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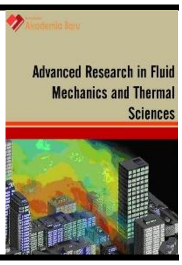

Analysis and Simulation of Sericite Mica Drying

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ABSTRACT

Drying is a process that requires a high amount of energy. In most situations drying proses was a major contributor to the production costs. Study by many researchers have proven that computational fluid dynamics (CFD) simulation is a cost effective and efficient tools to analyse and optimise the drying process. The objectives of this study are to analyse the sericite mica drying process and develop a CFD simulation model to simulate the drying behaviour of sericite mica. Physical experiment was carried out to validate the simulation results at 50, 60 and 70°C drying temperature. The experimental results show that higher drying rate was achieved with higher temperature. The result of simulated moisture content was compared with the experimental data and the root mean square error (RMS_{error}) and normalized root mean square error ($NRMS_{error}$) was calculated. The results for both RMS_{error} and $NRMS_{error}$ were less than 5%, which shows reasonable accuracy.

1. Introduction

Drying is a thermodynamics process where water is loss from the product by the evaporation. It is a complex process and consume high amount of energy. Research by Defraeye [1] stated that in an industrialized country, drying operation uses approximately 10% to 25% of the energy consumed in industrial processes. The optimization of existing drying technologies or the development of new technologies is focused on two aspects which is the reduction of energy expenditure and the time required to dry the product while maintaining the quality. To achieve this, deeper analysis of the drying process must be studied, including the distribution of temperature and moisture in the material and the various mechanisms that describe the mass and heat transfer inside the product during the drying process.

Experimental studies are costly and time-consuming. Furthermore, numerous precise instruments need to be utilized to obtain detailed information. With the rapid development of high-speed computers, computational fluid dynamics (CFD) has become an accessible and powerful tool for modeling a complex engineering problem that include fluid flow. Computer simulations make it

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possible to look inside the product and access a large amount of data with acceptable precision. Several advantages of the computer simulation compared to physical experimental works carried out in laboratories and pilot plants, includes possibility to see gradients of moisture and temperature inside the solid at various instants of time. Effect of the process to small changes of the process parameters can be analyze immediately thus eliminating uncertainties of experimental tests. Computer simulation also makes it possible the design and optimization of dryers or drying processes without necessarily having to construct a prototype, thus, reducing costs and there are no limitation on the drying conditions or safety concerns. Reduction of scale is not necessary as study can be done in the real scale. Furthermore, the implementation of computer simulation eliminates the need for larger laboratory space to perform the tests thus leading to financial savings [2].

Study by many previous researchers in the development of the CFD model to simulate the porous media drying, have proved that its ability to simulate the drying process with a good agreement with the actual experiment. Study by previous researchers in the development of CFD model and simulation in the drying of food and agriculture product have successfully proven the ability of the developed model to represent the actual condition in drying process especially the moisture content in relation to affecting parameter such as the temperature, humidity and air flow of drying air [3-6]. In ceramic and clay drying process, for example, Francisca *et al.,* [7] have successfully developed a CFD model for drying of hollow bricks in an industrial tunnel dryer. The developed model was successfully produce moisture content, temperature and humidity results which have a good correlation with numerical and physical experimental results. Ramzi *et al.,* [8] also have successfully developed 3-dimensional CFD model to simulate unsteady couple of heat and mass transfer during the convective facing bricks drying. Besides the ability of the model to produce results closed to actual condition it’s also successfully simulate the appearance and the evolution of the different phases of convective drying throughout the drying process.

The aim of the present research is to analyze sericite mica drying process and developed a CFD model of the process. The motivation for developing the model was originated from report by Mujumdar and Wu [9] and Norton and Da-Wen [10] which emphasized that the CFD approach is the cost-effective solutions that can push innovation and creativity in drying equipment design and development. Sericite mica is a very inert and stable material which has a particle size of 8-9 µm [11] and these characters causes the drying process requires an enormous amount of energy especially in large scale production. Therefore, by developing the accurate CFD model, the cost effective and energy efficient drying process able to be developed faster and with much lower cost.

