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Investigating airflow dynamics in a small CEA plant growth chamber under lunar conditions using computational fluid dynamics (CFD) modeling

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ABSTRACT

Optimizing airflow dynamics in controlled environment agriculture (CEA) is critical for plant growth, as proper airflow distributions can impact plant growth by promoting higher rates of gas exchange, enhancing nutrient uptake, and regulating the temperature and humidity of the microclimate around each plant. Therefore, understanding the best methods to optimize airflow dynamics in CEA systems is imperative, especially when venturing off-planet, where conditions are harsher. Computational fluid dynamics (CFD) modeling is an excellent tool for understanding and optimizing airflow in CEA systems, due to its ability to simulate and analyze airflow dynamics under complex user-defined environmental boundaries and constraints, including conditions reflecting space and/or lunar environments. This study investigated the internal airflow dynamics of a small-scale plant growth chamber of dimensions 21 cm (L x W x H), designed for lunar CEA, to ensure a homogenous environment optimized for plant growth. COMSOL Multiphysics was selected to produce a three-dimensional CFD model under the k-epsilon turbulent flow model and to examine streamline patterns and velocity distributions within the chamber. Appropriate environmental boundary conditions were set to represent lunar conditions, including reduced ambient pressure (57 kPa) and lunar gravity (1.625 m/s^2). A small (30 mm diameter) 5V DC fan with an inlet velocity of 2.16 m/s, mounted underneath the lid component, generated the airflow within the chamber. The airflow analysis investigated the ability of the system to maintain uniform airflow while mitigating turbulence and/or airflow instability. Based on the preliminary resulting streamline plots and velocity distribution heat maps, air was evenly circulated throughout the chamber, despite potential dead zones at the bottom of the chamber between the growth trays and the water collection reservoir. The velocity across the plant growth trays averaged between 0.25 m/s to 0.6 m/s, well within the desired range for optimal gas exchange (between 0.2 m/s to 1 m/s). Validation of the model will be performed using a sonic anemometer installed into the system. Eventually, the model will be further enhanced to include a heat transfer study to assess the convective heat transfer efficiency within the chamber.