**Advance Emission Control and Precision Agriculture CO2 Sequestration Using Algae Integrated Management System**

Ruzanna Abdul Rahman

1. The Potential of Algae Reactors for CO2 Sequestration

The article discusses the use of algae as a solution to minimize and mitigate carbon dioxide (CO2) emissions. The company Algaetech is working on a project to develop a system that diverts CO2 to open algal ponds and enclosed photo-bioreactors, where algae can consume the CO2 waste stream. The technology, called Algae Integrated Management System (AIMS), aims to reduce air pollution by utilizing power plant resources to grow microalgae at a low energy cost. This process not only helps to sequester CO2 but also produces valuable products and biofuels. The article highlights the potential of using algae reactors for CO2 sequestration to reduce greenhouse gas emissions.

2. The AIMS Technology: Integration of Algae Cultivation and Precision Agriculture

The AIMS technology relies on the photosynthesis process to produce microalgae under controlled conditions. The system integrates algae cultivation with precision agriculture to maximize production. The process involves the collection of sea water, filtration, treatment, and adding nutrients to create a suitable environment for algae growth. The algae undergo photosynthesis in photo-bioreactor tubes, where they capture CO2 from flue gas produced by power plants. After sufficient growth, the algae are harvested and the biomass is collected. The biomass goes through a drying process and is refined to obtain valuable products, such as biodiesel.

3. Advantages of Using Algae for CO2 Sequestration

Using algae for CO2 sequestration offers several advantages, including the ability to capture flue gas with low CO2 concentrations, the use of pollutants as nutrients, and the production of high-value commercial products through photosynthesis. The article also mentions the ongoing development of a 480,000-liter AIMS system in Indonesia, which aims to capture CO2 emissions from power plants and produce algae biomass for biofuels and other value-added products.

4. Profitability and Benefits of AIMS Technology for Greenhouse Gas Emission Reduction

Despite the initial cost, the AIMS technology has the potential to be profitable and beneficial for reducing greenhouse gas emissions. Biodiesel produced from algae can lower net emissions and has the advantage of being biodegradable. The AIMS technology offers a promising solution for carbon emission control and provides a viable alternative to traditional fuels.

**Temperature Influence and Heat Management Requirements of Microalgae Cultivation in Photobioreactors**

Thomas Hagen Mehlitz

This scientific article explores the use of photobioreactors for cultivating algae as a biofuel feedstock. It emphasizes the need for alternative energy sources to reduce greenhouse gas emissions and replace fossil fuels. The advantages of photobioreactors over open pond systems are highlighted. The article then provides an overview of different types of photobioreactors and their functions.

The experiment's materials and methods, including photobioreactor setup, culturing techniques, and data collection, are described. The article explains the development of a simulation model to analyze temperature influences on algae cultivation and heat management in photobioreactors. The results and discussion section presents the findings of the temperature experiments and the heat management model.

1. Conclusions and Future Research

The conclusions of the article include the optimal temperature range for algae growth and the importance of heat management in photobioreactors. It also emphasizes the potential of algae biomass as a feedstock for biodiesel production and the need for further research and improvement of photobioreactor systems for commercial applications.

1. Summary of Photobioreactors for Algae Cultivation

In summary, this article provides valuable information about the use of photobioreactors for cultivating algae and the potential of algae biomass as a renewable energy source. It highlights the importance of temperature control and heat management in optimizing algae growth and biofuel production. Further research is needed to improve the efficiency and scalability of photobioreactor systems for commercial use.

The article discusses the development of a temperature-sensitive growth function for Chlorella algae, which is important for the heat management of photobioreactors. The growth function was determined through temperature experiments, where the algae were exposed to different temperatures and their growth rates were measured. The experiments showed that the algae had a maximum growth rate at 29 °C and a range of temperatures where the growth rate was within 10% of the maximum. The data from the experiments were used to develop a simulation model for heat management in photobioreactors.

The simulation model was used to perform sensitivity analyses on different factors that affect the temperature in the photobioreactors. The analyses showed that the outside temperature had a direct impact on the temperature inside the photobioreactor and greenhouse, with a time lag due to thermal mass. The solar radiation, ground reflectivity, PBR column distance, and shading material transmissivity also had an impact on the temperature and energy requirements. Optimizing these factors could lead to more efficient heat management and higher productivity in the photobioreactor.

1. Insights and Practical Applications of Study

Overall, the article provides valuable insights into the temperature sensitivity of Chlorella algae and the potential for optimizing heat management in photobioreactors. The simulation model developed in the study can be a useful tool for photobioreactor operators to estimate their energy requirements and productivity.

1. Exploration of Microalgae Cultivation and Optimization

The article explores various aspects of microalgae cultivation and optimization for different purposes. It includes studies on the thermal performance of energy-conserving greenhouses with thermal storage and the verification and simulation of greenhouse microclimates. The significance of carbon source and light intensity in the growth rate of Haematococcus lacustris, a microalgae species, is also examined.

The article also focuses on the scale-up and optimization of microalgal photobioreactors for large-scale cultivation. It discusses the challenges and potential of using microalgae for biodiesel production. The potential of microalgae as a source of valuable products and the development of photobioreactors with improved light utilization are also highlighted.

1. Factors Affecting Astaxanthin Production and Biofuel Prospects

The article investigates the environmental and nutritional factors affecting the production of astaxanthin, a valuable pigment, from Haematococcus pluvialis. It also discusses the application of microalgae in CO2 scrubbing from biogas and the outdoor cultivation of microalgae for carotenoid production. The challenges and prospects of producing and processing microalgae into biofuels, particularly biodiesel, are further explored.

