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A. G. Niam ✉; T. R. Muharam; S. Widodo; M. Solahudin; L. Sucahyo

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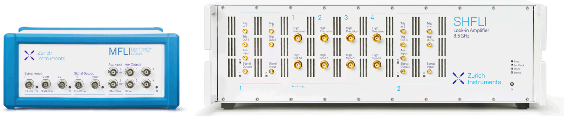

CFD Simulation Approach In Determining Air Conditioners Position In The Mini Plant Factory For Shallot Seed Production

AG Niam[1, a)] TR Muharam [2)] S Widodo [1)] M Solahudin[1)] L Sucahyo[1)]

[1]*Department of Mechanical and Biosystem Engineering, Bogor Agriculture University, West Java, Indonesia*
[2] *Bachelor student in Departement of Mechanical and Biosystem Engineering, Bogor Agriculture University, West Java, Indonesia*

[a)]Corresponding author: ghautsun@apps.ipb.ac.id

Abstract. The precision agricultural development paradigm leads to the effort of controlling environmental parameters based on the suitability of needs, responses, and shallot crop performance. The distribution of temperature and air flow pattern have been required for growing. Furthermore, the temperatures less than 20°C is suitable or comfort for flowering initiation of shallot. Therefore, CFD simulation has been applied to compute temperature distribution and pattern with two alternate positions of air conditioners. The simulated domain is a chamber from container 40 ft with dimension of 672 x 212 x 261 cm. The room is equipped with 6 planting media shelves in the form of a substrate with a drip irrigation system. Each layer of the plant shelf is equipped with 4 units LED @ 20 W. The cooling source in the cultivation room comes from 2 AC units with a capacity of 2 pk. The position of the AC is placed on the front and rear walls with two different combinations, namely the top-top and top-center. Numerical approach was carried out to verify the results of the calculation, which used the grid convergence index with the number of cells around 1.7 million and the result of simulated air velocity value reached 0.27-0.30 ms-1. The air inside the chamber was cooled until the air temperature reaches 16-18 ° C by using 2 standard AC units. The top-top AC position was the best position with an air temperature uniformity of more than 99.5% for the entire shelf layer.

INTRODUCTION

Flower induction and initiation are deemed important in shallot seed production. Flower induction and initiation is a complex systemic process regulated by numerous genes, promoters, and inhibitors, which are triggered by various signals, such as temperature and photoperiod [1]. The total number of flower per umbles could increase with photoperiod around 16 hours on shallot plant [2,3]. However, the most important factor controlling their flowering is the seasonal thermo-periodicity, whereas the effects of light on flower induction are commonly less important [4]. The best temperature for the flower initiation of shallot is around 17-19°C (highland temperature) [5]. The need of temperature might be different from each plant based on the ecological origin of the mother plant. [1]. In tropical regions, such as Indonesia, the temperature need for flower induction of shallot is around 20°C [6]. Generally, the optimal temperature for the initial organogenesis of shallot flower ranges from 15 to 21°C [7]. When shallot end its vegetative phase and start its generative phase, which is marked by the emergence of umbel, the best temperature for this umbel initiation is around < 20°C [8], while for the initiation of capsule and seed of shallot (pollination) genus Allium the best temperature is around 27-35°C [9]. Thus, the need for different temperature on each phase on shallot plant showed the need the need for a dynamic and effective temperature environment control and engineering system.

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Shallot production in Indonesia is still dependent on climate condition [10]. This certainly affects the shallot supply chain nationally, where shallot price fluctuations occured every year. In addition, shallot seed production in the rainy season also produces low seed quality [5] compared to shallot seed production in the dry season. Therefore, it is necessary to have a cultivation system solution that does not depend on climatic conditions, one of which is the cultivation system at the mini plant factory with a controlled growth environment.

Several techniques of shallot seed production have been widely carried out with hormonal and chemical approaches, such as increased pollen flowering and viability by using benzyl aminopurine (BAP) and boron in shallot plants in the highlands [8,11]. However, some researchers consider that the use of boron also has a toxic risk to the next cultivation within the same land [12], since some chemical elements will usually be left on the land for a long time, and one of them is boron. In addition, the flowering potential of onions can also be increased by adding gibberellin to the shallot seed tubers to be planted [7]. But gradually this can affect the bad nature of the plant phenotype. Moreover, the continuous use of tubers will reduce the quality of the plants. Therefore, the approach through controlled environmental factors is a better proposal than the approach through the addition of chemicals, where the adverse effects of sustainable shallot cultivation are expected to be avoided.

