Prediction of temperature distribution in sericite mica drying with variable temperature and airflow condition

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Abstract. To develop new drying facilities, it was important to know the impact of every input parameter to the drying process. Using a real prototype to carry out the experiment required high cost and time consuming especially for large scale drying. CFD simulation approached was one of the solution. Previous study of drying simulation only focuses on the fix value of the input parameter. This paper presents the result of CFD simulation to predict the heat distribution in sericite mica drying with variable temperature and airflow condition. Variable temperature and airflow was used because the only heat source for the dryer was from the solar energy therefore it’s only available in the day time. The analysis was carried out for 24 hours of drying time. The simulation result shows that the temperature inside the sericite mica increase 8 to 10°C when the solar energy is available and it is still increasing about 4 to 7°C for 5 hours after the solar energy is absent. The result also shows that during the drying time the temperature of sericite mica that is closer to the heat source was higher compared to the one that is further away with the maximum difference of 3.8°C.

1. Introduction
Sericite mica is an inert and stable mineral belongs to mica group. It has a sheet or plate like structure with excellent smoothness. The particle size average is 8–9 µm. Sericite mica was used widely in many industries such as cosmetic industry, plastics industry and rubber industry. Currently in the production of sericite mica it needs to be dry to facilitate the handling process and to reduce the transportation cost [1]. Drying process was done using dryer which used electricity or fuel that involve high costs and faced the issue of energy source depletion. For the last four decades, many researchers have successfully developed solar dryer as an alternative dryer for many commodities [2]. Compare to conventional open sun drying, solar dryers produce higher temperatures, lower relative humidity, lower product moisture content and reduced spoilage during the drying process. In addition, they take less space and time, and they are inexpensive compared to artificial mechanical and electrical drying methods. Low capital and operating costs are the primary advantages of solar dryers, as well as the fact that they require little expertise to operate [3]. As far as the authors’ knowledge, in the mineral processing industry, there is no report or study on the possibility of using solar dryer. In the development process of solar dryer for sericite mica, especially for large scale it was very important to make sure uniform drying rate throughout the drying chamber. Understanding of the drying process in detail is necessary for the process design optimizations in terms of preserving the quality of the
product and energy utilization. Typically full scale design and experiment was used to see the effect of the input parameter during the drying process. This is sometimes not feasible for a large scale drying as it involves high cost and time consuming. In a recent paper by Mujumdar and Wu [4] the authors emphasized the need for cost-effective solutions that can push innovation and creativity in drying equipment's. In the paper they suggest that a computational fluid dynamics (CFD) approach can be one of the solutions. CFD has been proven as an effective computational tool for predicting the flow behaviour and mass transfer phenomena occurring in many processes [5]. CFD based methods are gaining acceptance as a tool to evaluate and design commercial dryers for the many industries [6]. Study of previous researcher [7-9] proved that the performance of new dryer designs can be predicted by simulation work. These studies also proved that the CFD simulation result is comparable with actual conditions.

In the proposed solar dryer, it used only evacuated tube to supply heat to the dryer without the auxiliary heater. Therefore the heat will only be supplied to the system during day time when there is a solar energy from the sun. This was designed to minimize the cost of the dryer. Many past research on CFD simulation of heat distribution in the drying process involved the fix value of input parameter [8-12]. In this study variable input parameter in terms of heat source and air flow was used to represent the actual drying condition. Transient analysis was used to see the effect of the supply heat on sericite mica with time changes. The objective of this study is to predict the heat distribution inside the sericite mica with the changes in the heat source throughout the drying process for 24hours. In the drying process heat distribution was very important not only as its effect the drying rate, but it’s also having an impact on the quality of the dried product [13].

2. Methods and Simulation

2.1. Design of the dryer system
The dryer system for sericite mica consist of evacuated tubes, heat exchanger, blower and drying chamber (figure 1). The heat exchanger and blower was placed at one end of the drying chamber. There is an opening at the other end of the drying chamber to remove the evaporated moisture from the product to the environment. The evacuated tube will absorb heat from the sun and heated the water that are flowing in the piping system. The blower and heat exchanger was design to be switched on when the temperature of the water inside the pipe achieved 70°C. The blower will produce an air velocity of 2.5ms⁻¹ inside the drying chamber. Both the heat exchanger and blower will turn off once the temperature fall below 65°C. The drying chamber size was 1.2m height x 1.7m width x 17m long. The drying chamber was made of polycarbonate sheet. 10 pallets of sericite mica were placed inside the drying chamber where each pallet consists of 4 stack of sericite mica arrange 14 pieces per stack. The sericite mica have a round shape with approximately 0.63 m diameter and 0.05 m thickness.