2. Methodology

2.1 Drying Experiment

Lab scale drying experiment of sericite mica was performed to validate the CFD simulation in predicting the moisture content of the sericite mica. Sericite mica used in the experiment was obtained directly from the production line in the form of a cylinder with a diameter of 60 mm and thickness of 5 mm. Drying experiment was carried out using the laboratory thermal convective dryer (LTCD) unit model *VO200cool* for a temperature of 50, 60 and 70^{o}C. A total of 6 samples was prepared for each temperature. Product weight was measured using *AND Weighing GX-2000* precision scale in the interval of 1 hour. Average values of the moisture content of all the samples were used for drawing the drying curves. Initial moisture content of the samples was determined by using moisture determination balance *Kett FD-260*. The moisture content of the sample is calculated using Eq. (1).

$$M_{wb} = \frac{W_i - W_d}{W_o} \quad (1)$$

where, W_i, W_d and W_o are the current mass, dry mass and initial mass of the sample respectively.

Moisture ratio (MR) during drying was calculated using Eq. (2) [12], where M, Me, and Mo represent actual, equilibrium, and initial moisture content, respectively.

$$MR = \frac{M - M_e}{M_o - M_e} \tag{2}$$

The drying rate of sericite mica can be calculated by Eq. (3) [12].

$$Drying\ rate, \frac{\partial MR}{\partial t} = \frac{MR_n - MR_{n-1}}{t_n - t_{n-1}} \tag{3}$$

2.2 Mathematical Modelling

Commercial CFD software ANSYS ver. 14 was used in this study. Ansys Fluent used numerical finite volume methods to solve the 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. 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 were written as below [13].

Continuity equation for drying air,

$$\frac{\partial \rho_a}{\partial t} + \nabla.(\rho_a \vec{u}) = 0 \tag{4}$$

where ρ_a is the density and $\vec{u}$ is the velocity.
The momentum conservation equation for drying air,

$$\frac{\partial}{\partial t}(\rho_a \vec{u}) + \nabla.(\rho_a \vec{u}\vec{u}) = -\nabla p + \nabla.(\bar{\bar{\tau}}) + \rho_a \vec{g} + \overrightarrow{S_m} \tag{5}$$

Energy equation for the heat transfer inside the porous zone,

$$\frac{\partial}{\partial t}(\rho_a \varepsilon I_a) + \rho_s(1-\varepsilon)I_s + \nabla.(\rho_a \vec{u} I_a) = \left[k_{eff}\nabla^2 T\right] + S_h \tag{6}$$

where ε is the bed porosity and k_{eff} is the effective thermal conductivity of the material and calculated as

$$k_{eff} = \varepsilon k_a + (1-\varepsilon)k_s \tag{7}$$

The enthalpy of air and solid were defined as

$$I_a = \left(C_{pa} + wC_{pv}\right)T \tag{8}$$
$$I_s = C_{ps}T \tag{9}$$

where C_{pa}, C_{pv} and C_{ps} are specific heat capacity of air, vapour and moist solid respectively. The energy source term due to the effect of evaporative cooling was defined as

$$S_h = (1-\varepsilon)\rho \frac{\partial MR}{\partial t} h_{fg} \tag{10}$$

where, h_{fg} is the latent heat vaporization of water.
User define scalar (UDS) was used to simulate the distribution of moisture inside the porous bed. The equation used to predict the moisture transport is

$$\frac{\partial(\rho_a w)}{\partial t} + \nabla.(\rho \vec{u} w) = \nabla.\left(\rho_a D_{eff} \nabla w\right) + S_w \tag{11}$$

where w the absolute humidity of the drying is air, D_{eff} is the effective moisture diffusion coefficient and S_w is the moisture source due to the moisture evaporation from the porous media and defined as

$$S_w = -(1-\varepsilon)\rho_s \frac{\partial MR}{\partial t} \tag{12}$$

where $\frac{\partial MR}{\partial t}$ is the drying rate of the sericite mica.

In the simulation process, a User Define Function (UDF) written in C language was developed to expand the ability of Fluent software in the current study. The UDF was used to update and calculate the moisture content value in every time-step of the simulation and also to calculate the moisture and heat source terms. The 3-dimensional geometry and mesh used in the simulation was as shown in Figure 1 and Figure 2. Details regarding the CFD simulation setting are as listed in Table 1.