The article provides information on the growth rates of different algae species in relation to light and temperature, as well as the assimilation of nitrogen by oceanic diatoms. It also discusses the impact of temperature on algal growth and the temperature coefficient (Q10) in physiological calculations.

1. Overall Coverage and Importance of Microalgae Cultivation

Overall, the article covers various topics related to the cultivation, optimization, and potential applications of microalgae. It offers valuable insights into scientific research and advancements in this field and highlights the importance of microalgae as a sustainable source of valuable products.

**Effect of temperature control on green algae grown under continuous culture**

Carolann M. Knutson, Evelyn M. McLaughlin, Brett M. Barney

Investigating the effect of temperature control

This scientific article investigates the effect of temperature control on the growth of green algae, specifically Neochloris oleoabundans and Scenedesmus dimorphus. The researchers used a turbidostat-based photobioreactor system to compare the biomass production of these algae under tightly-controlled temperature conditions versus fluctuations in temperature that would be found in outdoor ponds or bioreactors.

The results showed that N. oleoabundans had improved growth rates under stringent temperature control at 22°C, while S. dimorphus had slightly higher growth under temperature fluctuations. Further analysis revealed that non-conventional temperature profiles could enhance growth yields for N. oleoabundans, potentially overcoming the detrimental effects of natural temperature fluctuations.

The study also explored the potential for turbidostat-based algal culture growth, which allows for continuous monitoring and control of culture density. The researchers tested different temperature profiles, including sinusoidal and step-like functions, to determine their effects on biomass production. They found that rapidly lowering the temperature during the dark phase of growth resulted in higher biomass yields for N. oleoabundans.

Implications of temperature control for large-scale algal cultivation

The authors also discussed the implications of temperature control for large-scale algal cultivation. Temperature control has significant energy-related costs associated with capital investment and ongoing cooling or heating. By understanding the effects of temperature on algal growth, researchers can assess the viability and economic feasibility of different strains for commercial use.

Importance of temperature control and optimizing biomass production

Overall, this study highlights the importance of temperature control in algal cultivation and suggests that unconventional temperature profiles could be used to optimize biomass production. By using a turbidostat system, researchers can gain insights into the growth dynamics of algae and develop strategies to maximize their productivity.

**Automatización De Un Fotobiorreactor Air-Lift Para La Disminución En La Concentración De Co2**

Nelson Alejandro Amaya Orozco

El artículo describe la automatización de un fotobiorreactor air-lift para reducir la concentración de CO2 proveniente de la pirólisis de biomasa lignocelulósica. El objetivo principal es desarrollar un sistema automatizado que controle y registre las lecturas de varios sensores, como pH, temperatura, luz, turbidez y CO2, para optimizar las condiciones de crecimiento de la microalga Chlorella sp. y reducir la concentración de CO2 en el aire.

El estudio comienza con una revisión bibliográfica para obtener los conocimientos necesarios sobre la programación y selección de los instrumentos adecuados. Luego, se programa y conecta cada sensor utilizando la tarjeta Arduino UNO.

Se utilizan varios sensores, como el K33 para medir la concentración de CO2, el PT100 WZP para medir la temperatura, el BH1750 para medir la intensidad de luz, el SEN0161 para medir el pH y el SEN0189 para medir la turbidez del agua. Se establecen criterios de selección para cada sensor, como pertinencia, rango de medición, sensibilidad, precisión y repetibilidad.

Se recomienda el uso del software LabVIEW para adquirir los datos de los sensores de manera precisa y presentarlos gráficamente. Se concluye que la automatización del fotobiorreactor y la medición de los sensores pueden mejorar el crecimiento de la microalga y reducir la concentración de CO2 en el aire.

En otro estudio, se analiza la retención de CO2 por parte de microalgas en un fotobiorreactor. Se encontró que el sistema tenía una eficiencia del 80% en la captura de CO2. Además, se investigó el impacto ambiental y económico de esta tecnología sostenible.

Otro artículo evaluó el desempeño de la microalga Chlorella sp. en la retención de CO2. Se encontró que la temperatura, la concentración de CO2 y la intensidad de la luz afectaban la producción de biomasa. Además, se observó que las microalgas capturaban y utilizaban el CO2 como fuente de carbono para su crecimiento.

Se analizó el efecto del diseño de los fotobiorreactores en la retención de CO2 en otro estudio. Se encontró que diferentes tipos de biorreactores tenían tasas de eliminación de CO2 variables. También se estudió el efecto de la temperatura y la intensidad de la luz en la retención de CO2 y la concentración de biomasa.

En general, estos estudios demuestran que las microalgas pueden retener CO2 y utilizarlo como fuente de carbono para su crecimiento. La temperatura, la concentración de CO2 y la intensidad de la luz son factores importantes a considerar para optimizar la retención de CO2 por parte de las microalgas en los fotobiorreactores. Estos resultados son prometedores para el desarrollo de tecnologías sostenibles de captura de CO2 y producción de biomasa.

El artículo también menciona diferentes sensores utilizados en aplicaciones de robótica y control de temperatura. Se habla sobre la combinación de LabVIEW y LEGO en el campo de la robótica.

Se menciona el Arduino Uno Rev3, una placa de desarrollo utilizada en proyectos de electrónica y robótica, y se destaca su disponibilidad en una tienda en línea.

