Mathematical Modeling of CO2 Enrichment, Capture and Utilization in Commercial Greenhouses

Mohammed B. Effat, Hamdy M. Shafey, A.M. Nassib

Abstract:

This paper investigates carbon dioxide enrichment in commercial greenhouses to improve CO2 capture and utilization. The paper develops and numerically solves a mathematical model that simulates the CO2 capturing process through the coupled-non steady- energy and mass species (CO2, H2O) balance equations in the greenhouse components. The model accurately treats the solar radiation transport inside greenhouse. The realistic photosynthesis sub model selected in the present work is a mechanistic one applicable to the commonly planted C3 species. The present model allows strategies for CO2 enrichment and for cooling air inside sealed and ventilated greenhouses. These strategies keep both CO2 concentration and air temperature inside the greenhouse at the required prescribed value within small specified deviation. The validity and accuracy of the present mathematical model were verified through the agreement of its numerical results with the available experimental data in the literature. Numerical predictions of the present model was obtained for a case study to investigate the effects of environmental conditions, CO2 concentration enrichment level, and the cooling method on the cumulative amount of captured CO2 in the greenhouse that describe its performance.

Keywords:

Carbon Capture and Utilization, CO2 enrichment, Greenhouses, Mathematical Model, Bio-fixation, Photosynthesis

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Introducing the Photosynthesis-Stomatal Conductance Coupled Model into Greenhouse Microclimate Studies

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Abstract:

This paper introduces the photosynthesis-stomatal conductance coupled model, well known and frequently used in the studies of vegetation-atmosphere interaction, to be incorporated into the studies of modeling greenhouses’ microclimate. The use of this model, unlike many of other models in the literature, allows accurate modeling of stomatal conductance for many plant types and under several environmental conditions. It also guarantees the modeling of the photosynthesis process, which is important for microclimate and CO2 enrichment purposes, due to the direct coupling between photosynthesis and stomatal conductance in this model. Although the many advantages of this model, the many details associated with it may be the reason behind not being used in greenhouse microclimate modeling studies. Thus, this paper comes with an aim of facilitating the use of this model and encouraging modelers of greenhouses’ microclimate to use this powerful model by providing them the necessary background for the treatment of the model in a well-organized form that contains all the necessary and required information they may need in their use of the model. In this paper, the photosynthesis-stomatal conductance coupled model is introduced by first illustrating briefly the biochemical background of the photosynthesis process and then introducing the accurate biochemical model that represents it. Then the photosynthesis-stomatal conductance coupled model is presented with its analytical solution methodology that gives accurate estimation of the photosynthesis rate and the stomatal conductance. Finally, validation of the model results with available experimental data is performed for a representative crop type under different environmental conditions. This validation proves the accuracy of the model in predicting the photosynthesis rate and in turn the stomatal conductance.

Keywords:

Photosynthesis, stomatal conductance, model, greenhouse, microclimate, CO2 enrichment

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Abstract:

Solar greenhouses can be considered as efficient places for biological CO2 capture and utilization if CO2 enrichment becomes a common practice there. As CO2 enrichment is applied only when greenhouses are closed, ventilated greenhouses - which represent a large percentage of greenhouses all over the world - cannot be considered for this practice, consequently cannot be available for CO2 capture and utilization. The aim this paper is to show-through modeling and simulation-that these ventilated greenhouses can be activated for serving as efficient CO2 capture and utilization places if they are kept closed (to apply CO2 enrichment) and used microclimate control methods alternative to ventilation. The paper introduces a realistic mathematical model in which all the processes and phenomena associated with the biological CO2 capture and utilization by photosynthesis inside greenhouses are considered. The model considers solar radiation attenuation through the atmosphere and absorption by the greenhouse components. It also accounts for the estimation of radiative heat exchange between the various surfaces inside the greenhouse. The realistic photosynthesis sub model selected in the present work is a mechanistic one applicable to the commonly planted C3 species. The model also provides a strategy for CO2 enrichment and microclimate control. In these strategies, the CO2 injection specific rate for enriching the greenhouse air to a specific concentration, and the cooling and dehumidification specific rates required to be keep the microclimate temperature and relative humidity within the favorable limits, are estimated. The model validity and accuracy were ensured through the good agreement of its numerical predictions with the available experimental results in the literature. The effect of different environmental conditions and planting conditions on the CO2 capturing process (the photosynthesis process) is investigated. Finally, a case study was chosen to investigate the effects of the cooling method, cooling temperature, planting conditions, and CO2 concentration level on the cumulative amount of captured CO2 considered to represent the greenhouse capturing performance. The results show that the capturing performance of greenhouse can be enhanced from value as low as 1.0 g CO2/m2.day for ventilated greenhouses to value as high as 52 g CO2/m2.day when alternative microclimate control methods and CO2 enrichment are used. In addition, the greenhouse has extended ability to capture as high as 140 g CO2/m2.day within its growing period considering the appropriate plant type. Furthermore, additional benefits besides CO2 capture are reported for the possible increase of the plant productivity and possible lowering of water consumption by plants.

Keywords:

Carbon Capture and Utilization, CO2 enrichment, Solar greenhouses, Mathematical model, Photosynthesis, microclimate control.

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Numerical investigations of the effect of flow arrangement and number of layers on the performance of multi-layer microchannel heat sinks,

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