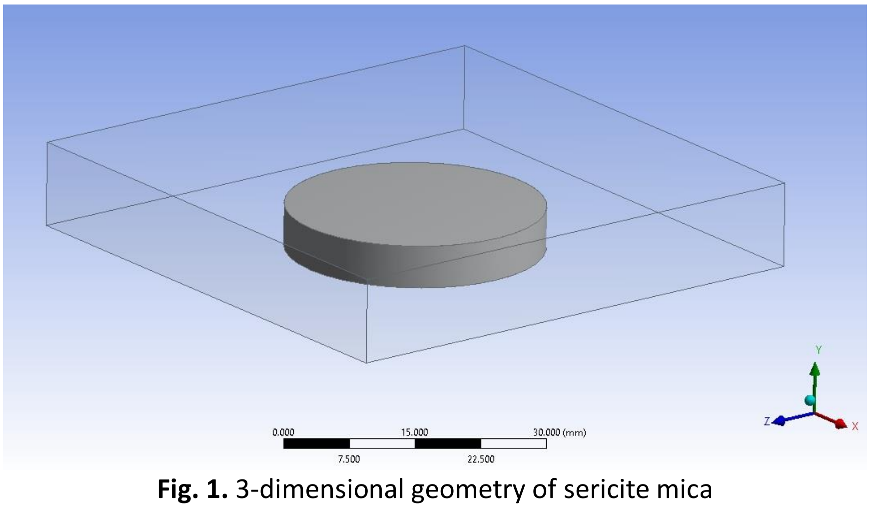

Fig. 1. 3-dimensional geometry of sericite mica

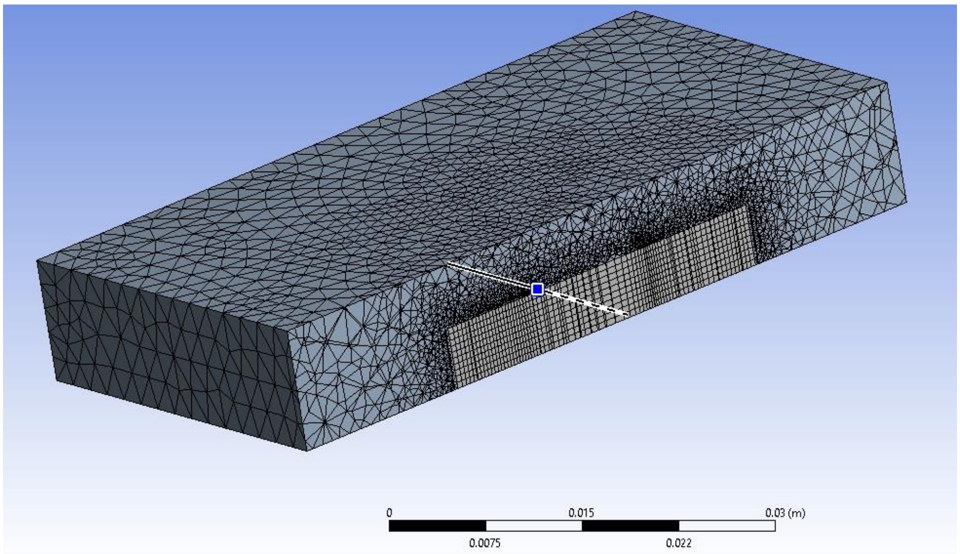

Fig. 2. Mesh of the geometry

Table 1
CFD simulation setting

Description	Value / Methods
Material	
Density (kg/m^3)	2820
Thermal conductivity (W/m-k)	0.35
Specific heat (J/kg-k)	880
Geometry	
Sericite mica height	5 mm
Sericite mica diameter	60 mm
Envelope dimension	100 x 100 x 10 mm
Operating, Boundary and initial condition	
Analysis type	Transient analysis
Operating pressure	101325
Gravitational acceleration	9.81
Inlet boundary condition	Velocity inlet
Wall boundary condition	Adiabatic
Viscous resistance of porous zone	5.9 x 10^{-13}
Inertial resistance of porous zone	5.6 x 10^{5}
Void fraction of sericite mica	0.2
Turbulence model	Standard *k-ε* model
Initial moisture content	0.54
Initial temperature of sericite mica	299 K
Reference ambient temperature	302 K

3. Results and Discussions

3.1 Experimental Results

The graph of moisture content versus the drying time from the experiment was plotted as shown in Figure 4. Figure 4 shows that sericite mica dried at higher temperature takes less time to be dried compare to sericite mica that is dried at lower temperatures. The moisture content of the sericite mica reduced from 54 % to almost 0 % in 7, 6 and 3 hours for 50, 60 and 70^{o}C drying temperature respectively. Figure 5 shows the drying rate for all different temperatures used in the experiment.

