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Tubular photobioreactor design for microalgae cultivation: Maximising efficiency for CO₂ fixation

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Abstract

Microalgae, which utilise photosynthesis to convert carbon dioxide (CO₂) into biomass, have gained significant attention as a sustainable source of renewable energy and high-value bioproducts. Among various microalgae cultivation systems, tubular photobioreactors (PBRs) are one of the most established and widely used closed cultivation systems. This review provides an in-depth evaluation of key design properties of tubular PBRs, such as tube geometry, diameter, length, material fabrication, and the selection of appropriate light sources. Critical operational factors, including mass transfer, aeration systems, and mixing strategies, were also covered in detail in this paper. Particular emphasis is given to the novel integration of a helical baffle and membrane sparger into a tubular PBR to improve overall system efficiency compared to conventional systems. Membrane-based CO₂ delivery systems were shown to improve biomass concentration, productivity, CO₂ fixation rate, and CO₂ utilization efficiency by approximately 10–14% compared to conventional sparging methods. Additionally, the integration of a helical baffle into a horizontal tubular PBRs has been shown to significantly enhance the mass transfer coefficient, prolong bubble residence time, reduce mixing time, and promote overall microalgal growth by up to 40%. These improvements are attributed to enhanced flow distribution, intensified mixing, and extended bubble residence time. This review concludes by outlining key design recommendations and future research needs to further optimise tubular PBR design for sustainable microalgae cultivation. © 2026 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY license. <http://creativecommons.org/licenses/by/4.0/>

Author keywords

Carbon dioxide; Helical baffle; Membrane; Microalgae; Tubular photobioreactors

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Abstract

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