Se menciona un sistema de control de temperatura y monitoreo de pH y humedad utilizado en el proceso de spin coating, desarrollado en la Universidad Autónoma de Occidente en Santiago de Cali.

Se hace referencia a la metodología de instrumentación industrial y electrónica como fuente de información relevante en este campo.

Se mencionan varios tipos de sensores, como el sensor de CO2 para medir la calidad del aire, el sensor de temperatura para regular la temperatura y el sensor de luz para medir la iluminación ambiental. También se menciona el sensor de turbidez para medir la claridad del agua.

Se mencionan marcas de sensores, como Mettler Toledo y CO2 Meter, y se proporcionan enlaces a sus productos en línea.

Por último, se mencionan conceptos clave, como la turbidimetría y los métodos turdidimétricos utilizados en ciencias de la vida, así como el biochar utilizado en la gestión ambiental.

En resumen, el artículo expone la importancia de los sensores en aplicaciones de robótica y control de temperatura, y proporciona información sobre diferentes tipos de sensores utilizados en estas áreas. También menciona fuentes de información adicionales y productos en línea relacionados con sensores.

**Temperature control of microalgae cultivation under variable conditions**

Elianne van Esbroeck

Introduction and Objective

The scientific article delves into the temperature control of microalgae cultivation in closed photobioreactors under variable conditions. The study focuses on finding the optimal input trajectory that maximizes microalgae growth while minimizing energy costs. Various scenarios, including location, season, and daily variations, are considered.

Temperature Model and Growth Kinetics

The temperature model used in the study incorporates heat balances for tubes, the bubble column, and a heat exchanger. It takes into account heat exchange with the ambient air and solar radiation. The biomass growth model is based on the growth kinetics of microalgae, considering factors such as light intensity and temperature. The growth rate of microalgae is influenced by specific growth rate, dilution rate, and maintenance metabolic coefficient.

Application of Optimal Control Methods

Optimal control methods are applied in the research, utilizing Tomlab software to calculate the optimal input trajectory. The study also explores the use of piecewise linear trajectories for comparison. The results reveal that the optimal control input trajectory is influenced by factors such as location, season, and daily variations.

Conclusion and Implications

In conclusion, the study emphasizes the significance of temperature control and optimization in microalgae cultivation, taking into account factors like location, season, and daily variations. It provides valuable insights into the potential of microalgae as a sustainable resource for various industrial applications.

The article discusses the use of optimal control strategies for regulating temperature in photobioreactors used for microalgae production. Two different optimization methods, Tomlab and piecewise linear trajectories, are compared. The results indicate that Tomlab was unsuitable for this system and did not yield reliable results. However, the piecewise linear trajectories method generated positive monetary outcomes and resulted in higher microalgae growth compared to the uncontrolled system. The study also examines the effects of location, season, and daily variations on the optimal control input trajectory. It is found that the location and season significantly impact the trajectory, with different temperature profiles observed in different scenarios. Additionally, the study demonstrates that controlling the temperature in the photobioreactor is profitable, particularly during the summer season. The authors recommend validating the heuristic control rules developed in this study using real data and suggest integrating the microalgae production system with other applications to reduce costs and enhance the competitiveness of microalgae for industrial use.

**The cultivation of mixed microalgae and CO2 fixation in a photo-bioreactor**

Jijun Du, Qing Wang

Investigation on Cultivation of Mixed Microalgae

This scientific article investigates the cultivation of wild mixed microalgae as a potential source of biomass energy and a means of reducing carbon dioxide emissions. The study was conducted in an airlift photo reactor, and the effects of carbon dioxide concentration and illumination conditions on the growth and crude fat content of the microalgae were examined over a 180-day period. The results showed that the growth rate of microalgae was significantly enhanced when fed with flue gas containing 10% carbon dioxide compared to air. Continuous illumination for 24 hours was found to be beneficial for microalgae growth and stability of growth rate. Furthermore, the accumulation of crude fat in microalgae was found to benefit from decreased radiation intensity and increased light time. The absorption of carbon dioxide by the mixed microalgae followed first-order kinetics, with a reaction constant of 0.015 1/min at a microalgae concentration of 1 g/L.

Potential of Mixed Microalgae Cultivation

The study highlights the potential of mixed microalgae cultivation for biomass energy production and carbon dioxide reduction. The researchers emphasize the importance of acclimation to high carbon dioxide concentrations and the selection of mixed microalgae from wild sources for efficient carbon dioxide fixation. The findings also suggest that continuous illumination for 24 hours can lead to higher microalgae growth rates and stability. The study provides valuable information for further research on the removal of carbon dioxide from flue gas.

Contribution to Renewable Energy Development

Overall, this research contributes to the development of renewable energy sources and the mitigation of global climate change by exploring the potential of microalgae as a biomass energy resource. The results have implications for optimizing microalgae cultivation strategies for carbon dioxide fixation and biomass production.

**Evaluación del efecto de la concentración de CO2 en un cultivo de Chlorella sp. y su aplicación en la industria**

Diego Bustos Torres

El artículo científico realizado por investigadores de la Facultad de Estudios Ambientales y Rurales y la Facultad de Ciencias de la Pontificia Universidad Javeriana aborda la evaluación del efecto de la concentración de dióxido de carbono (CO2) en el cultivo de la microalga Chlorella sp. y su aplicación en la industria. El objetivo principal es analizar cómo la concentración de CO2 afecta el crecimiento y la productividad de la biomasa de Chlorella sp. a nivel de laboratorio.