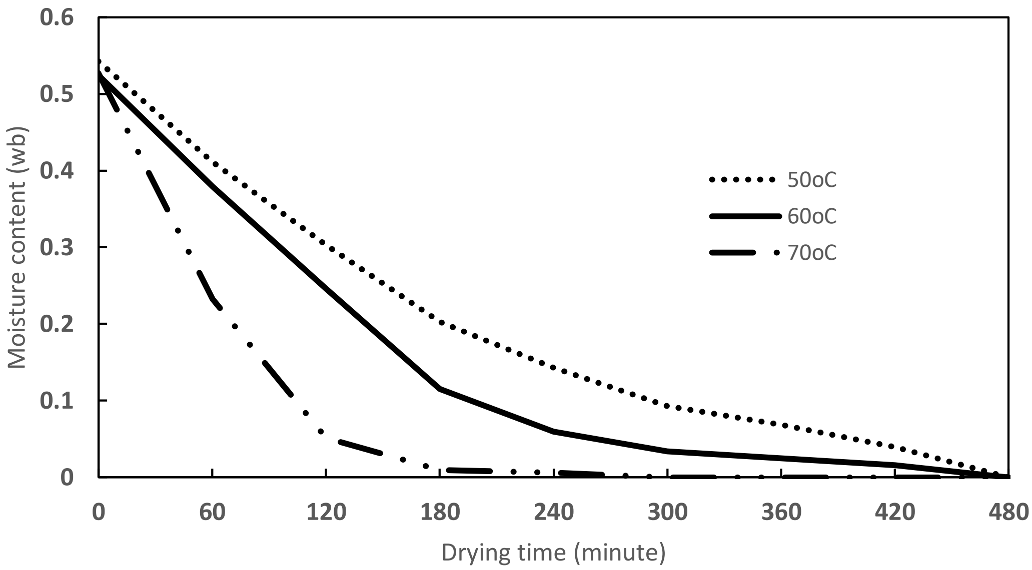

Fig. 4. Moisture content vs drying time for different temperature from experimental data

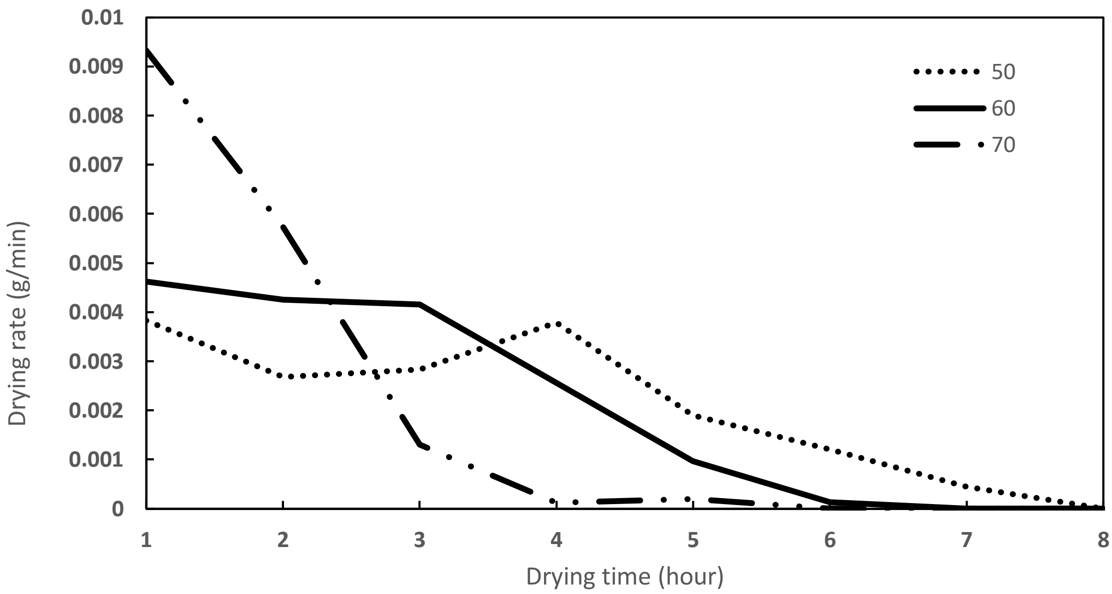

Fig. 5. Drying rate vs drying time for different temperature

During the first 2 hours of the drying process the drying rate for 70°C is higher followed by 60°C and 50°C. However, subsequently the reverse situation occurred because sample that's dried at higher temperature reached the falling period faster compare to sample dried with lower temperature. This is clearly shown after 4 hours of drying. At this hour, the sample that are dried at 70°C have already entered the falling period where the drying rate is lower as it involved the migration of the moisture from the inner part of the product to the surface to be evaporated. While for samples that are dried at 50°C the drying rate is higher as its still in the constant rate period where the moisture, which was evaporated was at the surface of the product.