![Figure 1. Schematic diagram of the sericite mica solar dryer.](image)
2.2. Basic governing equation.
The governing equations of fluid flow and heat transfer was considered as mathematical formulations
of the conservation laws of fluid mechanics and are referred to as the Navier-Stokes equations [5]. By
enforcing these conservation laws over discrete spatial volumes in a fluid domain, it is possible to
achieve a systematic account of the changes in mass, momentum and energy as the flow crosses the
volume boundaries. In Ansys Fluent the resulting equations can be written as below [14]

Continuity equation:
\[
\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{v}) = S_M
\]  
(1)

Momentum equation:
\[
\frac{\partial}{\partial t} (\rho \vec{v}) + \nabla \cdot (\rho \vec{v} \vec{v}) = -\nabla p + \nabla \cdot (\tau) + \rho \vec{g} + \vec{F}
\]  
(2)

Energy equation:
\[
\frac{\partial}{\partial t} (\rho E) + \nabla \cdot (\rho \vec{v} (\rho E + p)) = \nabla \cdot [k_{eff} \nabla T - \Sigma_j h_j \vec{j} + (\vec{e}_{eff} \cdot \vec{v})] + S_h
\]  
(3)

The first three terms on the right-hand side of equation (3) represent an energy transfer due to
conduction, species diffusion, and viscous dissipation, respectively. The turbulent kinetic energy, k,
and its rate of dissipation, \( \varepsilon \), are obtained from the following transport equations:

\[
\frac{\partial}{\partial t} (\rho k) + \frac{\partial}{\partial x_j} (\rho k \nu_j) = \frac{\partial}{\partial x_j} \left[ \left( \mu + \frac{\mu_t}{\sigma_k} \right) \frac{\partial k}{\partial x_j} \right] G_k + G_b - \rho \varepsilon - \gamma M - S_k
\]  
(4)

\[
\frac{\partial}{\partial t} (\rho \varepsilon) + \frac{\partial}{\partial x_j} (\rho \varepsilon u_j) = \frac{\partial}{\partial x_j} \left[ \left( \mu + \frac{\mu_t}{\sigma_\varepsilon} \right) \frac{\partial \varepsilon}{\partial x_j} \right] + C_1 \varepsilon \frac{\varepsilon}{k} (G_k + C_{3\varepsilon} G_b) - C_2 \varepsilon \rho \frac{\varepsilon^2}{k} + S_\varepsilon
\]  
(5)

2.3. Simulation Detail
In this study, commercial CFD software Ansys Fluent v. 14 was used. Ansys Fluent used numerical
finite volume methods to solve the equation. Unstructured 3D tetrahedral mesh was used to mesh the
solid geometry. The solid geometry of the model is as shown in figure 2. The inlet is where the heat
exchanger and blower position and the outlet is at the opening of the drying chamber. A special
function inside Ansys Fluent which is UDF (user define function) was used to specify the boundary
condition at the inlet because the temperature and air velocity at the inlet varied according to the water
temperature inside the pipe. Transient analysis was used in the study. The initial condition of the air
and sericite mica temperature used for the simulation was 30°C. To simplify the analysis, for 24 hours
drying time the variation of the temperature and air flow was divided into three stages as listed in the
table 1. Stage 1 represent the active drying period condition where the heat source from the sun is
available, stage 2 start when the sun is set and no heat source available until midnight and stage 3 start
from midnight until early morning before the sun rise. In stage 1 only 5 hours was taken into
consideration although the actual time where the sun is available is longer because it’s the average
time where the heat from the sun is enough to heat the water inside the tube to 70°C.
Table 1. Stages in drying time.

| Stage   | Drying hours | Inlet Temperature (°C) | Air speed (ms⁻¹) |
|---------|--------------|-------------------------|------------------|
| 1       | 1st to 5th   | 70                      | 2.5              |
| 2       | 6th to 15th  | 40                      | 0                |
| 3       | 15th to 24th | 30                      | 0                |

To simplify the solar radiation effect on the drying chamber, the boundary condition of the top surface of the drying chamber was assumed to receive an average heat flux of 800 w/m² [15]. This is applied only at stage 1. The drying chamber and the arrangement of the sericite mica was in symmetrical. Therefore, to save the computing time and simplify the analysis only half of the structure was modelled and symmetry boundary condition was used to represent the other half of the structure. The symmetrical plane is as shown in figure 2.

![Figure 2. Solid geometry of the simulation](image)

Other set-up of the simulation is as shown in table 2 below:

| Parameter | Value/input/setting |
|-----------|---------------------|
| Outlet    | Pressure = 0        |
| Side wall | No slip             |
| Bottom wall | No heat loss       |
| Analysis type | Transient analysis |
| Flow field | Realize k-ε model   |

The material properties used in the analysis as shown in table 3 below:

| Properties                  | Sericite mica | Pallet (wood) | Polycarbonate |
|-----------------------------|---------------|---------------|---------------|
| Density (kg/m³)             | 2820          | 700           | 1190          |
| Thermal conductivity (W/m-k) | 0.35          | 0.173         | 0.2           |
| Specific heat (J/kg-k)      | 210           | 2310          | 1100          |

3. Results and Discussion

The simulation was carried out and the heat distribution inside the drying chamber was analysed. The temperature distribution at the centre of the sericite mica vertically and horizontally at the end of every stage is as shown in figure 3, figure 4 and figure 5 respectively.