El estudio se realizó utilizando el medio de cultivo Bold Basal Medium (BBM) modificado y se evaluaron diferentes concentraciones de CO2 (5%, 10%, 15% y 20%) en un flujo de aire y CO2. También se expusieron las microalgas a la luz led blanca. Se determinó que Chlorella sp. crece de manera exponencial hasta los 10 días de cultivo, alcanzando el mayor crecimiento de biomasa con una inyección de CO2 al 15%. No se encontraron diferencias significativas entre las concentraciones de CO2 del 20% y del 15%.

Se concluyó que la eficiencia de captura de CO2 fue baja en ambas condiciones, por lo que se propuso utilizar concentraciones de CO2 más bajas (5% y 10%) en el flujo de gases. El flujo al 5% de CO2 fue el más eficiente en términos de captura de CO2.

Además, se mencionan las posibles aplicaciones de la biomasa obtenida de Chlorella sp. en la industria, como alimento, fertilizantes orgánicos y biorrefinerías para la producción de biocombustibles y otras biomoléculas.

El artículo destaca la importancia de seguir investigando sobre el cultivo de microalgas y su aplicación en la reducción de emisiones de CO2, así como en la producción de biomoléculas de interés industrial. Se mencionan algunas recomendaciones para futuras investigaciones, como el estudio de la adición de otros gases de combustión en el flujo de gases y la evaluación de diferentes especies y géneros de microalgas.

En resumen, el artículo científico proporciona información relevante sobre el efecto de la concentración de CO2 en el cultivo de Chlorella sp. y su posible aplicación en la industria. Los resultados obtenidos pueden contribuir al desarrollo de estrategias para mitigar las emisiones de CO2 y aprovechar la biomasa de microalgas en diversas aplicaciones industriales.

En otro estudio, se evaluó el efecto de la concentración de CO2 en un cultivo mixto de microalgas. Se encontró que la agitación de los cultivos de microalgas es esencial para mantener la homogeneidad del cultivo y garantizar la absorción adecuada de nutrientes. Además, ayuda a evitar la acumulación de oxígeno disuelto y mejora la transferencia de carbono, acelerando el proceso de captura de CO2.

Se utilizaron biorreactores abiertos y cerrados para agitar mecánicamente y airear los cultivos de microalgas. Se llevaron a cabo dos cultivos, uno preliminar y uno final, utilizando diferentes concentraciones de CO2. Se monitorearon varios parámetros durante el crecimiento, como el crecimiento de la biomasa, la concentración de nitrato y fosfato, el pH y la temperatura.

La concentración de CO2 afectó el crecimiento de las microalgas, con el mayor crecimiento observado en el cultivo final en el flujo de CO2 del 15%. Sin embargo, la eficiencia de captura de CO2 fue mayor en el flujo de CO2 del 5%. Además, se observó que la concentración de nitrato se agotó completamente en todos los cultivos, mientras que la concentración de fosfato se redujo pero no se agotó por completo.

En cuanto a la composición de la biomasa, se encontró un contenido similar de carbono total y nitrógeno total en ambos cultivos, mientras que el contenido de proteína fue mayor en el cultivo final en el flujo de CO2 del 5%.

En resumen, este estudio demostró la importancia de la agitación de los cultivos de microalgas y la concentración de CO2 en el crecimiento y la captura de CO2. También destacó el potencial de las microalgas como fertilizantes y su capacidad para proporcionar nutrientes esenciales para las plantas. Estos hallazgos pueden tener implicaciones significativas en la producción de microalgas y su uso en aplicaciones agrícolas y medioambientales.

El artículo científico analiza el uso de microalgas en diferentes aplicaciones y su potencial para abordar diversos problemas ambientales y agrícolas. En primer lugar, se discute cómo las microalgas pueden ser utilizadas para recuperar suelos agotados por monocultivos o erosionados, ya que estas algas pueden devolver nutrientes esenciales al suelo, mejorando así su calidad y utilización agrícola.

Luego, se examina el potencial de las microalgas en la producción de biodiesel. Se destaca que las microalgas contienen altas cantidades de lípidos, especialmente ésteres de ácidos grasos, que son fundamentales para la producción de biodiesel. Además, se discute cómo las microalgas pueden ser cultivadas utilizando aguas residuales que contienen altos niveles de nitratos y fosfatos, lo que reduce los costos de nutrientes y promueve un enfoque circular en la producción de biodiesel.

El artículo también aborda la captura de dióxido de carbono (CO2) utilizando microalgas. Se resalta que las microalgas son capaces de fijar el CO2 mediante la fotosíntesis, lo que ayuda a mitigar los efectos del cambio climático. Se discuten diferentes estrategias para mejorar la captura de CO2 por parte de las microalgas, como el suministro de luz, la adición de nutrientes y el control de las condiciones de cultivo.

En cuanto a la producción de alimentos, se menciona que las microalgas son una fuente prometedora de proteínas y otros nutrientes beneficiosos. Se destaca su alto contenido de proteínas, lípidos y carbohidratos, así como su potencial para su uso en la industria alimentaria como complemento alimenticio o fertilizante.

El artículo concluye que el uso de microalgas puede ser una solución sostenible y eficiente para abordar diversos desafíos ambientales y agrícolas. Sin embargo, se señala la necesidad de más investigaciones y desarrollo tecnológico para aprovechar completamente el potencial de las microalgas en estas aplicaciones.

