The Influence of Meshing Strategies on The Numerical Simulation of Solar Greenhouse Dryer

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Abstract. In the present study, we conduct the numerical simulation for solar greenhouse dryer performance by Ansys Fluent software. The numerical simulations compared the meshing strategies for the dryer and show the effects on both temperature distribution and relative humidity distribution of air inside the dryer. Unstructured meshes were used in the numerical simulation employing hexahedral meshing and tetrahedral meshing for mesh generation. The meshing strategies were evaluated through 2 size of cell i.e., 0.1 m and 0.05m. The results indicated that the size of cell have strong effect than the mesh type on the temperature profile and humidity of air inside the dryer. Thus, the results gave the engineers more options to select the optimum conditions for meshing and simulation the dryer.

1. Introduction

In agriculturally dominant countries, post-harvest preservation is a critical process to ensure long-term storage and preserve the nutritional value of agricultural products. The purpose of the drying method was to remove the moisture content inside the material and limit insects and molds to ensure food hygiene and safety. Many methods of drying agricultural products have been applied, but the traditional drying method is still used in developing countries [1]. The use of solar energy as a source of heat to dry agricultural products has existed for a long time. Solar drying is the best candidate because the process consumes a large amount of energy to evaporate the moisture of the material [2]. Vietnam has a hot and humid tropical climate and potential solar radiation intensity, favorable for agricultural production, especially vegetables, and fruits. Due to seasonal characteristics, fruits and vegetables often ripen simultaneously, and climatic conditions significantly affect the quantity and quality of products quickly. Therefore, the use of solar energy to dry the product after harvest is essential for long-term preservation.

In recent years, the widely designed and applied solar greenhouse dryer (SGHD) has been used in over 115 countries with many different applications. The SGHD has many shapes such as spherical dome, gable even span, single slope, mansard roof, and gothic arch [3]. However, the structure of drying houses in Vietnam and some Southeast Asian countries has differences in terms of frames and materials for SGHD. Currently, solar drying houses in Vietnam are being applied to primary agricultural products such as chili, bananas, fish, dried shrimp, and reishi mushrooms. These are all essential commodities, in which chili (Capsicum L.) is currently a relatively valuable fresh or dried export agricultural product and attracts the attention of farmers. However, chili drying is often used manually using direct solar radiation, and the usual process involves a considerable amount of heat and takes a long time to dry [4]. Therefore, using an SGHD is an effective drying method to overcome limitations and develop sustainably, taking advantage of the potential of solar radiation.

In the SGHD, the temperature and velocity of drying air are the significant factors that affect the drying rate of the product. In addition, the quality of the dried product depends on the uniformity of...
the drying air distribution inside the dryer [5]. The airflow through the dryer and pass over the tray, causing the parameters to not be uniform because of the location of products. In particular, a part of the chili at the inlet of the SGHD receives enough heat more effectively than the outlet. The distribution of the velocity, temperature, and relative humidity inside the dryer could be predicted by the computational fluid dynamics (CFD) analysis which applied mathematics to model flow simulations for the prediction of heat, mass and the momentum transfer [6].

Several studies were conducted on the SGHD simulation in which various programming software such as MATLAB, C/C++, and Fortran performed to simulate the relationship of temperature profile with location and time [7], but the research about this problem using ANSYS Fluent software are very few. The three-dimensional (3D) model of SGHD in ANSYS Fluent software is used more effectively than the two-dimensional (2D) because this model can be presented the general temperature, velocity, and relative humidity distribution based on space or time. In particular, the 3D determines the most accurate coordinates based on geographic location using the radiation model, which is impossible for 2D. Some research used the 3D model to simulate the distribution of temperature and velocity based on the location inside the dryer but not to mention the change of relative humidity [8].