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3.2 Simulation Results

Figure 6, 7 and 8 shows the result of moisture content in the sericite mica versus the drying time for CFD simulation compare with the experimental data at temperature 50, 60 and 70°C respectively.

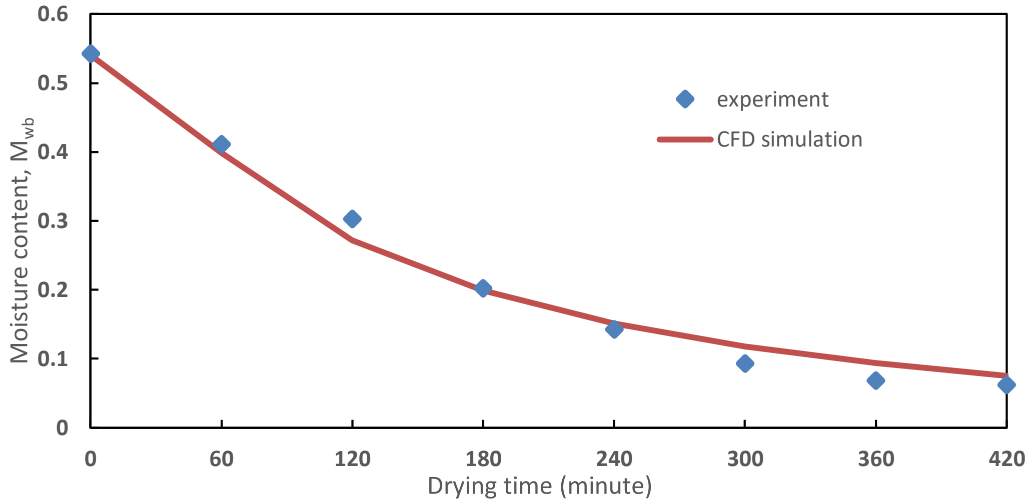


Fig. 6. Moisture content of sericite mica vs drying time at temperature 50°C

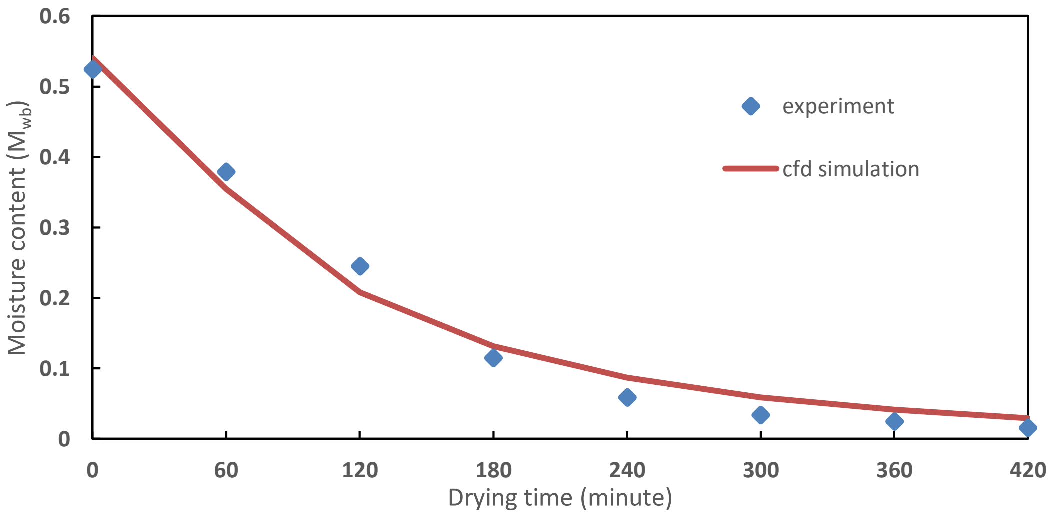


Fig. 7. Moisture content of sericite mica vs drying time at temperature 60°C

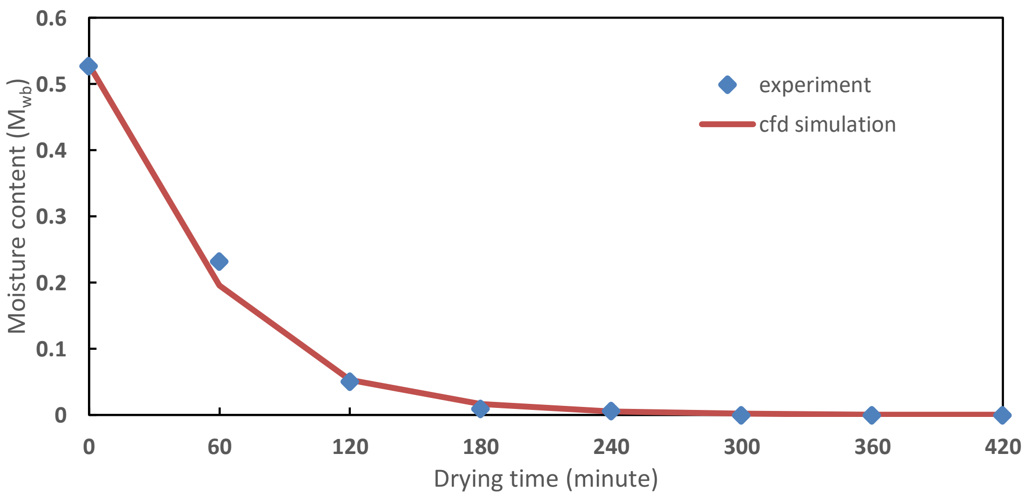


Fig. 8. Moisture content of sericite mica vs drying time at temperature 70°C

