Journal of Engineering in Industrial Research

2022, Volume 3, Issue 3

Original Article: Modeling of Calcium Carbonate Drying Process

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Citation A. Ahmadpour*, **Modeling of Calcium Carbonate Drying Process.** *J. Eng. Indu. Res.* 2022; 3(3):182-188.

https://doi.org/10.22034/JEIRES.2022.3.1

Article info:
Received: 08 February 2022
Accepted: 14 April 2022
Available Online:
ID: JEIRES-2202-1066
Checked for Plagiarism: Yes
Peer Reviewers Approved by:
Dr. Amir Samimi
Editor who Approved Publication:
Professor Dr. Mohammad Haghighi

Keywords:
Simulation; Drying process; Calcium carbonate; Spray dryer

ABSTRACT

Calcium carbonate is one of the most essential minerals with multiple applications in diverse food, pharmaceutical, chemical, plastic, and paper industries generated by the press, mangle, deposition, and classification. In the simulation process mentioned in this research study, a mathematical model was provided to obtain dryer yield information. According to different methods of preparation and purification of this material, spray dryers are at the end of the process as dry goods market or required properties. For this reason, the first Kinetic of the material drying obtained through the experiment and the momentum equations of suspended particles in the air, particle path differential equations in three dimensions, Reynolds number, heat, and mass transfer coefficients and then calculate the mass and energy balance for presenting a mathematical model has combined, for discover the accuracy of the model, the results compared with practical experiments. A concurrent spray dryer used in the laboratory and a computer programming language (MATLAB) were presented to compare the results of its execution with the experimental results to assess the software's accuracy.

Introduction

Various drying processes are in the industry and according to various drying methods required time for drying are a few seconds to a few days. The benefits of using a dryer machine are the following:

1-Prevent materials corruption

2-Reduce materials transportation and storage costs

Today, spray systems are used widely. Produced materials from this method are egg powder, coffee powder, milk, PVC, antibiotics, ceramic, and phosphate fertilizers. At the spray dryer, a liquid feed is splashed into a hot gas stream to produce powder from the liquid feed. Dryer feed could be a solution, suspension, or

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grout, and the dried product could be powder or granulated. In this process, feed is sprayed by a splashier, and liquid feed is broken into many fine droplets. With this process, a ratio of surface per volume increases and accelerates heat and mass transfer. This method is used for temperature-sensitive or dried material feeds quickly. This type of dryer, due to its larger size and lower thermal efficiency than other types of dryers, this type of dryer has higher installation and energy costs. Several studies in connection with spray Dryers have been done. In 1958, Van Meel [1] introduced Concession air drying with rotation turn in a dryer. In 1963, Smith and Cook [2] analyzed the design and application of a spray dryer. In 1972, Wang [3] studied particle size distribution in polymer solutions. In 1976, Beresford [4] reviewed and reported progress achieved in spray drying. In 1978, Masters & Moller [5] studied the effect of operational variables to predict particle size from the industrial rotary spray. In 1979 Piterskikh [6] studied the design of dryers equipped with rotary disk sprayers. In 1980, Filkova and Webber [7] researched on effects of sprayer geometry on particle size and particle size distribution in spray dryers. In 1980, Sears and Ray [8] evaluated particle suspension spray dryers. In 1982, O'Pourke and Wadt [9] studied a mathematical model of two-dimension two - phases for spray dryers. In 1985, Crow [10] studied a comprehensive evaluation of spray dryers' act with steam. In 1986, Van Der Lijn [11] conducted a comprehensive study on heat and humidity transfer simulation in a spray Dryer. In 1988, Zbicinski *et al*. [12] introduced a mathematical theory model for the performance of spray dryers. In 1988, Papadakis and King [13] proposed a model for temperature and humidity profiles to predict the behavior of particles in the spray dryer. In 1989, Zhele [14] studied the model of air and fed flow in a spray dryer. In 1991, Clement [15] analyzed the behavior of a dynamic spray dryer. In 1991, Oakley and Bahu [16] researched the behavior of spray mixing and gas within the spray dryer. In 1994, Langrish & Zabicinski [17] researched the effect of spray cone geometry and angle of input air spray per deposition on body spray dryers. In 1994, Masters [18] conducted a comprehensive analysis of the design and scale-up of spray dryers. In 1997, Oakle [19] proposed produced uniform particles method in the spray drying process. At the years 2000 and 2003, Kalbasi *et al*. [20, 21] performed modeling of materials in drying operations. In 2003, Kalbasi *et al*. [22] studied operational variables in the spray drying process of melamine formaldehyde.

