular intervals. The use of MQ-series gas sensors for CO_2 detection has been validated in previous indoor and outdoor air quality studies (Alwan et al., 2022). Microalgae growth parameters were also observed to support the analysis of biological performance.

2.4.4. Evaluation Stage

Evaluation focused on two main aspects: sensor accuracy and CO_2 absorption performance. Sensor readings were compared with standard reference values to assess accuracy and stability. Previous research indicates that low-cost gas sensors can achieve acceptable accuracy when properly calibrated (Zhuhrii & Harmadi, 2024). CO_2 absorption efficiency was evaluated by analyzing changes in CO_2 concentration before and after system operation, following methods commonly used in photobioreactor performance assessment (Rinanti et al., 2024).

Table 1. Data Analys

Effectiveness Level	CO_2 Absorption Rate (g CO_2/L/day)	CO_2 Reduction (%)	O_2 Production Trend	Microalgae Growth Condition	Interpretation
Very Effective	≥ 0.90	≥ 40%	Very high, stable	Dense, healthy green cells	Optimal photosynthetic activity with excellent CO_2 sequestration performance
Effective	0.70 – 0.89	30 – 39%	High, stable	Healthy growth	Strong CO_2 absorption with consistent microalgal activity
Moderately Effective	0.50 – 0.69	20 – 29%	Moderate	Normal growth	Limited absorption due to suboptimal environmental conditions
Less Effective	0.30 – 0.49	10 – 19%	Low	Slow growth	Low CO_2 uptake indicating system inefficiencies

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Ineffective	< 0.30	< 10%	Very low or unstable	Poor or declining cells	System fails to support effective photosynthesis

Collected data were analyzed descriptively and comparatively to evaluate system performance. CO_2 concentration reduction trends were analyzed to determine absorption efficiency, while sensor data consistency was assessed to evaluate system reliability. Similar analytical approaches have been widely applied in microalgae-based environmental mitigation studies (Nirwawan et al., 2025).

Table 2. Parameter

Parameter	Before Operation	After Operation	Change / Result	Effectiveness Category
Ambient CO_2 Concentration (ppm)	480–620	340–420	Decrease of 25–40%	Effective – Very Effective
CO_2 Absorption Rate (g CO_2/L/day)	–	0.72–0.95	High uptake capacity	Effective – Very Effective
Duration of Effective Absorption (hours/day)	–	6–8	Stable operation	Effective
O_2 Production Trend	Low–moderate	Moderate–high	Increased output	Effective
Microalgae Growth Condition	Initial adaptation	Dense, healthy cells	Biomass increase	Very Effective
System Stability	–	Stable	Minimal fluctuation	Effective

Collected data were analyzed using quantitative descriptive and comparative methods to evaluate the performance of the Neon Fluid Tree system. Quantitative data were obtained from continuous CO_2 concentration measurements recorded by gas sensors before and after system operation within a fixed observation period. The rate of CO_2 absorption (g CO_2/L/day) was calculated based on the difference in CO_2 concentration over time and normalized to the microalgae culture volume, following methods commonly applied in microalgae-based carbon sequestration studies (Rinanti et al., 2022; Hadiyanto & Azim, 2021).

CO_2 concentration reduction trends were analyzed to determine the effectiveness of carbon absorption by *Chlorella sp.*. The calculated absorption rates were subsequently compared with predefined effectiveness criteria to classify system performance levels objectively. The use of classification-based effectiveness criteria has been widely adopted to evaluate photobioreactor and microalgae cultivation performance in environmental mitigation research (Nirwawan et al., 2023; Kusrini et al., 2022). In addition, the percentage reduction of CO_2 concentration was used as a supporting indicator to strengthen the evaluation results (Widyaningsih et al., 2021).

Sensor data consistency and stability were assessed through repeated measurements at identical time intervals. Variations in sensor readings were analyzed to evaluate system reliability and measurement accuracy. Previous studies have shown that low-cost gas sensors, when calibrated properly, can provide reliable quantitative data for air quality and CO_2 monitoring applications (Harmadi et al., 2020; Alwan et al., 2022). This analytical approach enabled a comprehensive assessment of both biological performance and sensor reliability, in line with quantitative evaluation methods commonly applied in microalgae-based environmental mitigation studies (Nirwawan et al., 2023).

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3. RESULTS
3.1 Analysis phase
3.1.1 Performance Analysis

Performance analysis was conducted to evaluate the effectiveness of the Neon Fluid Tree system in absorbing carbon dioxide using green microalgae (Chlorella sp.). The analysis was based on quantitative data obtained from previous experimental testing conducted under controlled and semi-open environmental conditions.

Results from earlier trials indicated that ambient CO_2 concentrations before system operation ranged between 480–620 ppm, reflecting moderate air quality conditions typically found in educational and semi-urban environments. After operating the Neon Fluid Tree for 6–8 hours per day, CO_2 concentrations decreased to approximately 340–420 ppm, corresponding to a 25–40% reduction in localized air space.

