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New Design of Cross-flow Fluidized Bed Dryers

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ABSTRACT: Drying process demands high power consumption due to the low efficiency of this process in the industries. Therefore, modeling and simulation of dryers in order to optimize them and to design more efficient dryers is necessary. In this research, a cross-flow fluidized bed dryer has been simulated in order to evaluate a new design of the dryer. A mathematical model has been used to predict outlet solid moisture and temperature as well as outlet air humidity and temperature of a single story fluidized bed. The simulation results were evaluated using the experimental data of a pilot cross flow fluidize bed dryer. The comparison showed that the model can reasonably predict the process. Therefore, the simulation was used to investigate a new design of three story dryer (three sequential single story dryers). The simulation results showed while inlet solid moisture was 0.32 and outlet solid moisture for the single-story dryer was 0.19, in the same conditions, outlet solid moisture for the three-story dryer was 0.13. This means the new design can reduce solid moisture by 50 percent more, indicating the better use of hot air and subsequently more energy saving.

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1- Introduction

Mathematical modeling of fluidized bed drying is essential to find the best performance of the existing systems and to design a new dryer [1]. Researchers had done several studies on the performance of the fluidized bed dryer over the years [2-4]. Because of the low energy efficiency of industrial dryers, drying process needs high input energy that plays an important role in the cost of the process [5]. In this research, a cross-flow fluidized bed dryer has been simulated in order to evaluate a new design of the dryer. A mathematical model has been used to predict outlet solid moisture and temperature as well as outlet air humidity and temperature of a single story fluidized bed.

2- Mathematical Modeling

The assumptions made are as follows:

- Complete particle mixing in the vertical direction
- Temperature and the solid moisture content are uniform in the horizontal elements of the dryer.
- Drying gas flow (air) inside the compartment has been considered as an ideal plug flow.
- For solid particles during the bed, dispersed plug flow is considered.
- The dynamic and physical characteristics of the particles are constant.
- Temperature gradient of solid particles is ignored.

To develop the mass balance in the particles in addition to transport by bulk flow at a constant axial solid flow velocity, the particles are transported by axial dispersion through any cross-section of the bed.

$$D\frac{d^2M}{dx^2} - u\frac{dM}{dx} - R = 0 \tag{1}$$

In air flow, Moisture is transported by bulk flow.

$$-U_0\rho_g\frac{dY}{dz} + R\,\rho_{bed} = 0 \tag{2}$$

The energy balance in the particles is Similar to the mass balance in the particles. We consider bulk flow, dispersion, convection, and evaporation to develop energy balance in the particle.

$$\begin{aligned} &D\frac{d^2H_p}{dx^2} - u\frac{dH_p}{dx} + \frac{a\alpha\left(T_{g,in} - T_p\right)}{\rho_{bed}} \\ &-R\left(C_w\left(T_p - T_{ref}\right) + h_v + C_v\left(T_{g,in} - T_p\right)\right) = 0 \end{aligned} \tag{3}$$

H_p is equal to

$$H_p = \left(C_p + C_w M\right)\left(T_p - T_{ref}\right) \tag{4}$$

To develop the energy balance in air flow, we consider bulk flow, convection and evaporation to develop energy balance in the particle.

$$\begin{aligned} &-U_0\rho_g\frac{dH_g}{dz} - a\alpha\left(T_{g,in} - T_p\right) \\ &+R\,\rho_{bed}\left(C_w\left(T_p - T_{ref}\right) + h_v + C_v\left(T_g - T_p\right)\right) = 0 \end{aligned} \tag{5}$$

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H_g is equal to

$$H_g = (C_g + C_v Y)(T_g - T_{ref}) + Y h_{v_0} \tag{6}$$

The mass and the energy boundary conditions at the solid inlet of the dryer can be written as Eqs. (7) and (8) and at and outlet ports Eqs. (9) and (10), respectively.

$$M_{in} = M_{=0} - \frac{D}{u}\left(\frac{dM}{dx}\right)_{=0} \tag{7}$$

$$H_{p,in} = H_{p\,x=0} - \frac{D}{u}\left(\frac{dH_p}{dx}\right)_{x=0} \tag{8}$$

$$\left(\frac{dM}{dx}\right)_{x=L} = 0 \tag{9}$$

$$\left(\frac{dH_p}{dx}\right)_{x=L} = 0 \tag{10}$$

Boundary conditions for mass and energy of the air flow at the inlet can be written respectively by:

$$Y_{z=0} = Y_{in} \tag{11}$$

$$T_{g_{x=0}} = T_{g,in} \tag{12}$$

The drying rate of the particles in the fluidized bed drying as follows [6]:

$$R\left(\frac{1}{k} + \frac{1}{k_i}\right) = a\left(C_{sat} - \frac{P}{R_g T}\frac{Y}{\frac{Y}{M_W} + \frac{1}{M_a}}\right) \tag{13}$$

3- Result and Discussion

3- 1- Validation

Initially, the equations are solved for a single tray bed and compared with the results of the experimental data [7]. The comparison showed the model can reasonably predict the process (see Fig. 1).

3- 2- Series Process

The simulation was used to investigate a new design of three-story dryer (three sequential single story dryers that can be seen in Fig. 2).