En resumen, el artículo destaca el potencial de las microalgas en la recuperación de suelos, producción de biodiesel, captura de CO2 y producción de alimentos. Se enfatiza la importancia de aprovechar este recurso natural en beneficio del medio ambiente y la agricultura sostenible.

**Multivariable control strategy for the photosynthetic cultures of microalgae**

George Adrian Ifrim

1. Controlling dissolved inorganic carbon (DIC) in photobioreactors for microalgae cultivation

This scientific article addresses the problem of monitoring and controlling dissolved inorganic carbon (DIC) in a photobioreactor, which is crucial for photosynthesis rate in microalgae cultivation. The authors conducted experiments in a lab-scale photobioreactor and found that pH control by CO2 gas injection alone is not sufficient to ensure optimal growth conditions for microalgae. They propose a control strategy based on measuring DIC levels, which they implemented in a simulation using a dynamic model that accurately describes the observed behavior. The simulations show promising results for the proposed control solution.

2. Using wastewater treatment plant effluents for microalgae production

Microalgae biomass has attracted significant interest due to its potential applications in various industries. However, the high production and processing costs have limited its industrial applications. To make microalgae production profitable, it needs to be cultivated on a large scale using renewable sources of nutrients and carbon. The authors suggest that wastewater treatment plant effluents can serve as a viable alternative for microalgae production, as they contain the necessary nutrients and carbon, such as CO2.

3. Importance of monitoring and controlling the design of photobioreactors

The design of photobioreactors is crucial for providing optimal growth conditions for microalgae. The authors emphasize the importance of monitoring and controlling both the liquid and gaseous phases in the reactor. The cultivation process is complex and involves biological and physicochemical interactions. The control community has shown interest in developing control strategies to optimize microalgae growth in photobioreactors.

In their study, the authors utilized a dynamic model to describe the growth of photosynthetic microorganisms in a laboratory airlift photobioreactor. They validated the model using experimental data and then used it to propose a control strategy based on DIC measurement. They also discuss the importance of monitoring pH and dissolved oxygen.

4. Conclusion and future research on monitoring and controlling DIC in photobioreactors for microalgae cultivation

In conclusion, this article provides insights into the monitoring and control of DIC in photobioreactors for microalgae cultivation. The proposed control strategy based on DIC measurement shows promising results and could contribute to the optimization of microalgae production on a large scale. However, further research is needed to validate the control strategy with real-scale photobioreactors and different microalgae strains.

**A review on photobioreactor design and modelling for microalgae production**

Jack Legrand, Arnaud Artu, Jeremy Pruvost

The scientific article titled "A review on photobioreactor design and modelling for microalgae production" by Legrand et al. delves into the various aspects of photobioreactor design and modelling for microalgae production. The authors emphasize the significance of comprehending the intricate interplay between physical operating parameters and biological responses in microorganism culture processes.

Advantages and focus of modelling microalgae production in photobioreactors

The article commences by underscoring the advantages of modelling the diverse phenomena involved in the microalgae production process. Models aid in comprehending the process's behavior and defining optimal process parameters. The authors specifically concentrate on photobioreactors, which are employed for in-depth analysis of the physiological aspects of microalgae culture and for industrial production.

The article explores different approaches to modelling the kinetic growth of microalgae and the radiative field in photobioreactors. The unique feature of photobioreactors lies in the importance of the light factor, which impacts the growth rate and productivity of microalgae. The authors also emphasize the significance of modelling other factors such as temperature, pH, carbon dioxide concentration, and nutrient availability.

Overview and analysis of different photobioreactor designs

The article provides an overview of various photobioreactor designs, including tubular, cylindrical, flat panel, raceway, and inclined plane systems. It explains the pros and cons of each design, along with their application in different scenarios. The authors also discuss the importance of efficient mixing and agitation in photobioreactors to prevent biomass sedimentation and ensure uniform distribution of light, nutrients, and gases.

Utilization of mathematical models for optimizing photobioreactor performance

Lastly, the article mentions the utilization of mathematical models for optimizing photobioreactor performance. These models can predict biomass productivity, optimize resource utilization, and reduce production costs. The authors highlight different modelling approaches, including metabolic flux modelling and light attenuation modelling.

Overall review and the importance of further research

Overall, the article offers a comprehensive review of photobioreactor design and modelling for microalgae production. The authors stress the importance of understanding the complex interactions between physical and biological factors and the need for further research in this field.

The article also discusses the factors influencing the productivity of a photobioreactor (PBR) for microalgae cultivation. The authors note that optimal performance is achieved when parameters such as temperature, agitation, and light attenuation are maintained at their optimum levels. They propose a simplified engineering law for PBR sizing, which considers parameters such as photon conversion efficiency, molar quantum oxygen efficiency, and specific rates of regeneration of respiratory chain co-factors.

The researchers also delve into the dependence of PBR productivity on the reactor's geometry. They explain that the volume productivity of a PBR is linked to the specific surface area of the reactor. They highlight the importance of having a large specific surface area to increase volume productivity. They provide experimental data and theoretical predictions to support their findings.

Understanding microalgae physiology and types of PBRs

The article emphasizes the significance of understanding the physiology of microalgae to optimize their growth in PBRs. The authors mention that the growth of photosynthetic microorganisms is influenced by various environmental factors such as light, mixing, gas-liquid transfer, temperature, and pH. They discuss different types of PBRs, including open systems and closed systems, and acknowledge that there is no perfect PBR for mass cultivation of microalgae due to the need to balance investment and operating costs.