Through the CFD solution, the computational domain 3D was discretized by mesh generation and meshing is a most important part of the quality and convergence of the solutions. The discretization of the domain was based on the finite volume method, by means of the decomposition of the domain into small control volumes, generating a three-dimensional mesh of nodes. The quality of the mesh leads to either success or failure of the numerical simulation. Generating a high-quality mesh is extremely important to obtain reliable solutions and to guarantee numerical stability. Meshing strategies have a key impact on the accuracy and efficiency of CFD simulations. Once a meshing strategy is made, it affects not only the types, number, direction of grid elements, but also simulation stability, convergence, and accuracy. Therefore, the main objective of this research is to simulate the impact of weather conditions on the distribution of temperature and humidity inside SGHD by the change of suitable grid by ANSYS Fluent. Two type of mesh including tetrahedral and hexahedral meshing were conducted in this research and the number of cells generating a mesh is various value, dependent on the size of cell.

2. Experimental setup

The SGHD comes in a Quonset shape and construction consisting of polycarbonate (PC) panels, a metal frame, an aluminium (Al) tray, and a concrete base. Currently, this device is located in Dong Thap Province, Vietnam (10° 23’25.1” N 105° 26’ 12.7” E). The dryer measures 8.0 m long by 6.0 m wide and 3.5 m high. The floor of the dryer is totally made of concrete and the structure is made of Aluminium tubes. The dryer uses PC sheets to cover the products inside, ensuring product safety when changing weather suddenly. The solar irradiance meter is placed on the roof of the drying house and measured by Kipp and Zonen pyranometers. In addition, thermocouples (type K) and a digital probe Bioblock thermohygrometer with an accuracy of ±3% were used to measure the air temperature and relative humidity of the ambient air in the dryer.

3. Methodology

In this research, the fluid inside the SGHD assumed a transient state, incompressible and turbulent. Thus, according to the Ansys Fluent Theory Guide [9], the solution for heat and mass transfer is the continuity, momentum, and energy equations as follow:

Continuity equation:
\[ \nabla ( \rho \vec{u} ) = 0 \]  

Momentum equation:
\[ \nabla ( \rho \vec{u} \vec{u} ) = -\nabla ( p ) + \nabla ( \tau ) + \rho \vec{g} \]  

Energy equation:
\[ \nabla ( \rho \vec{u} T ) = \nabla \left( \frac{k}{c_p} \nabla T \right) + S_h \]
where \( \vec{u} \) is the velocity vector, \( \rho \) – the density, \( p \) – the pressure, \( g \) – the gravity, \( \mu \) – the viscosity, \( H \) – the enthalpy, \( k \) – the thermal conductivity, \( C_p \) – the specific heat, \( S_h \) – a source term, \( T \) – the temperature, and \( \tau \) – the stress tensor defined.

This study used a solar load model to calculate radiation effects from the sun's rays that enter a computational domain. The equation for normal direct irradiation applying the Fair Weather Conditions Method is taken from the ASHRAE Handbook:

\[
E_{dn} = \frac{A}{e^{mpB}} \beta \tan \beta \tag{5}
\]

Where \( A \) is solar irradiation at air mass, \( B \) is Atmospheric extinction coefficient, and \( \beta \) is solar altitude (in degrees) above the horizontal. Based on hourly data on global and diffuse solar irradiance measured on a horizontal surface near a greenhouse scene with different conversion factors for ray (\( R_b \)), diffusion (\( R_d \)), and irradiance reflectance (\( R_r \)) is used to calculate the intensity of solar radiation (\( I_i \)) on each wall and roof of the greenhouse. The solar radiation intensity is calculated as below [10]:

\[
I_i = I_b(R_b) + I_d(R_d) + r(R_r)(I_b + I_d) \tag{6}
\]

4. Simulation

4.1. Geometry

The geometry of GHSD was built by Spaceclaim tool was present in Figure 1, consist two rectangles (1.0 m length and 0.2 m width) at front and three circles (0.25 m diameter) at backside which represents the input windows and fans ventilator exit, respectively.