The cultivation system in the mini plant factory allows the environment conditions to be controlled automatically according to the needs of the plants. To ensure the accuracy of the system design, a preventive approach is needed that can represent the interaction behavior of physical parameters in the cultivation space. Both in terms of temperature, air flow, radiation, lighting and other environmental parameters. Examples of simulations that have been carried out for the development of shallot plant environment are the determination of the cooling pipe applied to cool the root area in the substrate hydroponics [13] and the distribution temperature of the planting hole in floating hydroponics [14] through the computational fluid dynamics (CFD) approach. This paper describes a simulation of the temperature distribution of a mini plant factory cultivation space in order to determine the location of an air conditioner (AC) that is suitable to the needs of the shallot plant growth using CFD design tools.

Requirements for growing shallots

Shallots are one of the long day plants (14-17 daylight) which can grow well at temperatures around 25-32 °C [15]. These temperatures are generally found in the lowlands. However, the optimum temperature for germination is around 18-24° C [16], while for the development of leaves and red onion canopy it is very suitable at air temperatures around 20-25° C [9]. Conditions to grow air temperature for onion plants at each stage of growth can be seen in table 1.

TABLE 1. Temperature requirements [°C] for the various stages of the shallot growth

Stage of growth	Range of temperature (°C)	Ref.
Germination/sprouting	18 – 24	[16]
optimal leaf growth	20 - 25	[9]
Bulb development	15 - 17	[9]
bulb induction	12.8 - 24	[15]
bolting	7.2 - 10	[1,16]
initial organogenesis and flower induction	15 – 21	[1,5,7,8]
pollination	27 – 30	[5,9]
seed development	25 - 30	[9]

Viewed from the perspective of seed production, Table 1 shows that the temperature requirements for vegetative stages until initial organogenesis and flower induction are difficult to do optimally on land in low-lying areas, since the air temperature range in the lowlands is 28-35 ° C. Generative stages, especially pollination and seed development, require warm temperatures which are generally found in low-lying areas. Therefore, it can be stated that controlling the optimum temperature for one cycle of shallot planting season is difficult to do on open land, both lowland and highland, since the required air temperature variations cannot be met by just one location criterion.

Description of mini plant factory

The factory with artificial lighting (PFAL) is defined as a closed crop production system with a building structure equipped with thermal insulators that are not translucent, minimal ventilation and a light source for plant growth using artificial light [17,18]. The concept is based on the concept of a closed plant production system (CPPS) which consists of six important elements [19], namely: 1) impermeable wall structure, 2) multitier system, generally 4-8 layers with a height of about 40 cm between layers, 3) cooling device and dehumidifier as well as air circulator, 4) CO2 enrichment units, 5) fertilizer system and 6) fertilizer controller.

The developed mini plant factory was made in a 40 ft. container consisting of a control room, chamber room (cultivation room) and nutrient room. The simulated room is only a chamber with dimension of 672 x 212 x 261 cm. The room is equipped with 6 planting media shelves in the form of a substrate with a drip irrigation system. Each layer of the plant shelf is equipped with 4 units of lights as a lighting source for the photosynthesis process. The cooling source in the cultivation room comes from 2 AC units with a capacity of 2 pk. The position of the AC is placed on the front and rear walls with two different combinations, namely the top-top and top-center. The top position of the air conditioner is about 10 cm from the ceiling right in the middle of the wall, while the center position is around 60 cm from the ceiling. Figure 1 displays chamber (a), top-top AC position layout (b) and top-center AC position (c).

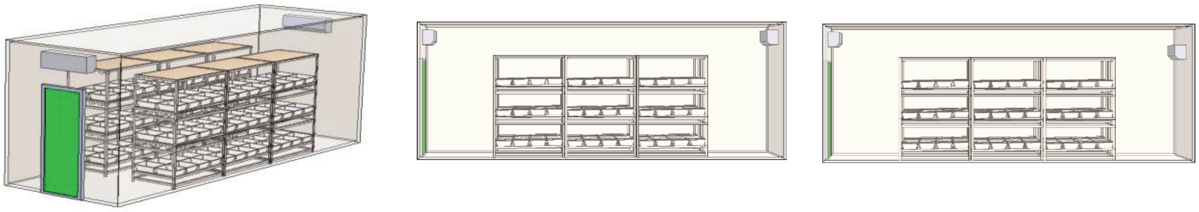

(a) (b) (c)

FIGURE 1. 3D Preview of Chamber Room (a), top-top AC position (b), and (c) top-center AC position.