Article Details

In this article, a simple model was presented to predict drying velocity and temperature, supposing that speed drying moved to drop by the heat transfer rate of dryer gas. Water evaporation occurs on drops at boiling point. Concerning known ΔT as driving forces, we can establish an energy balance for drop [23-25].

$$hA\left(T_{gas}-T_{drop}\right)+\Delta H_{Vap}\frac{d_{mdrop}}{dt}=m_{drop}C_P\frac{dT_{drop}}{dt}$$

Heat transfer by radiation and mixing is assumed negligible. Drops mass changes related to mean mass of water in drop:

$$\frac{dm}{dt}=\frac{m_s}{\left(1-\omega_{avg}\right)^2}\frac{d\omega_{avg}}{dt}$$

As fixedso m_s

$$\omega_{avg}=\frac{m_\omega}{m_\omega+m_s}$$

Drops boiling point is estimated from the average boiling point of water in a drop and desired material. While the temperature of the drop is a partial function of the percentage of water:

$$T_{drop}=f\left(\omega_{avg}\right)$$

In the solution, water equilibrium pressure is low. However, with the presence of a solvent, equilibrium temperature will rise, so in Equation (1), the energy accumulation term is negligible, and the result is the following equation:

$$T_{gas}-T_{drop}\left(\omega_{avg}\right)=\frac{-\Delta H_{vap}}{hA}\frac{m_s}{\left(1-\omega_{avg}\right)^2}\frac{d\omega_{avg}}{dt}$$

This equation could measure as integrated numerically to predict the structural development of drying speed and temperature as a function of time. The equation used when a drop splashed in a dryer gas and T_{gas} and h are time variables.

A correction factor enters in the equation to match experimental data and model because conduction heat transfer in solid, increasing heat transfer surface, increasing gas heat transfer coefficient with inflated drops.is the best α Correction coefficient that is always less than $\frac{1}{hA}$.

$$T_{gas} - T_{drop} = -\alpha \frac{\Delta H_{Vap} m_s}{\left(1-\omega_{avg}\right)^2} \frac{d\omega_{avg}}{dt}$$

Value in this model is its simplicity, i.e., the overall speed of the drying is independent and independence of details and structural development. Considered particle falling into a dryer, written forces balance at equilibrium solved equations in three directions x, r, t (tangential, radial, and axial) :

$$\frac{dU_{p,x}}{dt} = \left(1 - \frac{\rho_g}{\rho_p}\right) g - \frac{3}{4} C_D \frac{U_{p,x} \pm U_{g,x}}{\rho_p d_p} U_p \rho_g$$

$$\frac{dU_{p,r}}{dt} = \frac{U_{p,t}^2}{r} - \frac{3}{4} C_D \frac{U_{p,r} \pm U_{g,r}}{\rho_p d_p} U_p \rho_g$$

$$\frac{dU_{p,t}}{dt} = -\frac{U_{p.t} U_{p,r}}{r} - \frac{3}{4} C_D \frac{U_{p,r} \pm U_{g,r}}{\rho_p d_p} U_p \rho_g$$

With integrating the above equation:

$$U_p = \left[\left(U_{p,x} \pm U_{g,x}\right)^2 + \left(U_{p,r} \pm U_{g,r}\right)^2 + \left(U_{p,t} \pm U_{g,t}\right)^2\right]^{\frac{1}{2}}$$

Negative mark signs concurrent flow and positive mark signs counter-current flow. Assuming one dimensional air flow and high length tower, the equation could write as follow:

$$U_{g,t} = U_{g,r} = 0$$

A) Mass balance equations: For the determination of particle moisture and air humidity around particles, the following relations are used:

$$\frac{dX}{dt} = -\frac{\omega_D (1+x)}{\rho_P V_p}$$

$$\frac{dY}{dt} = -\frac{U_P (1+x)}{(1+x) U_a \rho_a} \frac{dX}{dt}$$

Drying rate is expressed with the following relationship:

$$\omega = f K_g S_p \rho_a \left(Y^* - Y\right)$$

B) Heat balance equations: Particle temperature is determined as follows:

$$\frac{dT_p}{dt} = \frac{1}{m_p C_p} \left[K_H S_p \left(T_a - T_p\right) - \omega_D \left[\lambda + C_v \left(T_a - T_p\right)\right]\right]$$

$$\frac{dT_a}{dt} = \frac{1}{\upsilon_a C_c \rho_a} \left[m_p C_c \frac{dT_p}{dt} + \omega_D \left[\lambda + C_v \left(T_a - T_p\right)\right]\right]$$