In conclusion, the article offers insights into the factors affecting PBR productivity for microalgae cultivation. It underscores the importance of optimizing the parameters and geometry of PBRs to maximize productivity. The research contributes to the understanding of microalgae growth and provides guidance for designing and operating PBRs to achieve high productivity.

**Closed photobioreactors for production of microalgal biomasses**

Bei Wang, Christopher Q. Lan

1. Challenges in Designing Closed Photobioreactors

The article discusses the design of closed photobioreactors for producing microalgal biomass. Microalgal biomass has various industrial applications, including biofuel production and CO2 bio-sequestration. However, designing photobioreactors that effectively capture and convert solar energy has been a major challenge. The article reviews recent developments in this field.

2. Considerations in Photobioreactor Design

The design of photobioreactors involves considerations such as light capturing, distribution, and utilization; CO2/O2 balance and gas exchange; temperature; pH; mixing; sterility and cleanability. Different types of photobioreactors, such as vertical column, flat panel, and tubular, are described. Each type has its advantages and disadvantages, and ongoing research aims to improve their performance.

3. Exploring Technologies for Improved Light Capture

Internally illuminated photobioreactors, which use optical fibers to deliver light to the algae, and spectral shifting, which uses florescence dyes to absorb non-photosynthetically active radiation and emit photosynthetically active radiation, are two technologies that are being explored to improve light capturing and efficiency.

4. Innovative Photobioreactor Designs

Membrane photobioreactors and plastic bag photobioreactors are two examples of innovative designs that have been developed. Membrane photobioreactors use membranes to facilitate gas/liquid mass transfer and separation of extracellular metabolites, while plastic bag photobioreactors are low-cost and easy to construct.

5. Conclusion: Evolving Field of Photobioreactor Design

In conclusion, the design of photobioreactors for microalgal biomass production is a rapidly evolving field. Ongoing research and development aim to improve light capturing, mass transfer, and other aspects of photobioreactor performance.

**Dynamic Modeling of Microalgal Production in Photobioreactors**

I. Fernández, J.L. Guzmán, M. Berenguel and F.G. Acién

1. Introduction and Overview of Dynamic Models for Microalgal Production

This scientific article introduces dynamic models for microalgal production in both open and closed photobioreactors, considering spatial and temporal gradients for key culture variables, including fluid dynamics and biological phenomena. Calibration and validation tests were conducted in real industrial photobioreactors, yielding successful results. The models accurately predicted the evolution of crucial variables such as biomass concentration, pH, dissolved oxygen, and total inorganic carbon. They serve as valuable tools for optimizing photobioreactor design and operation, as well as designing control strategies for optimal biomass production. The article also explores the potential applications of microalgae production systems in various industries, including pharmaceuticals, cosmetics, animal feeds, and biofuels. It emphasizes the necessity of high-quality photobioreactor models to effectively control and optimize biomass production, with the models presented in this article representing a significant step towards achieving this objective.

2. Development and Validation of a Dynamic Model for Microalgal Production in Photobioreactors

The article details the development and validation of a dynamic model for microalgal production in photobioreactors. Through calibration and validation using experimental data, the model accurately simulated variations in dissolved oxygen and pH under different operating conditions. It also accounted for carbon dioxide transfer and consumption, enabling simulation of pH variations and CO2 injections for pH control.

The model successfully captured the variations in dissolved oxygen resulting from daily fluctuations in solar radiation and photosynthesis rate. Additionally, it determined the characteristic parameters of the growth model for the specific microalgae strain used, typically determined through laboratory experiments. The calibration procedure revealed mass transfer coefficients consistent with previous reports for the same reactor, indicating that mass transfer primarily occurs in the sump and paddle wheel.

Utilizing the model, the article examined the impact of reactor design parameters on biomass productivity. It discovered that reducing the water depth in the reactor increased biomass productivity by 72%. Furthermore, the model demonstrated that oxygen accumulates in the culture due to a higher photosynthesis rate compared to the oxygen desorption capacity, while injected CO2 is primarily lost to the atmosphere.

5. Conclusion: The Power and Importance of Dynamic Models in Microalgal Production

In conclusion, the developed model is a powerful tool for studying microalgal production in photobioreactors. It facilitates the optimization of reactor design and operation, as well as the implementation of advanced control strategies. Compared to static models, the dynamic model provides a more accurate representation of spatial and temporal variations in culture conditions. Ultimately, dynamic models based on first principles are crucial for enhancing the performance of industrial-scale photobioreactors.

**Dynamic Modeling of the Microalgae Cultivation Phase for Energy Production in Open Raceway Ponds and Flat Panel Photobioreactors**

Matteo Marsullo, Alberto Mian, Adriano Viana Ensinas, Giovanni Manente, Andrea Lazzaretto and François Marechal

This scientific article presents a dynamic model of microalgae cultivation in open raceway ponds and flat panel photobioreactors. The model takes into account various parameters that affect microalgae growth, such as CO2 and nutrients concentration, light intensity, temperature, and microalgae species. The model is able to predict microalgae productivity and energy consumption in both cultivation systems. Comparisons with experimental data show that the model predictions are consistent and slightly overestimate the productivity in the case of closed photobioreactors.

Microalgae have gained attention as a potential source of biofuels due to their fast growth, ability to grow in various environments, and their ability to capture CO2 released by industries. The article also highlights the advantages of microalgae over traditional biofuels sources, such as their high productivities, use of wastewater, and ability to grow in a wide range of conditions.

The article discusses the history and development of microalgae research, including the Aquatic Species Program in the United States. It also mentions the various cultivation and transformation technologies for microalgae, such as open ponds and closed photobioreactors.

