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RESEARCH ARTICLE

Modelling and Simulation of Rotary Dryer for Wheat drying

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ABSTRACT

Drying of the agricultural product has been one of most effective methods to reduce postharvest losses. Different studies are conducted to evaluate the performance of a rotary drier for drying of agricultural products. Rotary dryer is capable of processing a variety of agricultural product with a large number of thermo-physical and flow properties. Rotary dryers are used for drying of grains, beans, nuts, vegetables, herbs, woody biomass, animal feeds, agricultural wastes, and by-products. During this paper, a dynamic model to simulate the dehydration process of wheat in a rotary dryer is proposed. The results are validated with the experimental data obtained. The model predicts air and product moisture and temperature depending on operating conditions of the rotary dryer.

Keywords: Air Temperature, Product Moisture, Rotary Dryer

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INTRODUCTION

Drying is a process of commercial importance in several industrial applications ranging through the food, agricultural, manufacturing, and mining sectors. Drying is definitely one in every of the foremost energy-intensive operations in industry and most dryers operate at low thermal efficiency. Drying is a process in which an unbound and/or bound volatile liquid is removed from a solid by evaporation. The conventional heat transfer methods for drying are conduction, convection and infrared radiation and dielectric heating.

Most agricultural products contain a significant amount of moisture during the harvesting stage. The presence of this moisture will increase the deterioration rate of the product throughout storage, handling, and processing periods. Microorganisms that cause food spoilage and decay cannot grow and multiply in the absence of water. Also many enzymes that cause chemical changes in the food and biological materials cannot function without water. When the water content is reduced to below about 10wt% the microorganisms are not active. However, it is usually necessary to lower the moisture content below 5 wt% in foods to preserve flavor and nutrition. The first objective of drying is to reduce the moisture content of the product therefore on retard adverse biological (such as growth of spoilage microorganisms, germination, insect attack, etc.), chemical, and enzymatic processes. Additionally, drying reduces the bulk weight of the produce that helps to reduce the costs of transportation.

In the rotary dryer heat is transferred by convection, the necessary heat usually being provided by direct contact of a hot gas with the wet solid. Rotary drying is a complicated process involving simultaneous heat, mass transfer, and momentum transfer phenomena. Rotary dryers are normally employed in the chemical and pharmaceutical industry but also are used to dry

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agricultural products like alfalfa or beet pulp. It allows the handling of heterogeneous or sticky products and products that flow with difficulty. Large quantities of granular material with particles of 10mm or larger that are not too fragile or heat-sensitive, or cause any other handling problems are dried in rotary dryers in process industries.

A substantial number of papers have been published on rotary dryers covering various aspects such as drying, residence time distribution, and solids transportation. The mathematical model to predict the optimal values of heat and mass transfer coefficients and the shape of stationary profiles of temperatures and moisture were studied for the gas and solid phases for counter-current cascading rotary dryer of sugar (Rastikian et al., 1999).The drier performance in terms of humidity and temperature by working with onions in a rotary drier were determined (Pelegrina et al., 2002).A dynamic model to simulate the dehydration process of wastes of vegetable by dividing the rotary dryer into ten sections was established. The model predicts air and product moisture and temperature depending on operating conditions of the rotary dryer (Iguaz et al., 2003).

The ratio of water activity and moisture content versus water activity were determined. It was shown that the relative derivative of the transformed equation expresses the deviation of the sorption isotherm from the linear relationship between the moisture content and water activity (Blahovec and Yanniotis , 2010). A physical model was developed to evaluate temperature and moisture for granular solids during the drying was carried out inside a rotary drum. Moreover, model results were analyzed and compared to several measurements performed in an actual asphalt mix plant at the industrial scale (Laur´edan et al., 2011). The model for the fertilizer drying in rotary dryers was developed and determined the influence of overall volumetric heat transfer coefficient, coefficient of heat loss, drying rate, specific heat of the solid and specific heat of dry air (Silva et al., 2012, Kumar et al., 2014).

The mathematical model for the concurrent rotary dryer for ammonium nitrate including heat and mass transfer equations between solid and air was developed. Regardless of the slope and speed of the dryer, inlet AN moisture and air temperature have been shown to be the variables that have the greatest effect, on the outlet moisture content of the product (Hamed et al., 2013). A mathematical model of heat and mass transfer for flexible filamentous particles in a counter-current cascading rotary dryer is developed. The influence of moisture content and humidity on flexible filamentous particles and hot gas in the rotary dryer is studied (Conghui et al., 2014).