Normalize root mean square error ($NRMS_{error}$) was used to validate the CFD simulation results with the experimental data. $NRMS_{error}$ was calculated using Eq. (13).

$$NRMS_{error} = \frac{RMS_{error}}{y_{max} - y_{min}} \tag{13}$$

$$RMS_{error} = \sqrt{\frac{\sum_{i=1}^{n} \hat{y}_i - y_i}{n}} \tag{14}$$

where,

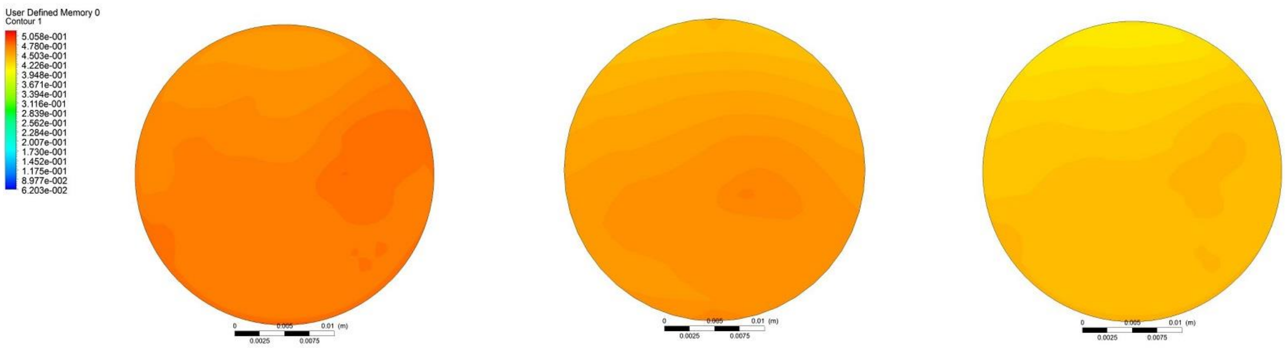
$\hat{y}_i$ = experimental result at time i
y_i = simulation result at time i
n = number of data
y_{max} = maximum data from simulation
y_{min} = minimum data from simulation

From Table 2, it shows that the value for RMS_{error} and $NRMS_{error}$ for 50, 60 and 70°C were below 0.05 (5%). Therefore, it can be concluded that the developed CFD model was able to represent the actual experimental result with a good agreement.