Numerical simulation

The CFD program was run using commercial software Flow Simulation Solidworks. The numerical approach commonly used in this CFD program uses the Reynolds Averaged Navier-Stokes (RANS) model approach. However, to predict turbulence flow, Solidworks uses the Favre-Average Navier-Stokes approach.

The flow in the fluid region in the chamber is generally incompressible and turbulent due to the velocity level and the dimensions. RANS modeling solves the mean flow variables by using turbulence transport models, includes the mass conservation and momentum equations. Solidworks Flow Simulation software is able to consider both laminar and turbulent flows. To predict turbulent flows, the (FANS) are used. To consider this system of equations, this commercial software employs transport equations for the turbulent kinetic and its dissipation rate, using the *k-ε* model [20]. The modified *k-ε* turbulence model with damping functions proposed by Lam and Bremhorst. The turbulent viscosity is determined to form:

$$\mu_t = f_\mu \frac{C_\mu \rho k^2}{\varepsilon}, \tag{1}$$

where Lam and Bremhorst's damping function $f_\mu$in determined from:

$$f_\mu = (1 - e^{-0.025 R_y})^2 . \left(1 + \frac{20.5}{R_t}\right), \tag{2}$$

and:

$$R_y = \frac{\rho \sqrt{k y}}{\mu}, \tag{3}$$

$$R_t = \frac{\rho k^2}{\mu \varepsilon}, \tag{4}$$

y is the distance from a point to wall and Lam and Bremhorst's damping functions $f1$ and $f2$ is determined from:

$$f_1 = 1 + \left(\frac{0.05}{f_\mu}\right)^3, f2 = 1 - e^{R_t^2} \tag{5}$$

The uniformities of the mass fraction of carbon dioxide in the chamber is defined by:

$$CU_m = \left(1 - \sum_{i=1}^{n} \frac{|\bar{m} - m_i|}{n.\bar{m}}\right) \times 100 \tag{6}$$

where CU_m is the uniformities of mass fraction of carbon dioxide (%), n is the total number of point parameters, i is a number of pint parameter, $\bar{m}$ is the average of mass farction.

Discretization and iteration model

The principle of discretization approach to simulation flow, Solidwork used a Cartesian mesh approach, where the completion of numerical equations is based on finite volume methods [21]. The iterative model is calculated using a tri-diagonal matrix algorithm or better known as TDMA (Tri-Diagonal Matrix Algorithm). This iterative model is a standard algorithm for calculating solution equations for flow in cartesian coordinates which has 2 main stages in the iteration, namely forward elimination and back substitution [22]. This method is considered faster and easier to do iteration calculations is also simple in the integration of counts between fluids with solid for CFD cases both 2D and 3D.

To ensure the accuracy of the simulation results, a model verification is carried out using the Mesh Independency Study (MIS) approach. There are several understanding techniques, such as adaptive mesh refinement, Richardson extrapolation, curve-fitting method, and grid convergence index, to apply mesh independency study [23]. The technique used is the grid convergence index by doing repetitive simulations using a different mesh from rough to smooth.

TABLE 2. Mesh composition with initial mesh variations

		a	***b***	***c***	***d***	***e***	***f***	***g***
Nx		23	32	32	38	40	46	46
Ny		6	12	13	15	16	18	18
Nz		4	5	5	6	6	7	7
channels		3	5	6	5	6	5	7
cells	*top-top*	805648	1038213	1246929	1507816	1742660	1995681	2320830
	top-center	802590	1033532	1239117	1501984	1736156	1993361	2311315

CFD model setup

Simplifications of the actual problem are needed to develop the CFD simulation, which allows for an analysis with reasonable effort. The following assumptions are made:

1) Air in the chamber is incompressible
2) flow and heat transfer phenomena occur in steady state conditions,
3) The wall temperatures are constant
4) the fluid involved only air (single phase)
5) gravity (9.81m/s^2), is taken into the simulation.

Then, the general settings are used in the simulation. The general setting consists of five parts: the type of analysis, the determination of the type of fluid, the type of material solid (solid), the condition of the wall surface, and the initial condition. In addition, other input data are entered according to those listed in Table 2.