The dehydration of residues of acerola generated as byproduct of fruit processing industry, due to its potential use as food supplementation was investigated. The effect of a pretreatment with ethanol prior to the air-drying has also been analyzed. The performance of this dryer and the effect of processing variables are investigated considering the drying responses, as well as the quality of product (Priscila et al., 2015). The dynamic transport of flexible ribbon particles in a laboratory rotary drum was investigated. First, a box-chain model in 3 dimensions was established for flexible ribbon particles. Then, dynamic behavior of certain particles was investigated through numerical simulation that vividly represents particle flexibility, multi-particle web and multiple particle collisions. Based on this model, residence time of particles and mean residence time of particles within the drum were mentioned in terms of key variables, together with rotational velocity, drum slopes and initial velocity of air flow (Fan et al., 2016).

It has been discovered that, though many models have been proposed, there is not a general theory to explain the mechanism of rotary drying and it looks that specific models for an equipment and material are more useful than general models. In this work, a dynamic model for the dehydration of wheat in rotary dryer is developed and the influence of different operating variables in the outlet moisture content of the solid is studied.

MATERIALS AND METHODS

Model Equations

In this section, mathematical model of the counter current single pass direct contact rotary dryer is to be developed.

To develop the model, the dryer was transversally divided into ‘n’ control volumes of area A length L/n as shown in Fig 1. Fig 2 shows the schematic representation of the control volumes of the dryer.

The following assumptions are made in formulating the rotary dryer for wheat drying:

- During the drying process, there is no constant-rate period that means that drying happens during the falling-rate only.
- The mass flow of air remains constant through the whole dryer.
- It is considered that the dryer always works in optimal load conditions, happens when the material held in the dryer is between 3% and 7% of its total volume.
- For each control volume, the inlet flow rate of product is equal to the outlet flow rate of product from the previous control volume**.**

Mass Balances

Product:

Rate of change of mass of product in the control volume = [Rate of mass of product entering the control volume] – [Rate of mass of product leaving the control volume]

$$\frac{dM_p}{dt} = G_{Pin} - G_{Pout} \qquad (1)$$

where,

$$G_{Pout} = \frac{M_p}{t_r} \qquad (2)$$

Moisture in the product:

[Change in the amount of water in the product] = [Water entering into the dryer element with the product] – [Water leaving the dryer element with the product] –[Water evaporated from the product]

$$\frac{d(M_p W)}{dt} = G_{Pin} W_{in} - G_{Pout} W - R_w M_P \qquad (3)$$

$$W \frac{dM_p}{dt} + M_p \frac{dW}{dt} = G_{Pin} W_{in} - G_{Pout} W - R_w M_P \qquad (4)$$

$$\frac{dW}{dt} = \frac{1}{M_p}\left[G_{Pin} W_{in} - G_{Pout} W - R_w M_P - W \frac{dM_p}{dt}\right] \qquad (5)$$

Moisture in the air:

[Change in the amount of water in the air] = [Water entering into the dryer element with the air] – [Water leaving the dryer element with the air] + [Water evaporated from the product]

$$\frac{d(M_a Y)}{dt} = G_{ain} Y_{in} - G_{aout} Y + R_w M_P \qquad (6)$$

$$Y\left(\frac{dM_a}{dt}\right) + M_a\left(\frac{dY}{dt}\right) = G_{ain} Y_{in} - G_{aout} Y + R_w M_P \qquad (7)$$

Since M_a is constant $\frac{dM_a}{dt} = 0$

$$\frac{dY}{dt} = \frac{1}{M_a}[G_{ain}Y_{in} - G_{aout}Y + R_w M_P] \qquad (8)$$

Heat Balances

Product temperature:

[Enthalpy change of the product] = [Enthalpy of the product entering into the dryer element] – [Enthalpy of the product leaving the dryer element] + [Heat transferred from the air to the product] – [Required heat to remove and vaporize moisture of the product] – [Required heat to heat the water vapor to air temperature] – [Heat lost through the shell of the dryer].

$$\frac{d(M_p C_{P_P} T_P)}{dt} = G_{P_{in}} C_{P_P} T_{P_{in}} - G_{P_{out}} C_{P_P} T_P + U_V aV(T_a - T_P) - R_w M_p q_{lat} - M_P C_{P_v}(T_a - T_P) - Q_P \qquad (9)$$

$$C_{P_P} T_P \frac{dM_p}{dt} + M_p T_P \frac{dC_{P_P}}{dt} + M_p C_{P_P} \frac{dT_P}{dt} = G_{P_{in}} C_{P_P} T_{P_{in}} - G_{P_{out}} C_{P_P} T_P + U_V aV(T_a - T_P) - R_w M_p q_{lat} - M_P C_{P_v}(T_a - T_P) - Q_P \qquad (10)$$

$$\frac{dT_P}{dt} = \frac{1}{M_p C_{P_P}}[G_{P_{in}} C_{P_P} T_{P_{in}} - G_{P_{out}} C_{P_P} T_P + U_V aV(T_a - T_P) - R_w M_p q_{lat} - M_P C_{P_v}(T_a - T_P) - Q_P - C_{P_P} T_P \frac{dM_p}{dt} - M_p T_P \frac{dC_{P_P}}{dt}] \qquad (11)$$

Air temperature:

[Enthalpy change of the air] = [Enthalpy of the air entering into the dryer element] - [Enthalpy of the air leaving the dryer element] - [Heat transferred from the air to the product] + [Enthalpy of the water evaporated from the product]

$$\frac{d(M_a C_{p_a} T_a)}{dt} = G_a C_{p_{a_{in}}} T_{a_{in}} - G_a C_{p_a} T_a - U_V aV \Delta T_{lm} + R_W M_P C_{P_V} T_a \qquad (12)$$

$$C_{p_a} T_a \frac{dM_a}{dt} + M_a T_a \frac{dC_{p_a}}{dt} + M_a C_{p_a} \frac{dT_a}{dt} = G_a C_{p_{a_{in}}} T_{a_{in}} - G_a C_{p_a} T_a - U_V aV \Delta T_{lm} + R_W M_P C_{P_V} T_a \qquad (13)$$

$$\frac{dT_a}{dt} = \frac{1}{M_a C_{p_a}}[G_a C_{p_{a_{in}}} T_{a_{in}} - G_a C_{p_a} T_a - U_V aV \Delta T_{lm} + R_W M_P C_{P_V} T_a - C_{p_a} T_a \frac{dM_a}{dt} - M_a T_a \frac{dC_{p_a}}{dt}] \qquad (14)$$

Drying Rate Equations

The equations for this system are as follows (A.Iguaz[1])

$$R_w = K_d(W - W_e) \qquad (15)$$

where,

$$K_d = 0.00719 \exp\left(-\frac{130.64}{T_a}\right) \qquad (16)$$

The parameters used in the above equations were calculated from the following equations (Blahovec J.[3]):

$$W_e = \frac{W_m C K a_w}{(1 - K a_w)[1 + (C - 1) K a_w]} \qquad (17)$$

where,

$$W_m = 0.0014254 \exp\left(\frac{1193.2}{T_K}\right) \qquad (18)$$

$$C = 0.5923841 \exp\left(\frac{1072.5}{T_K}\right) \tag{19}$$

$$K = 1.00779919 \exp\left(-\frac{43.146}{T_K}\right) \tag{20}$$

Residence time

$$T_r = 0.3\left[\frac{0.23L}{(tan\alpha)(N^{0.9})(D)} \pm \frac{3LG_a}{{D_P}^{-0.5}G_{P_{out}}}\right] \tag{21}$$

Thermal Properties

Latent Heat:

$$q_{lat} = L_w(1 + 0.9227771 \exp(-13.4313166W)) \tag{22}$$

Latent Heat of Vaporization:

$$L_w = 2500.6 - 2.364356T_P \tag{23}$$

Specific Heat of Product:

$$C_{P_P} = 1.382 + 2.805W \tag{24}$$

Specific Heat of Humid Air:

$$C_{P_a} = C_{P_{as}} + C_{P_V}Y \tag{25}$$

Heat Transfer

$$Q = U_v a V \Delta T_{lm} \tag{26}$$

$$U_v a = 0.52\left(\frac{G_a}{A}\right)^{0.8} \tag{27}$$

$$Q_p = U_p \pi D L(T_a - T_{amb}) \tag{28}$$

RESULTS AND DISCUSSION

The model equations were solved using the Matlab Simulink tool. This is a block-diagram-oriented environment within which numerous dynamic blocks are chosen from a library of elements and interconnected on the screen to create a system. The system will then be simulated directly from the diagram with no additional programming. Simulation studies were applied to evaluate the effect of the number of elements the dryer is split into on the performance of the model. It's been observed that ten is an adequate number of elements because a higher number leads to slight modification in the results while computer time is significantly exaggerated. The differential equation set, Eqs. (1), (5), (8), (11) and (14), was established in each control volume of the dryer. The differential equations were solved using the variable step numerical method ode 15s of Matlab. The maximum order was fixed at 5 and the absolute tolerance was 10^6. The initial condition for the differential equations were an equivalent as those of the dryer inlet streams of air and product. In each dryer element the solver integrates the equations between the actual time and the following time that is determined by the step time. This makes that, for a dryer element in a determined time, the inlet variables are the outlet variables of the previous element within the previous time. It is possible to know the dryer outlet values for the air and product moisture and temperature by fixing a simulation stop time. During this study the simulation time was fixed in 5000 s. The model was validated in a pilot counter current rotary dryer.

CONCLUSIONS

The following conclusions can be drawn from the present work:

- The model developed in this work is shown to successfully predict the steady state behavior of a counter current-flow rotary dryer. From the model it's possible to find the moisture content and temperature of the outlet air and product by knowing the operating parameters. Also, the evolution on the dryer of several variables can be found.

- Within the range of conditions examined, the inlet air temperature is the highest effect of the predicted outlet product moisture content, followed by the airflow rate.

- This model will be used to simulate the response of the system to a modification within the operating conditions, and so, it can be used to study new control strategies.

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