Table 2
RMS_{error} and $NRMS_{error}$ value between experimental and simulated results for drying at 50, 60 and 70°C

Temperature (°C)	RMS_{error}	$NRMS_{error}$
50	0.0182	0.0392
60	0.0233	0.0456
70	0.0132	0.0249

Figure 9 and 10 shows the moisture content contour distribution inside the sericite mica after 1 hour and 7 hours of drying respectively. The figures clearly show that the area near the heat source dried faster compared to the opposite. This is due to the condition where the temperature in this area increase faster compared to the one that was further away. The figure also shows that for the same drying interval, moisture content value was lower at higher temperature compared to lower temperature. Figure 11 show the air flow distribution during the simulation process.



(a) (b) (c)

Fig. 9. Contour of moisture content distribution inside sericite mica after 1 hour of drying time for (a) 50°C (b) 60°C and (c) 70°C

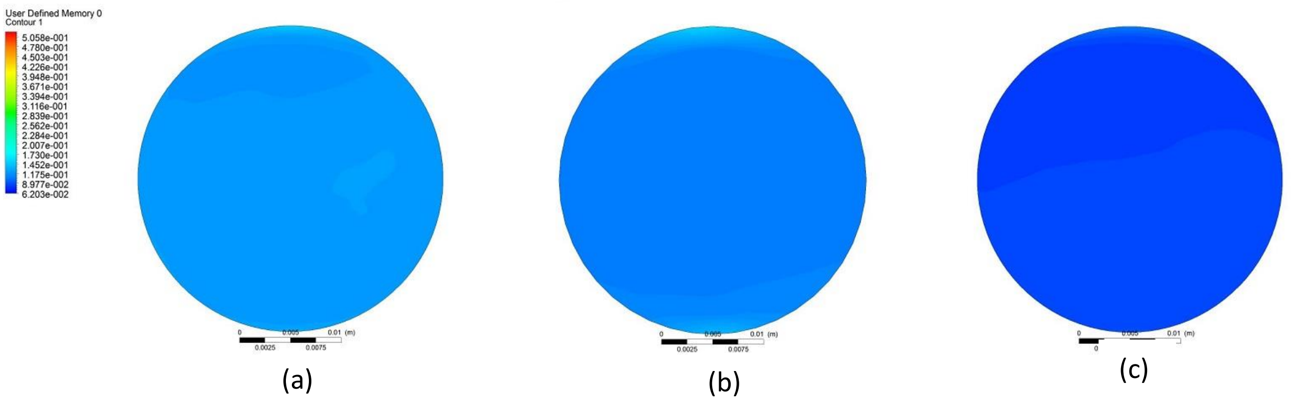


Fig. 10. Contour of moisture content distribution inside sericite mica after 7 hours of drying time for (a) 50^{o}C (b) 60^{o}C and (c) 70^{o}C

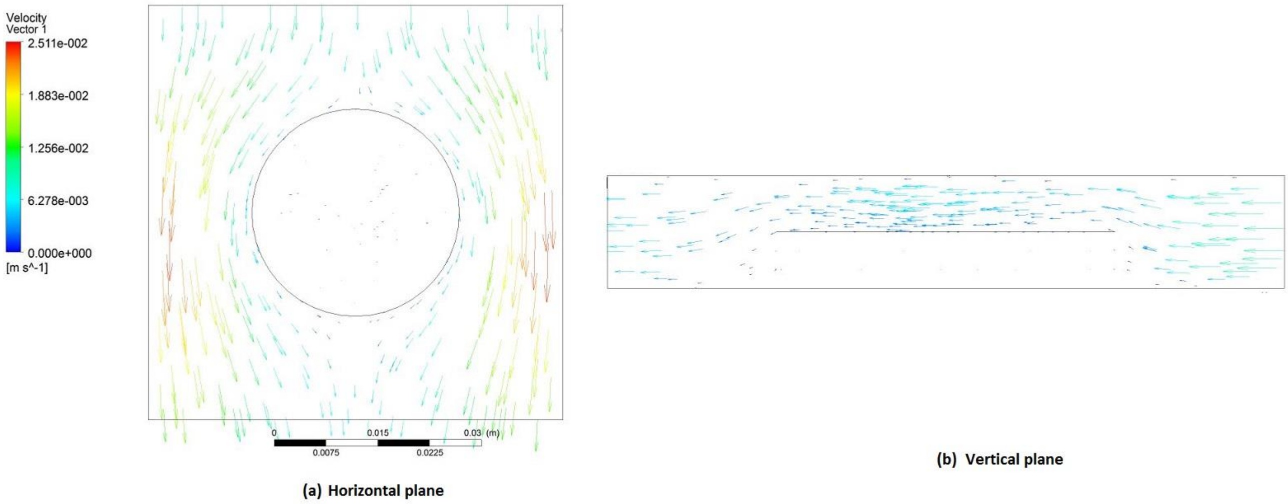


Fig. 11. Airflow distribution at the (a) horizontal and (b) vertical plane.

