MATHEMATICAL MODELING OF COFFEE BEAN ROASTING IN A NOVEL SPOUTED MULTISTAGE SYSTEM

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Abstract:
Background: Arriola[1] has developed a novel spouted bed multistage system that has several advantages over previous designs. It has a novel configuration without dead zones or moving parts, hydrodynamic stability, scale up advantages, operation and control simplicity, low pressure drop, very simple column start-up and shutdown procedures/conditions, continuous withdrawal of solids from the bottom stage through an “S-valve” [2], and intense and controlled air-grain contact. This system can be used for heat and mass transfer, as well as chemical reaction processes [1], such as coffee roasting. To describe the process it is necessary to develop a mathematical model that takes into account not only the transport phenomena (or/and chemical reaction), but also considers the contact scheme in the system [3].
Aim: The focus of this project is to develop a mathematical model that describes the coffee bean roasting process in a vertical multistage spouted bed system designed by Arriola[1].
Method: The main component lost during the roasting process is water; a drying model of the process was considered appropriate. Fick’s equation was solved, and the results were combined with the RTD (Residence Time Distribution) function selected by Arriola[4], which comprises a compartment model of two flow regimes (plug and mixed). The model was fitted to the moisture kinetics obtained from experimental runs where a 3-stage column was used. Airflow and temperature were 110 L/min and 450°C, and the solids flow was varied between 1.9 x10-3 and 7.5 x10-3 kg/s.
Results: Drying kinetics obtained by Fick’s equation, where an effective diffusion coefficient was estimated (Deff = 2.45 x 10-8 m2/sec), fitted experimental data fairly well (R2 = 0.95). Using this model and the RTD, we estimated the number of stages needed and the corresponding tp (plug flow average residence time) and tM (mixed flow tank average residence time), for drying from initial moisture content to a final average moisture content. Results found indicate that in order to reach moisture content of 7%, a column of 10 stages should be used, and the values of tp and tM are 30.95% and 69.05, respectively.
Conclusions: Fick’s equation combined with the RTD function generated an adequate model to predict the average moisture of the roasted coffee beans at the exit of the multistage spouted bed system.

Reference 1: Arriola, E. (1997). Residence Time Distribution of Solids in Staged Spouted Beds. Oregon State University.
Reference 2 : Guatemala, G. M., Santoyo, F., Virgen, L., Corona, R. I., & Arriola, E. (2012). Hydrodynamic model for the flow of granular solids in the S-valve. Powder Technology, 230, 77–85.
Reference 3 : Levenspiel, O. (1999). Chemical Reaction Engineering (3rd editio.). John Wiley & Sons.
Reference 4 : Arriola, E., Cruz-Fierro, C. F., Alkhaldi, K. H., Reed, B. P., & Jovanovic, G. (2004). Residence time distributions in staged spouted beds. The Canadian Jourganl of Chemical Engineering, 82, 94–101.

Highlight 1: A novel spouted bed multistage system without dead zones or moving parts has been developed
Highlight 2: This system can be used for heat and mass transfer, as well as chemical reaction processes.
Highlight 3: Fick’s Law combined with RTD function generated a model to predict the moisture of roasted coffee beans.