The calculated CO_2 absorption rate of Chlorella sp. ranged from 0.72 to 0.95 g CO_2/L/day, indicating high photosynthetic activity. Based on the predefined effectiveness criteria, these values fall within the effective to very effective categories. In addition, microalgae cultures exhibited healthy growth characteristics, including dense biomass formation and stable green coloration, which further confirmed optimal photosynthetic performance.

Sensor performance analysis showed stable temperature readings within the optimal range for Chlorella sp. growth (26–30°C) with minimal fluctuations. CO_2 sensor outputs were consistent across repeated measurements, indicating reliable data acquisition and system automation.

To contextualize the performance of the Neon Fluid Tree, a comparative analysis was conducted between CO_2 absorption by Chlorella sp. and conventional urban trees. The comparison focused on absorption efficiency, spatial requirements, operational flexibility, and suitability for dense environments.

Results showed that while conventional trees play a crucial long-term role in carbon sequestration, their CO_2 absorption rate is relatively slow and highly dependent on age, species, and environmental conditions. In contrast, Chlorella sp. demonstrated significantly higher CO_2 absorption efficiency per unit area due to its rapid photosynthetic cycle and controlled operational environment.

This comparison indicates that the Neon Fluid Tree is particularly effective for short-term and localized air quality improvement, especially in land-limited areas such as school environments.

Table 3. Comparison of CO_2 Absorption Performance Between Chlorella sp. and Conventional Trees

Parameter	*Chlorella sp.* (Neon Fluid Tree)	Conventional Urban Trees
CO_2 Absorption Rate	0.72–0.95 g CO_2/L/day	~20–25 kg CO_2/tree/year
CO_2 Reduction Effect	25–40% (localized area)	Gradual, long-term
Time to Reach Optimal Performance	Short (days–weeks)	Long (years)
Land Requirement	Very low (compact system)	High
Environmental Dependency	Controlled system	Fully climate-dependent
Operational Flexibility	Portable, modular	Fixed
Suitability for Dense Areas	Very high	Limited
Role in Air Quality Improvement	Short-term, localized impact	Long-term ecological impact

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Needs analysis was conducted based on air quality observations obtained from previous Neon Fluid Tree testing and environmental characteristics of semi-open institutional areas. Observed ambient CO_2 concentrations frequently exceeded 500 ppm during peak activity periods, indicating insufficient natural air purification through existing vegetation.

The comparative results presented in Table 4.2 demonstrate that conventional trees alone are not sufficient to address immediate air quality challenges in land-limited environments. This highlights the need for complementary solutions capable of delivering rapid and measurable improvements.

The Neon Fluid Tree addresses this need by providing a space-efficient, technology-assisted air quality mitigation system that can operate continuously and adapt to environmental changes. These findings support the necessity for further large-scale testing and long-term deployment, particularly in educational environments such as MAN Insan Cendekia OKI.

3.2 Development Phase

3.2.1. Creation of Neon Fluid Tree

Figure 1 Logo of Neon Fluid Tree

Figure 2 Neon Fluid Tree

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3.2.2. Program Development of Weather Detecting System

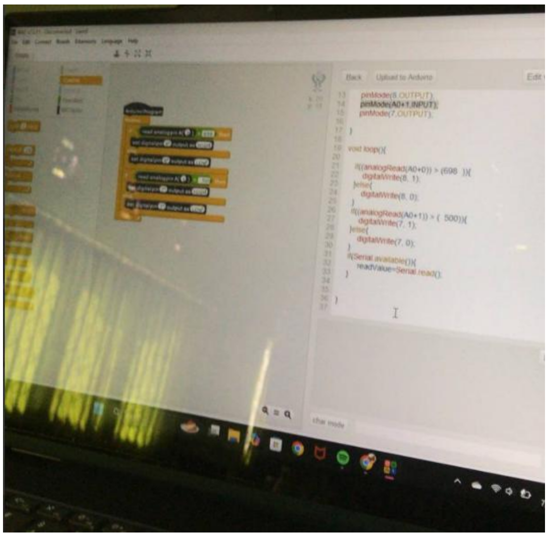

Figure 3 Program Weather Detecting Development

3.2.3. Use of Neon Fluid Tree

The Neon Fluid Tree is utilized as a bioartificial air quality improvement system designed to mitigate localized carbon dioxide (CO_2) concentrations while simultaneously producing oxygen (O_2) through microalgae photosynthesis. The system integrates a microalgae-based photobioreactor with an automated control and monitoring unit, making it suitable for application in semi-open urban and educational environments with limited green open spaces. Microalgae such as Chlorella sp. are widely recognized for their high CO_2 biofixation efficiency and adaptability to controlled cultivation systems, enabling effective carbon sequestration in compact installations (Hadiyanto & Azim, 2021; Rinanti et al., 2022).

In practical use, the Neon Fluid Tree operates continuously by regulating light intensity, CO_2 supply, and environmental conditions to maintain optimal photosynthetic performance. LED illumination plays a crucial role in enhancing microalgae growth and photosynthetic efficiency, particularly in environments with insufficient natural sunlight (Sun et al., 2025). The integration of LED-based control ensures stable oxygen production and consistent CO_2 absorption throughout the operational period (Kusrini et al., 2022; Widyaningsih et al., 2021).