The goal of the article is to develop a comprehensive modeling framework to assess and compare different microalgae cultivation technologies in a consistent and holistic manner. The model includes the influence of various physical and chemical parameters on microalgae growth. The model outputs include microalgae biomass productivity, energy productivity, and the quantities of compounds consumed or produced during the cultivation process.

Overall, the article provides a detailed model for predicting microalgae productivity and energy consumption in open raceway ponds and flat panel photobioreactors. The results of the simulations are consistent with experimental data and provide valuable insights for optimizing microalgae cultivation for biofuel production.

**First Principles Model of a Tubular Photobioreactor for Microalgal Production**

Ignacio Fernandez

■ INTRODUCTION

Microalgal production systems are gaining attention due to their potential in various industrial applications, including the production of bioproducts, greenhouse gas mitigation, wastewater treatment, and renewable energy. However, the current production capacity and costs of microalgal systems are insufficient to compete with traditional biodiesel feedstocks. To address this, researchers have focused on optimizing photobioreactor design, reducing production personnel, and incorporating low-cost nutrient sources. In terms of control, efforts have been made to minimize CO2 losses and optimize the pH. Various control strategies, such as proportional integral derivative (PID), filtered Smith predictor (FSP), and model predictive control (MPC), have been used to improve the performance of the system. Nonlinear multivariable controllers have also been developed to control biomass concentration and pH. Such controllers are based on mechanistic models and account for various system variables. However, obtaining dynamic nonlinear models for biological systems is challenging due to the complexities and time-varying nature of these systems. In this study, a dynamic model based on physicochemical and biological principles was developed to predict important variables in microalgal production systems. The model was calibrated and validated using an outdoor tubular photobioreactor. The paper provides guidelines and recommendations for model calibration and discusses the limitations and potential applications of the model. The paper is organized into sections covering materials and methods, model explanation, results and discussion, and conclusions.

■ MATERIALS AND METHODS

The researchers used the microalgae strain Scenedemus almeriensis in a tubular photobioreactor for their experiments. The photobioreactor was operated in continuous mode at a dilution rate of 0.34 L/day. The culture medium was prepared using agricultural fertilizers instead of pure chemicals. The system consisted of a solar receiver and a bubble column used for mixing, degassing, and heat exchange. The total culture volume was 2600 L, with the photobioreactor being 19.0 m in length and 0.7 m in width. The solar receiver was made of transparent tubes joined in a loop configuration. The microalgal culture was circulated using a centrifugal pump, and the pH was controlled by injecting CO2. The dissolved oxygen was removed by constant air flow, and the temperature was controlled using a heat exchanger. Measurements of pH, temperature, and dissolved oxygen were taken at different positions along the photobioreactor using probes connected to a control-transmitter unit. The carbon dioxide uptake was modeled as a one-to-one molar ratio with oxygen. The growth of the microalgae was modeled based on the photosynthesis rate, which was influenced by factors such as light availability, pH, temperature, and dissolved oxygen. The mass balances in the liquid phase were described by partial differential equations, while heat balances were added to consider the temperature of the system. The mass transfer of gases and mixing were also considered in the model.

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The section discusses mass and temperature balances in a photobioreactor system. The mass balances focus on the gas phase, specifically the nitrogen, oxygen, and carbon dioxide components. Equations are presented to describe the molar ratios and flow rates of these gases in different parts of the system. The gas holdup, which affects mass transfer, is also discussed and modeled using different expressions for the solar receiver and bubble column. The mass transfer coefficient for CO2 is related to the oxygen transfer coefficient. The interfacial area between the gas and liquid phases is another parameter considered in characterizing mass transfer.

The temperature balances in the system are important for microalgal growth. The culture temperature is controlled by a heat exchanger in the bubble column, and heat balances are developed to describe the fluid-dynamic and heat transfer phenomena. Equations are provided for the temperature in the culture medium, the heat transmission between the ambient and culture temperature, and the heat transmission in the bubble column and heat exchanger. The output temperature expelled by the heat exchanger is also considered. Overall, these equations and models provide a framework for understanding and optimizing the mass and temperature dynamics in the photobioreactor system.

■ RESULTS AND DISCUSSION

The calibration and validation of a biological system is a complex task that requires numerous experimental tests and the calibration of multiple parameters. In this study, the parameters were divided into different groups based on their characteristics, such as biological and fluid-dynamic parameters. Physical and chemical parameters were determined by experimental data or known fluid-dynamic relationships, while biological parameters were calculated at the laboratory scale and then adjusted for outdoor culture conditions. The whole system was adjusted using experimental data from outdoor cultures and error metrics were used for optimization. Special care was taken with the pH variable and possible disturbances that affect it. The model was implemented in Matlab and solved using sequential quadratic programming methods. Calibration and validation were performed using experimental data of solar radiation, biomass concentration, pH, dissolved oxygen, and temperature. The model accurately captured the dynamics of the system and showed good agreement with experimental data. The model can be used for optimization, design, virtual sensor, and control strategies in photobioreactors.

■ CONCLUSIONS

This research paper presents a comprehensive dynamic model for microalgal production, taking into account both biological and fluid-dynamic phenomena that occur in microalgal cultures. The model is developed based on fundamental principles and considers the distributed characteristics commonly found in microalgal production photobioreactors. This means that the model can be applied to different types of photobioreactors. The model has several practical applications, such as being a useful tool for the design and operation of photobioreactors, virtual sensors for variables that are not directly measured, a simulation framework, and a tool for analyzing and designing advanced control strategies for optimal plantwide control.