TABLE 3 CFD simultation data input

Parameters	Value/type	unit
Environmental temperature	28	°C
Air pressure	1	atm
AC temperature	16	°C
Air velocity	0.295	m^3/s
Lamp heat	20	W
Fluid	air/gas	
Type of wall	*Real wall*	

RESULT AND DISCUSSION

To avoid numerical errors from the iteration process, the model must be verified through a variety of mesh compositions in both layouts by considering the iteration result goal parameter values. Mesh variation shown by the number of cells has a significant effect on the calculation results of a parameter, especially in minimizing errors and maintaining the accuracy of calculations. Figure 2 shows Correlation of Cells total numbers to air velocity for each layout.

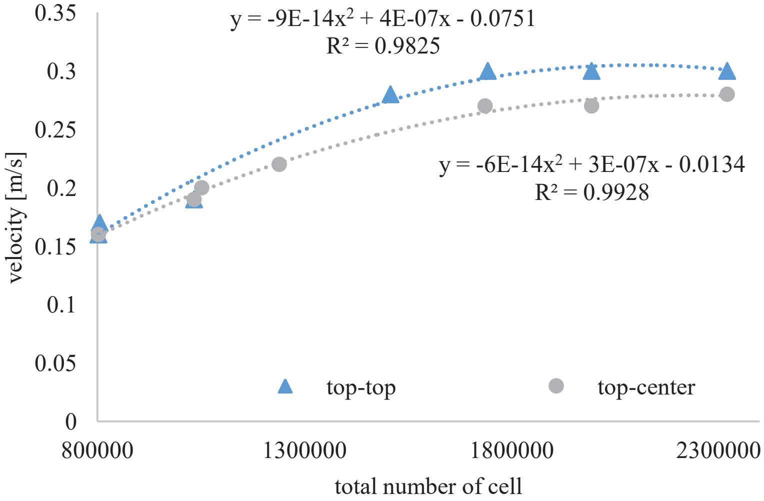
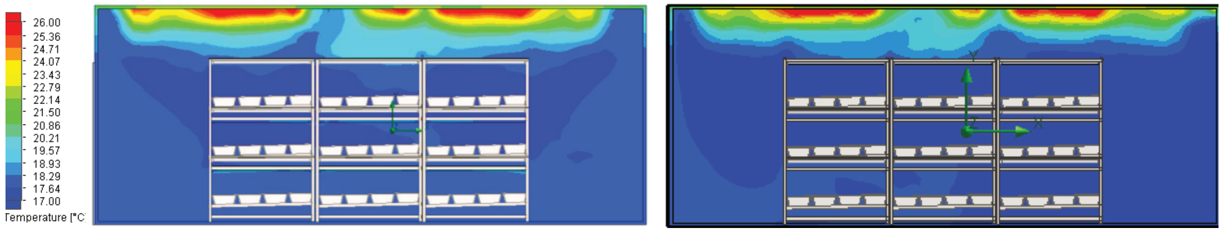


FIGURE 2. Correlation of cell total number to velocity for each layout.

Figure 2 showed that the change in the number of cells initially was quite significant to the value of air velocity, but these changes began to stabilize in the number of cells around 1.7 millions of cells. This means that the calculated parameters are not significantly affected by the number of discretized cells, or in other words the iteration process can be said to be convergent. The air velocity values when converging for top-top and top-center layouts were 0.30 ms-1 and 0.27 ms-1. This value was the average air velocity value taken along the center line of each layer of the plant shelf. Position the line around 10-15 cm from the planting medium. This value was very suitable for increasing net photosynthesis, where the air velocity of around 0.30 ms-1 could increase net photosynthesis of potato sweet plants by 2 times, while for rice plants can increase by 2 to 2.5 times if the horizontal air velocity is increased from 0.01 to 0.80 ms-1 through the plant canopy [24].

The temperature around the plant canopy had a high uniformity coefficient, both in the top-top AC position and top-center position. Uniformity in the top-top AC position is almost 100%, where from the top shelf to the bottom rack respectively were 99.74%, 99.84%, and 99.58%. On average, the air temperature was not so much different, which were around 17.55 °C, 17.44 °C, and 18.07 °C. At the top-center position, sequential uniformity values reached 99.75%, 98.83%, and 97.85%, with a mean temperature of 17.23 °C, 16.98 °C, and 17.31 °C. The use of 2 standard AC units (where the standard AC specifications, the temperature limitation is only up to 16 °C) turned out to be able to show a good temperature distribution for the onion vegetative growth phase until the beginning of the generative phase (flowering initiation); see in table 1, both for top-top AC positions and top-center positions. But the top-top AC position is the best choice with a temperature uniformity value of more than 99.5% for each shelf layer.