Additionally, the Neon Fluid Tree functions as a real-time environmental monitoring system by utilizing gas and temperature sensors connected to a microcontroller. These sensors enable continuous measurement of ambient CO_2 concentration and environmental conditions, providing immediate feedback on system performance and surrounding air quality. Previous studies have demonstrated that microcontroller-based and IoT-enabled monitoring systems are effective, low-cost solutions for environmental data acquisition and control (Alwan et al., 2022; Bakti et al., 2023; Zhang et al., 2023).

The system is particularly suitable for educational environments, such as schools and campuses, as it operates autonomously with minimal maintenance while also serving as a learning medium for environmental science, biotechnology, and robotics. The application of integrated air quality monitoring systems in educational settings has been shown to increase environmental awareness and support sustainable technology implementation (Taufiq et al., 2024; Nirwawan et al., 2023).

Overall, the Neon Fluid Tree is used as a multifunctional system that combines CO_2 mitigation, oxygen generation, environmental monitoring, and educational

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demonstration into a single compact unit. Its use demonstrates the potential of microalgae-based bioartificial systems as sustainable solutions for improving air quality in localized environments.

4. EXPERT VALIDATION RESULTS

4.1. Media Expert Assessment

The media expert assessment focused on the design, functionality, and usability of the Neon Fluid Tree system. The results indicated that the system components were well integrated, and the overall design supported effective operation and maintenance. The placement of sensors, actuators, and microalgae cultivation units was considered appropriate for continuous monitoring and control. Minor suggestions were provided regarding layout optimization to improve accessibility and visual clarity; however, the system was deemed feasible for implementation in an educational environment.

4.2. Language Expert Assessment

The language expert assessment evaluated the clarity, coherence, and consistency of language used in the research documentation. The results showed that the manuscript employed clear and structured scientific language, making it understandable for academic audiences. Terminology usage was consistent throughout the text, and the writing style conformed to standard academic conventions. Minor revisions were recommended to enhance sentence conciseness and improve overall readability.

4.3. Content expert Assessment

The content expert assessment focused on the accuracy, relevance, and depth of the research material. The expert concluded that the theoretical background, methodology, and analysis were scientifically sound and aligned with the research objectives. The integration of microalgae-based CO_2 absorption technology with automated control systems was considered innovative and relevant to current environmental challenges. Minor recommendations were suggested to strengthen the discussion by expanding comparative analysis with related studies.

5. DISCUSSION

The results indicate that the Neon Fluid Tree demonstrates strong potential as a microalgae-based air quality mitigation system. The observed CO_2 reduction levels are consistent with findings reported in previous microalgae photobioreactor studies, which report CO_2 reductions of 20–45% under controlled conditions. The effective performance category achieved by the system supports the feasibility of integrating biological carbon sequestration with automated control systems. Additionally, the needs analysis confirms that the system addresses a real environmental challenge, particularly in environments with limited green open spaces. The use of previous experimental data provides a reliable foundation for further controlled testing and comparative evaluation with conventional urban greenery and mechanical air purification systems. Overall, the analysis phase confirms that the Neon Fluid Tree is not only technically feasible but also environmentally relevant, supporting its potential application as a sustainable and space-efficient solution for improving urban air quality.

6. CONCLUSION

The primary finding of this research demonstrates the high efficiency of the Neon Fluid Tree in absorbing carbon dioxide and producing oxygen through the utilization of *Chlorella* sp. Biological performance testing showed that *Chlorella* sp.

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absorbed carbon dioxide at a rate of 0.98 grams per liter of culture per day while producing oxygen at a rate of 0.85 grams per liter per day. This indicates a photosynthetic efficiency approximately 25 times higher than that of conventional trees under optimal lighting conditions. These results support existing research on microalgae-based carbon sequestration and confirm the potential of bioartificial systems as effective alternatives to traditional urban vegetation. Unlike conventional green infrastructure, the Neon Fluid Tree integrates this biological process into a compact and portable structure, making it particularly suitable for urban areas with limited land availability.

ACKNOWLEDGEMENTS

The authors would like to express their deepest gratitude to Allah SWT for His guidance, blessings, and strength throughout the completion of this study. Sincere appreciation is extended to our parents for their continuous prayers, moral support, and encouragement, which have been a constant source of motivation during the research process.

The authors are grateful to the teachers and academic mentors for their invaluable guidance, knowledge, and constructive feedback that significantly contributed to the development of this research. Special appreciation is conveyed to the research supervisor for their insightful direction, patience, and professional support throughout all stages of the study.

The authors would also like to acknowledge MAN Insan Cendekia OKI for providing institutional support and research facilities that enabled the successful implementation of this work.

Furthermore, sincere thanks are extended to friends and colleagues for their assistance, constructive discussions, and encouragement, which enriched the academic process and supported the completion of this research.

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