The simulation results in Figs. 3 and 4 show while inlet solid moisture is 0.32 and outlet solid moisture for the single-story dryer is 0.19, in the same conditions, outlet solid moisture for the three-story dryer is 0.13. This means the new design can reduce solid moisture by 50 percent more, indicating the better use of hot air and subsequently more energy saving.

We defined a new parameter (F) to the investigation of performance dryer:

$$F = \frac{(M_{in} - M_{out})_{series} - (M_{in} - M_{out})_{single}}{(M_{in} - M_{out})_{single}} \tag{14}$$

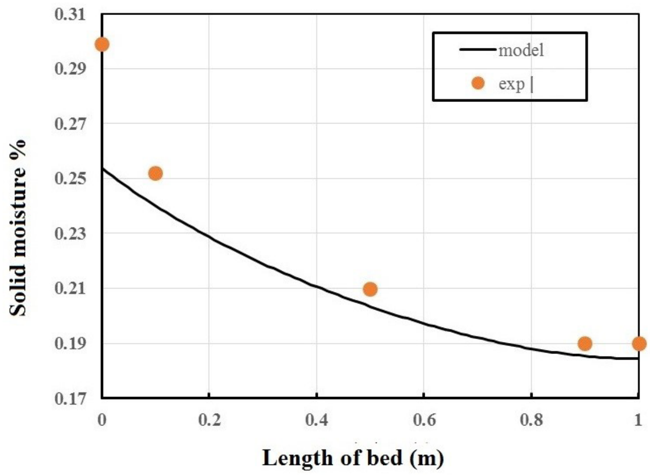

Fig. 1. Comparing the result of the model and experimental data [7]

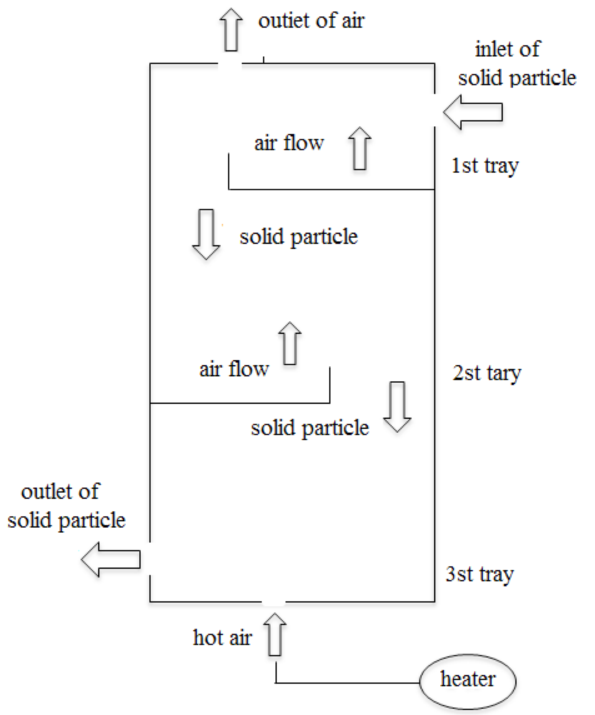

Fig. 2. Schematic view of the new design of three-story dryer

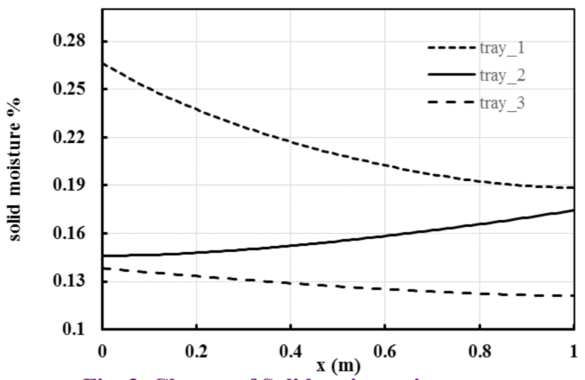

Fig. 3. Change of Solid moisture in trays

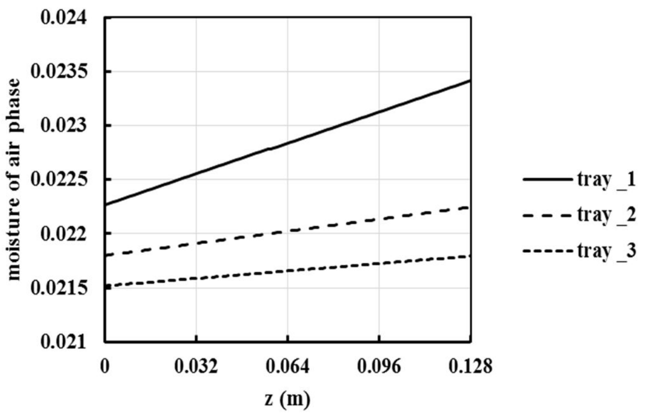

Fig. 4. Change of air moisture in the height of trays

F is 0.54 for the first tray but for second and tired tray are 0.15. Thus increasing the number of tray does not influence the performance of dryer.

4- Conclusions

The simulation was used to investigate a new design of three-story dryer. The simulation was used to investigate a new design of three-story dryer (three sequential single story dryers). The simulation results showed while inlet solid moisture was 0.32 and outlet solid moisture for the single-story dryer was 0.19, in the same conditions, outlet solid moisture for the three-story dryer was 0.13. This means the new design can reduce solid moisture by 50 percent more, indicating the better use of hot air and subsequently more energy saving.

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