![Figure 1: The geometry of GHSD](image)

4.2. Boundary Condition

Inside the SGHD, the airflow proposed is turbulent. Therefore, the standard \( \kappa-\varepsilon \) model was used because it is the most widely validated turbulence model in literature [5,6]. In the \( \kappa-\varepsilon \) model, \( \kappa \) is the turbulence kinetic energy and \( \varepsilon \) is the turbulent dissipation. Thus, the data of the operating conditions have been established, as shown in Table 1.

| The operating conditions | Governing Equations |
|--------------------------|---------------------|
| Solver                   | 3D simulation       |
|                          | Implicit formulation|
|                          | Absolute velocity formation |
|                          | Transient state     |
| Energy equation          | Activated           |
| Viscous model            | Realizable \( \kappa-\varepsilon \) model |
The CFD analysis requires boundary conditions, in particular with the surface bounding of the domain. For this study, the boundary conditions were defined as follows in Table 2.

| Boundary conditions | Material          | Parameters              | Parameters          |
|---------------------|-------------------|-------------------------|---------------------|
| Wall                | PC                | Thickness [m]           | 0.001               |
|                     |                   | Emissivity              | 0.9                 |
|                     |                   | Thermal conductivity [W/mK] | 0.2              |
| Concrete            |                   | Thickness [m]           | 0.2                 |
| Tray                | Aluminum          | Thickness [m]           | 0.001               |
| Inlet               | Moist air         | Temperature [K]         | 303.15              |
|                     |                   | Velocity [m/s]          | 0.5                 |
|                     |                   | Mass fraction           | 0.021               |
| Outlet              | Moist air         | Gauge pressure [Pa]     | 0                   |

5. Results and discussions

5.1. The sensitive mesh

The CFD was used for the analysis of the temperature and relative humidity distribution inside the SGHD. A mesh sensitivity analysis was conducted to find the relation of size and number of cells suitable for this analysis. The correct cell size will increase the accurately resolve every gradient that may occur in flows. Tetrahedral cells are more adaptive to a flow domain with a complicated boundary. However, a tetrahedron is not as accurate as a hexahedron with the same grid number. The grid number of a tetrahedral mesh is larger than that of a hexahedral mesh with the same cell dimensions. Compared with tetrahedral, hexahedral meshes can be aligned with the predominant direction of a flow, thereby decreasing numerical diffusion. The relation between different grids, sizes, and the number of cells in this research is shown in Table 3.

| Mesh type     | Abbreviation | Size of cell [m] | Number of cells |
|---------------|--------------|------------------|-----------------|
| Tetrahedral   | T01          | 0.1              | 905,709         |
|               | T005         | 0.05             | 7,179,729       |
| Hexahedral    | H01          | 0.1              | 132,597         |
|               | H005         | 0.05             | 993,111         |

The role of grid type was investigated by using hexahedral, tetrahedral as shown in Figure 2. For evaluating grid number, a mesh of at least 1 hundred thousand elements is necessary in order to describe dryer details that are important for simulating the temperature and relative humidity distribution. Because of limitations on our computing resources, the maximum cell number used was about 7 million.
In Figure 1, the grid distributions of hexahedral and tetrahedral mesh types had similar. The distribution with different size of cell is investigation defined the large mesh dimension used in the main flow region as the global mesh dimension.

5.2. Influence of number of cells on the simulated results
The modelling of internal conditions in solar dryers is the key factor to investigate the efficiency of dryer. The internal conditions of SGHD depended on not only the location but also the time. Beside of temperature, the velocity vector of the airflow is one of the essential factor effects on the properties of dryer. Figure 3 compares the simulated temperature profiles and the velocity vector of the air inside SGHD at 10 AM with tetrahedral meshes of different cell numbers from 905,709 cells to 7,179,729 cells. When the number of cells was increased, the predicted air temperature distributions agreed well with the measured distribution.