4. Conclusions

From the experimental results of sericite mica drying it can be concluded that higher drying temperature produce higher drying rate. A CFD model for sericite mica was successfully developed and it was validated by comparing the results with the experimental data. The model was found to be reliable in predicting the average moisture content of sericite mica in convective drying. CFD simulation results also able to visualize the pattern of moisture content distribution inside the drying product which is not possible with physical experimental results. By the development of the validated CFD simulation model, it can be used not only in the optimization of sericite mica drying, but also in the design and development of the suitable dryer without the need to carry out the physical experimental. This will save time and cost, especially for a large-scale application.

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References
[1] Defraeye, Thijs. "Advanced computational modelling for drying processes–A review." *Applied Energy* 131 (2014): 323-344.

[2] Araújo, Morgana Vasconcellos, J. M. P. Q. Delgado, and A. G. Barbosa de Lima. "On the use of cfd in thermal analysis of industrial hollow ceramic brick." In *Diffusion Foundations*, vol. 10, pp. 70-82. Trans Tech Publications, 2016.
[3] Khan, Furqan Ahmad, and Anthony Gerald Straatman. "A conjugate fluid-porous approach to convective heat and mass transfer with application to produce drying." *Journal of Food Engineering* 179 (2016): 55-67.
[4] Ranjbaran, Mohsen, Bagher Emadi, and Dariush Zare. "CFD simulation of deep-bed paddy drying process and performance." *Drying technology* 32, no. 8 (2014): 919-934.
[5] Ranjbaran, M., and D. Zare. "CFD modeling of microwave-assisted fluidized bed drying of moist particles using two-fluid model." *Drying Technology* 30, no. 4 (2012): 362-376.
[6] Sanghi, Achint, RP Kingsly Ambrose, and Dirk Maier. "CFD simulation of corn drying in a natural convection solar dryer." *Drying technology* 36, no. 7 (2018): 859-870.
[7] Tavares, F., S. Neto, E. Barbosa, A. Lima, and C. Silva. "Drying of ceramic hollow bricks in an industrial tunnel dryer: A finite volume analysis." *The International Journal of Multiphysics* 8, no. 3 (2016).
[8] Rzig, Ramzi, Nidhal Ben Khedher, and Sassi Ben Nasrallah. "THREE-DIMENSIONAL SIMULATION OF MASS AND HEAT TRANSFER IN DRYING UNSATURATED POROUS MEDIUM." *Heat Transfer Research* 48, no. 11 (2017).
[9] Mujumdar, Arun S., and Wu Zhonghua. "Thermal drying technologies—Cost-effective innovation aided by mathematical modeling approach." *Drying Technology* 26, no. 1 (2007): 145-153.
[10] Norton, Tomás, and Da-Wen Sun. "Computational fluid dynamics (CFD)–an effective and efficient design and analysis tool for the food industry: a review." *Trends in Food Science & Technology* 17, no. 11 (2006): 600-620.
[11] Noh, A. Mohd, Sohif Mat, M. H. Roslan, and E. Salleh. "Prediction of temperature distribution in sericite mica drying with variable temperature and airflow condition." In *IOP Conference Series: Materials Science and Engineering*, vol. 210, no. 1, p. 012059. IOP Publishing, 2017.
[12] Angelopoulos, Panagiotis M., Efthymios Balomenos, and Maria Taxiarchou. "Thin-layer modeling and determination of effective moisture diffusivity and activation energy for drying of red mud from filter presses." *Journal of Sustainable Metallurgy*2, no. 4 (2016): 344-352.
[13] ANSYS Fluent Theory Guide
[14] Ankush Shankar Pujari, C.H. Bhosale, M.M.Wagh, N.N. Shinde. "Effect of Temperature on Drying Rate of Various Types of Bricks." *International Research Journal of Engineering and Technology (IRJET)*3, no.5 (2016): 2793-2795.