C) Momentum balance equations:

$$\frac{dU_{p,x}}{dt} = \left[1 - \frac{\rho_a}{\rho_p}\right] g - \frac{3}{4} C_D \frac{\rho_a U_p \left(U_{pax} - U_a\right)}{\rho_p d_p}$$

$$\frac{dU_{p,t}}{dt} = -\frac{3}{4} C_D \frac{\rho_a U_p U_{p,t}}{\rho_p d_p}$$

$$\frac{dU_{P,r}}{dt} = \frac{U_{p,t}^2}{hr} - \frac{3}{4} C_D \frac{\rho_a U_p u_{P,r}}{\rho_p d_p}$$

Particle relative velocity is calculated from the following relationship:

$$U_p = \left[\left(U_{p,x} - U_a\right)^2 + U_{p,t}^2 + U_{P,r}^2\right]^{\frac{1}{2}}$$

For determine particle diameter could write:

$$d_p = d_{po}\left[\frac{\rho_{pso}-\rho_\omega}{\rho_p-\rho_\omega}\right]^{\frac{1}{3}}$$

The accuracy of the simulation study performed, it is necessary to adjust simulation results with experimental data. For this purpose, use experimental data obtained from experiments in the laboratory dryer. Performed tests results are as follows:

1-Food conditions:

Flow rate: $1.2\frac{lit}{hr}$

Humidity: $4.27\frac{kg}{kg}$

Feed density: $1053.2\frac{kg}{m^3}$

Average diameter: $60\mu m$

Feed temperature: $20^\circ C$

2- Hot air conditions:

Flow rate: $1\frac{lit}{s}$

Humidity $0.01\frac{kg}{kg}$

Input temperature: $150^\circ C$

Output temperature: $76^\circ C$

3- Product conditions

Humidity: $0.07\frac{kg}{kg}$

Product temperature: $71^\circ C$

Simulation results are as follows:

Output air temperature: $80^\circ C$

Output product temperature: $75^\circ C$

Tower height: $28 Cm$

Particles residence time: $0.91 Sec$

Conclusion

In this work, calcium carbonate drying with the spray method was studied. Calcium carbonates are essential minerals in most industries; dryer system methods are used at the end of purification and preparation for marketing release. For improving the process, a dryer simulation could be a great help. One of the goals in-unit simulation is the optimization of the process. In the drying spray process of calcium carbonate presented in this project, various parameters affect product specification, and dryer dimensions are described as follows.

A) Air temperature input A dryer system's heat transfer driving force is the difference between input air temperature and particles temperature. Any increase in input air temperature causes increasing in heat transfer rate and consequently evaporation rate and decreasing in drying time. So reducing the input air temperature causes reduce in evaporation rate and increasing in drying time. The relevant diagram is shown in Figure (1).

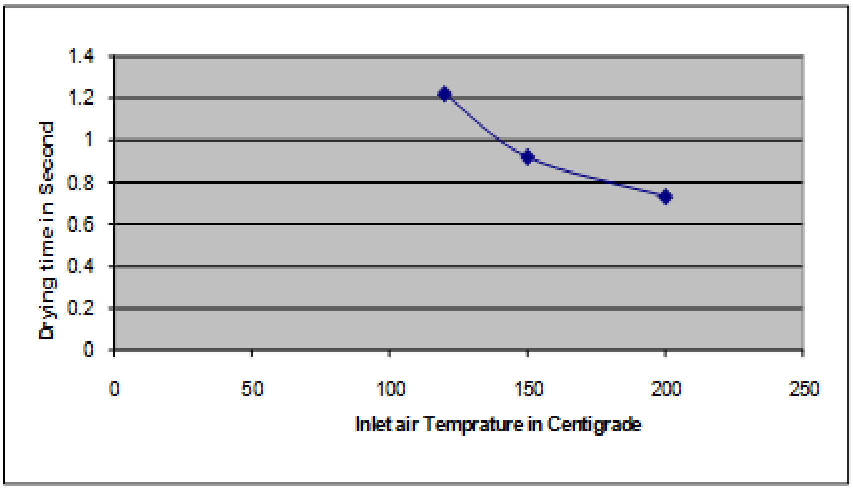

Figure 1: Effect of inlet air temperature on drying process

B) Input air flow rate

The first outcome of increasing input airflow is increasing airspeed in the dryer chamber. With increasing airspeed, heat and mass transfer coefficients increase which means evaporation rate and drying time will decrease but drag force and particles' heat resistance increase consequently. Therefore the reduced particles speed could affect yield and dryer product characteristics adversely. The relevant diagram is shown in Figure (2).