The researchers also demonstrated in a simulation example that productivity can be increased by implementing a simple control of pH and temperature conditions. Moving forward, future efforts will focus on finding numerical solutions to the diffusion equations in the model, while taking into consideration the computational costs involved in order to fully include this effect. Additionally, the researchers aim to determine the optimal placement of sensors in the installation. Furthermore, the biological part of the model will be expanded to include the representation of the "aging" state of the microalgal culture. This indicates that the researchers plan to refine and enhance the model by incorporating additional elements and improving its accuracy.

**Lab‑scale photobioreactor systems: principles, applications, and scalability**

Philipp Benner

Photobioreactor Designs and Considerations

This scientific article provides a comprehensive review of laboratory-scale photobioreactors used for cultivating phototrophic microorganisms. It discusses various types of photobioreactors, including illuminated microtiter plates, microfluidic devices, shake flasks, bubble column reactors, flat plate bioreactors, and stirred-tank bioreactors. It also covers less common designs such as plastic bags and aquarium tanks. The article emphasizes the importance of selecting the appropriate photobioreactor design based on specific research needs and scale-up considerations.

Light Availability and Scaling Challenges

A critical factor for the growth and productivity of microalgae and cyanobacteria in photobioreactors is light availability. The article explores different methods for providing light, including artificial sources like LEDs or fluorescent lamps, as well as utilizing natural sunlight. It also addresses the challenges of scaling up photobioreactor processes, such as selecting robust microalgae strains, addressing contamination issues, and considering temperature control.

Scale-Up Factors and Considerations

In terms of scale-up, the article recommends adjusting the scale-up factor based on the level of photoinhibition during cell expansion. It suggests using light-dependent microalgae growth kinetics as the basis for model-based scale-up, considering factors like light intensity and path in the suspension. Maintaining a constant surface area to volume ratio during scale-up is also emphasized.

Importance of Design and Scale-Up Considerations

Overall, this article provides valuable insights into the design and scale-up considerations of photobioreactors for cultivating phototrophic microorganisms. It highlights the need for careful selection of photobioreactor design, light supply, and process parameters to achieve successful scale-up and maximize productivity.

The article also discusses the scalability of photobioreactors for microalgae cultivation. It emphasizes the importance of optimizing mixing and aeration to promote optimal microalgae growth without compromising cell integrity. Preventing biofilm formation by applying sufficient wall shear stress is also highlighted.

Different Types of Photobioreactors and their Suitability

Different types of photobioreactors, such as microtiter plates, shake flasks, bubble columns, flat plate reactors, tubular reactors, and stirred tank bioreactors, are discussed in terms of their advantages, disadvantages, and suitability for different cultivation purposes. Each type of photobioreactor has specific considerations regarding light availability, gas exchange, and nutrient distribution.

Challenges in Scaling Up Photobioreactors

Scaling up photobioreactors is challenging due to limitations in light distribution and energy dissipation. The article emphasizes the need to carefully consider geometric differences and their effects on microalgae growth behavior when scaling from lab-scale to industrial-scale reactors.

Modeling and Simulation Approaches for Scale-Up

The importance of modeling and simulation approaches for the scale-up of phototrophic production processes is also highlighted. Integrating light-dependent microalgae growth kinetics with the physics of light transport and fluid dynamics can provide valuable insights for photobioreactor design and optimization.

Conclusion and Further Research

In conclusion, this article provides a comprehensive overview of different photobioreactor designs and their scalability considerations for microalgae cultivation. It emphasizes the need for further research and experimentation to improve the understanding and implementation of photobioreactors in large-scale microalgae production.

**Toward Optimal Control of Flat Plate Photobioreactors: the Greenhouse Analogy**

G. van Straten

1. Introduction: Application of dynamic optimization and optimal control methodologies to microalgae cultivation.

This scientific article explores the application of dynamic optimization and optimal control methodologies to the cultivation of microalgae in a flat plate photo-bioreactor (PBR). The goal is to maximize algal biomass production, which has potential uses in food supplements and sustainable biofuels. The study takes inspiration from the optimization strategies used in greenhouse crop production.

2. Model and Methodology: One-state space model and dynamic optimal control trajectories.

A one-state space model is presented for the algal biomass in the reactor. The growth rate vs. light curve is parameterized based on experimental evidence, and the spatial distribution of light and growth rate between the plates is considered. The control variable is the dilution rate, and dynamic optimal control trajectories are computed for different goal functions and solar irradiation patterns over a 3-day period.

The results show that the remaining algae in the reactor at the end of the optimization horizon have value for future production. It is found that the optimal control is bang-(singular-)bang, meaning that the dilution rate needs to be adjusted depending on the weather conditions. The optimal biomass concentration also depends on the available light, and it may take several days to achieve a new optimal steady cycle after a prolonged change in weather.

The study suggests a control law that maximizes the effective growth rate, which is the growth rate integrated over the entire day. The co-state of the algal biomass plays a crucial role in developing on-line controllers. The results also indicate that it is important to adjust the pumping regime to the light conditions to optimize biomass production.

5. Conclusion and Future Directions: Demonstrating potential, need for further investigations.

Overall, this study demonstrates the potential of dynamic optimization and optimal control strategies in maximizing algal biomass production in photo-bioreactors. Further investigations are needed to consider other control aspects, such as temperature and pH control, as well as the production of valuable chemicals.