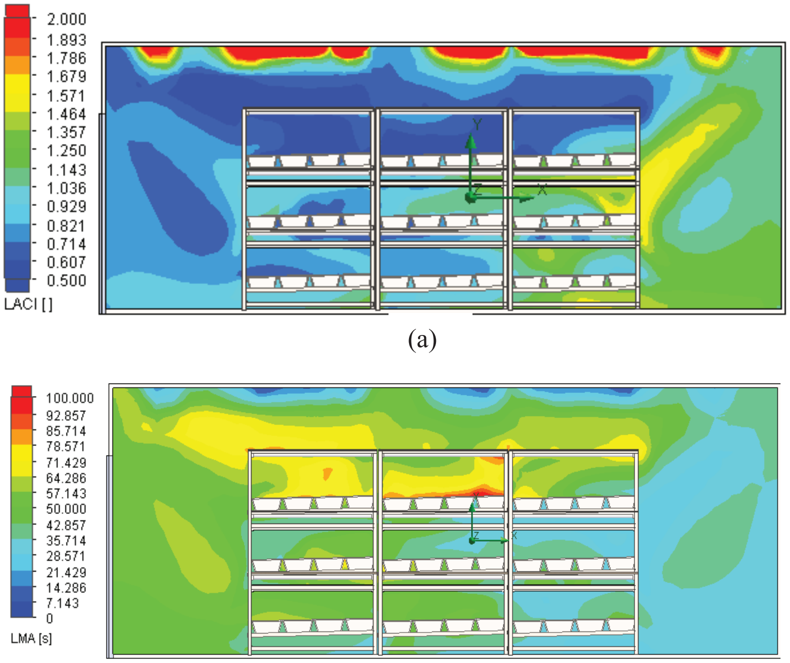
The effect of the temperature of the LED lights (20 W) installed on each roof layer as much as 4 lanes did not give any significance. However, on the roof of the second room, there is a higher air temperature compared to the air below it. The temperature is convection from the container roof which is defined as real wall with an initial temperature of 28 °C. In detail, the distribution of air temperature in the chamber can be seen in figure 3 with a description in the form of a color gradient that shows the level of temperature difference.



(a) (b)

FIGURE 3. Air temperature distribution dalam chamber; (a) top-top, (b) top-center

Another important factor that influences the air quality in the chamber is air exchange. The effectiveness of air exchange within a particular domain (local domain) is represented by the local air change index (LACI) and Local Mean Age (LMA). LMA is the average time the movement of air passes through an open domain taking into account the air velocity and diffusion factors, while LACI is the LMA divided by the ratio between the local domain volume divided by the air flow rate passing through the volume. Therefore, these two parameters are considered in determining the design of mechanical ventilation and natural ventilation.



(a)

(b)

FIGURE 4. Contours of the local air changes index (a), and local mean age (b).

Figure 4 showed that the LACI value on the upper shelf is much lower than the middle layer. The average LACI value along the top shelf was about 0.67, while in the middle and lower shelves were 1.04, and 0.93. LACI was inversely proportional to the LMA value (figure 5.b), where the upper shelf had an average of about 61.30 s, while the middle and lower shelves were only 39.94 s, and 44.37 s. The air around the rack was moving fast enough compared to other shelves, because of the slope of the air blowing from the air conditioner. Even so, the distribution of temperature obtained was very suitable to the needs of the shallot plant during the vegetative phase, even in the middle shelf, the calculated uniformity parameter was very high, reaching 99.84%. This was certainly very good from the perspective of hydroponic cultivation, which in fact pays attention to product uniformity.

CONCLUSION

CFD simulation approach could help in designing the cultivation room cooling system for shallot production. CFD simulations have been numerically verified and converged with the number of cells around 1.7 million cells. The calculation results showed that by using 2 units of standard air conditioner, the air in the chamber can be cooled to an air temperature of 16-18 ° C. The top-top AC position was the best position with more than 99.5% uniformity for the entire rack layer.

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