As shown in figure 3, when there is a heat source from the inlet of 70°C and heat flux from the roof of the structure the temperature inside the sericite mica increase significantly. At this stage the blower is switch on to create an air flow of 2.5ms⁻¹ flowing from the inlet towards the outlet. This create a
uniform heat distribution inside the drying chamber. At the end of stage 2 (figure 4) when the blower is turn off and the heat source was gone as the result the temperature inside the sericite mica was decreasing. At stage 3 (figure 5) the temperature inside the sericite mica is further reduce as the temperature inside the dryer is lower compare to stage 2. To see in detail of the temperature variation inside the sericite mica due to difference in stage condition, a temperature at 5 points inside the sericite mica was plotted versus the drying time. The 5 point location is as shown in figure 6.

![Figure 3](image1.png)
**Figure 3.** Temperature profile at the centre of the sericite mica (a) vertically and (b) horizontally at the end of stage 1.

![Figure 4](image2.png)
**Figure 4.** Temperature profile at the centre of the sericite mica (a) vertically and (b) horizontally at the end of stage 2.

![Figure 5](image3.png)
**Figure 5.** Temperature profile at the centre of the sericite mica (a) vertically and (b) horizontally at the end of stage 3.

![Figure 6](image4.png)
**Figure 6.** Location of the 5 points inside the sericite mica.

The temperature variation at every point for every hour of drying time is as shown in figure 7. From figure 7 it shows that when the heat source is applied, the temperature at point 1 which is the closest to the inlet increase up to 45.3°C and decrease to 37.3°C at the end of the drying time. The temperature increment of the sericite mica is decreasing in proportion with the distance from the inlet. Therefor point 5 is having the lowest temperature increment, which is maximum at 41.4°C and decrease to 33.3°C at the end of drying time. The temperature variation between point 1 and point 5 was 3.8°C. When the heat source is gone at stage 2 and 3, the temperature drop at point 1 and point 5 is about 8°C. However, for sericite mica located at the centre of the dryer (Point 3, 4 and 5) the temperature drop is smaller, which is about 7°C, this is due to the heat was stored much longer at the centre of the drying chamber compare to the area near the inlet and outlet.
As shown in figure 7, although after hour 5 where the heat source was removed, the temperature inside the sericite mica was keep increasing about 6°C until hour 12 for point 1 to point 4. This is due to the heat that was stored inside the drying chamber and the low thermal conductivity properties of sericite mica and polycarbonate that slowing down the heat loss process to the environment. For point 5 the increment of the temperature of sericite mica after the heat source is gone is lower which is only 3°C because it was located near the opening of the outlet and expose to environment condition which is having lower temperature.

4. Conclusion
From this study it can be concluded that CFD simulation was able to predict the temperature distribution inside the sericite mica in a condition where the temperature and air flow is varied during the drying time. The simulation results show that the temperature inside the sericite mica is increasing when the heat source is available. Even after the heat source was gone the temperature of the sericite keep increasing for a few hours before its start to drop. The simulation result also shown that there is a variation in the temperature of the sericite mica depending on the location of the sericite mica from the heat source. The simulation result shows the trend that when the drying process continued the next day the starting temperature of the sericite mica will be higher and higher and this will indirectly reduce the total drying time.

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Nomenclature:

\( \nabla \)  Partial derivative of a quantity with respect to all directions in the chosen coordinate system.

\( S_M \)  Mass added to the continuous phase from the dispersed second phase

\( p \)  Static pressure

\( \tilde{\tau} \)  Stress tensor

\( \rho \)  Density of fluid

\( \vec{v} \)  Velocity vector

\( u \)  Dynamic viscosity

\( \vec{g} \)  Gravitational body force

\( \vec{F} \)  External body forces

\( k_{\text{eff}} \)  Effective conductivity

\( \vec{J}_j \)  Is the diffusion flux of species \( j \)

\( S_h \)  Includes the heat of chemical reaction, and any other volumetric heat sources

\( k \)  Turbulent kinetic energy

\( \varepsilon \)  Rate of dissipation

\( G_k \)  Generation of turbulence kinetic energy due to the mean velocity gradients

\( G_B \)  Generation of turbulence kinetic energy due to buoyancy

\( C_{1\varepsilon}, C_{2\varepsilon}, C_{3\varepsilon} \)  Constant used in turbulent model

\( \sigma_k, \sigma_\varepsilon \)  Turbulent Prandtl numbers for \( k \) and \( \varepsilon \) respectively.

\( S_k, S_\varepsilon \)  User-defined source terms.

\( \mu \)  Molecular viscosity

\( \mu_t \)  Turbulent (or eddy) viscosity