Figure 2: Mesh distribution of SGHD for different mesh grid types: (a) hexahedral mesh H01, (b) hexahedral mesh H005, (c) tetrahedral mesh T01 and (d) tetrahedral mesh T005
Figure 3: Temperature distribution and velocity of air inside SGHD at 10AM for different mesh grid size: (a) and (c): tetrahedral mesh T01, (b) and (d) tetrahedral mesh T005

From morning to afternoon, the roof and inside the dryer absorb the solar radiation and were heated due to greenhouse effect. This figure shows the strongly relation of solar irradiation through the polycarbonate wall on the distribution of the temperature. To investigate the effects of grids number on the temperature simulation, the average temperature and the maximum temperature of the air inside SGHD for different mesh grid size were conducted and show in Figure 4.

The simulation results implied the different grid numbers led to different temperature simulated results. The average temperature distribution results were very similar and the error value lest than 5%. However, the simulation results of maximum temperature inside the dryer were different from those with finer grids. Hence, a further increase in grid number had influence on the simulated temperature profiles

5.3. Influent of mesh type on the simulated results

The simulated temperature distributions and the temperature volume rendering of the air inside the SGHD using hexahedral mesh type with two size of cell is shown in Figure 5 and the comparation of the average temperature and the maximum temperature of the air inside SGHD using different mesh type is shown in Figure 6.
Figure 5: Temperature distribution and the temperature volume rendering of air inside SGHD at 10AM using hexahedral mesh type, (a) and (c): hexahedral mesh H01, (b) and (d): hexahedral mesh H005

Figure 6: Comparison of the average temperature profiles (a) and the maximum temperature profiles (b) computed using hexahedral mesh type T01 and tetrahedral mesh type H01

In this research, when the size of cell is similar, the number of cells by using tetrahedral mesh type was more than 7 times the number of cells by using hexahedral mesh type. In Figure 6 and Figure 7, the result of temperature distribution of air in the SGHD by using the hexahedral grid had the higher accuracy than the result which was used tetrahedral grid and at sufficiently high grid numbers, the effect of mesh type on the simulation results was small. In the Figure 6, the different value of average temperature profiles was not significant and the maximum air temperature of air in the SGHD of hexahedral mesh type was normally lower than the maximum air temperature of air in the SGHD of hexahedral mesh type.

Further, the influence of mesh type on the relative humidity of air inside the GHSD was investigated. The relative humidity of moist air inside the SGHD differs widely in space and depend on time. The results of simulation with various mesh types are illustrated in Figure 7.
Relative humidity decreases with time inside the dryer from sunrise to sunset. This was caused by decreasing relative humidity of the ambient air and increased water holding capacity of the drying air due to temperature increase. The comparison of the relative humidity simulation result using hexahedral mesh type and tetrahedral mesh type is present at Figure 8.

With the same cell size, the result of relative humidity simulation computed using hexahedral mesh type (T01) was very similar with the result using tetrahedral mesh type. The error value of relative humidity computed between hexahedral mesh type and tetrahedral mesh type was very small. The profile RH values could be interpreted clearly by the temperature distribution of moist air in the volume of GHSD in Figure 6. Relative humidity of air inside the dryer decreases from day to night but the relative humidity of the air inside the dryers was always lower than that of the ambient air. The computing time of experiments was strongly depending on the number of cells and the node numbers of the cells. In this research, the computing time was nearly proportional to the grid number and the hexahedral meshes take the longest computing time.

6. Conclusion
CFD simulation was able to simulate and predict the temperature and air flow distribution inside the GSHD for various possible operating condition. This study evaluated the performance of two mesh types combination with two size of cells for predicting airflow and temperature distributions in the GSHD. The result prove that the hexahedral and tetrahedral mesh type has the same result of air flow distribution inside the GSHD simulation. Therefore, increase the number of cells was the best method to improve the accuracy and efficiency of GSHD simulations

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