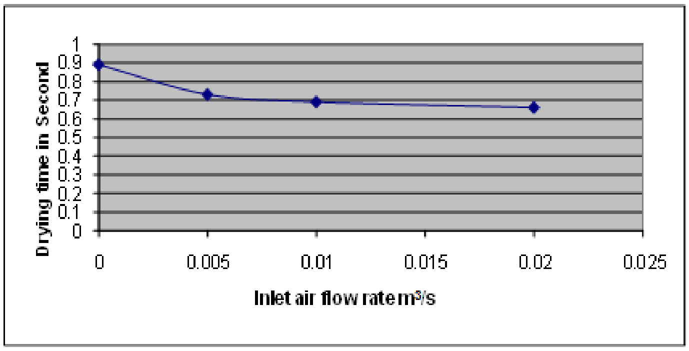

Figure 2: effect of inlet air flow rate on drying process

C) Input air humidity Mass transfer driving force decreases with increasing humidity and the evaporation rate decreases. Then more time will be required for drying. Relevant diagram is shown in Figure (3).

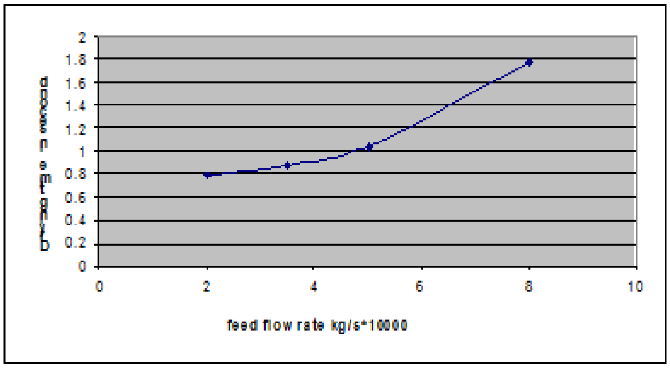

Figure 3: effect of inlet air floe rate on drying process

D) Feed flow rate With increasing feed flow rate, humidity rises, and temperature is reduced. Therefore, heat and mass transfer driving force and consequently evaporation rate decreases and dryer temperature increases. The relevant diagram is depicted in Figure 4.

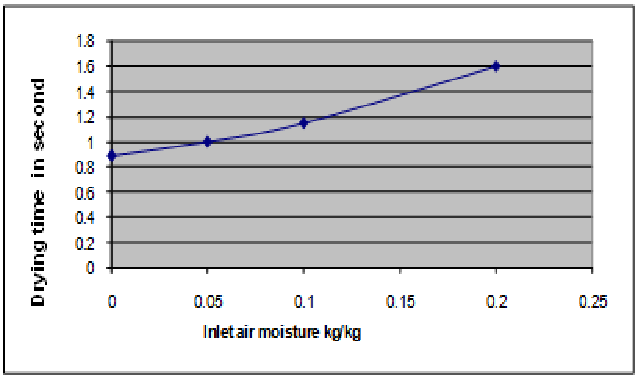

Figure 4: effect of inlet air moisture on drying process

E) Sprayed drop diameter Droplets sprayed from the atomizer is a spherical shape, and the spherical drop surface is proportional to the diameter square. As drops mass according to its density related to cube diameter, so if a certain mass of feed transformed to drops, drops number is according to drop inverse cube diameter and also total mass and heat transfer surface could be expressed with a drop surface multiplied to several droplets, so any increase in drop diameter, causes a decrease in heat and mass transfer effective surface, evaporation rate decreased and therefore drop drying required time increases. The relevant diagram is shown in Figure (5).

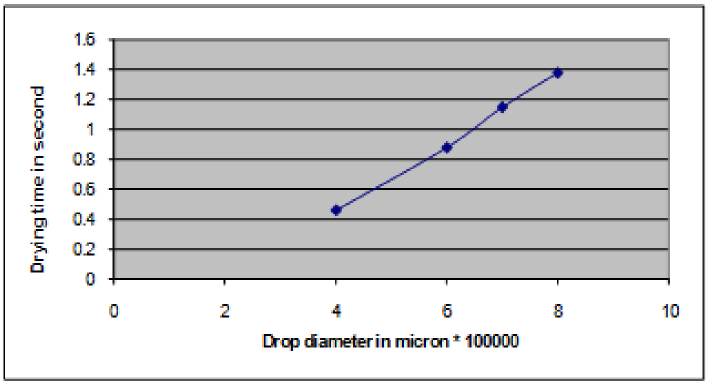

Figure 5: effect of sprayed drop diameter on drying process

List of Symbols

C_D : Drag coefficient
C_P : Particle Heat capacity
d_p : Particle diameter
f : Drying relative intensity
g : Gravity
K_H : Heat transfer coefficient
K_g : Mass transfer coefficient
m_p : Particle mass
r : Particle radius
S_P : Particle surface
T_P : Particle temperature
t : Time
U_p : Particle relative velocity in air flow
U_g : Gas relative velocity
V_p : Particle velocity
X : solid Moisture based on dry
Y : Air humidity based on dry
ω_D : Drying intensity

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