ABSTRACT

The aims of this dissertation is to develop a mathematical model of rotary dryer to dry the ammonium sulfate fertilizer by assuming plug flow pattern (PF) and plug flow with back-mixing pattern (PFBM) for uniform and non-uniform particle size. This work was carried out in three steps: mathematical model development of solid particle drying with special attention in particle shape effect, determination of drying rate characteristic of ammoinium sulphate (ZA) fertilizer, and mathematical model development of ZA fertilizer drying process in rotary dryer.

First, this dissertation developed a mathematical model, using isothermal diffusion theory, of drying process of solid particles with various shapes : sphere and cylinder with H / D = ¼ and 4. The mathematical model was solved analytically, using variable separation method, and with polynomial approximation method. The mathematical model was used to examine the influence of particle shape on the rate of drying. Particle shape was described using Wadell sphericity ϕ_S. This work proposed a new, diffusion based, shape factor Ψ which is defined as the ratio between the equivalent particle radius and the average diffusion path length. The latter was the distance between the particle center and its outer surface. The solution for the unsteady-state model are presented as dimensionless plots of the average moisture content versus drying time and rate of drying versus average moisture. The approximate solution agreed very well with the analytical solution for Biot number of 0.1 to 5. As expected, particles with either the lowest Wadell sphericity, ϕ_S = 0.694 or the highest diffussion-based sphericity, Ψ = 2.8845, (cylindrical particle with H/D = 0.25), exhibited the highest drying rate. The dimensionless drying rate of this particle was approximately 400% faster than that of the spherical particle. Note that the specific surface of this particle was 144% greater than that of the spherical particle and the moisture diffusion length was 290% shorter. Thus, it appears that in comparison with the particle specific surface, the moisture diffusion length has a greater effect on the drying rate.

The experimental study was carried out using tray dryer to obtain drying rate characteristic data for ammonium sulphate. These data was used to determine effective diffusivity of moisture in ammonium sulphate fertilizer particle at various temperatures by fitting of isothermal diffusion model and the following correlation was obtained: $D_{eff} = 9.7 \times 10^{-18} T^{2.702}$. The isothermal diifusion model used Newman boundary condition modified with partition factor $\beta = e^{-\left(\frac{M_0 - M(t)}{M_0}\right)}$ to account for the surface resistance. By assuming effective diffusivity of moisture in ammonium sulphate particle at rotary dryer is the same as that obtained in try dryer, and by assuming spherical particle shape, then the ZA particle drying rate in rotary dryer was predicted, using isothermal diffusion model, at various condition of drying air and the following correlation was obtained: $R_W = 1.67184 x 10^{-12} v^{0.75719} H^{-0.01773} T^{4.87650} Dp^{-1.27485} \overline{X}$

Then, this dissertation developed a mathematical model of drying process of ammonium sulfate in a rotary dryer by using the drying rate characteristics that have been studied previously. In the development of this mathematical model, it is assumed a steady state condition, plug flow and plug flow with back-mixing pattern of gas and solid flow in the rotary dryer (PF model and PFBM model). In this model, overall heat transfer coefficients, solid hold up in a rotary dryer, and axial dispersion numbers were obtained from the empirical correlations in the literature. The mathematical model developed produce system of diferencial equations with the dependent variable the moisture content in solid, air humidity, air temperature and the temperature of solid. The mathematical models were solved numerically using finite difference method to produce non-linear algebraic equation system solved by Newton Raphson method using Matlab 6.1. The results of the theoretical prediction were validated with a rotary dryer operating data of PT. Petrokimia Gresik with specifications: diameter = 2.418 meters, length = 2.12 m, speed 3.5 rpm, and the slope of 4.5 degree. Apparently PFBM model gives predictions with a smaller deviation with pilot data compared to PF model. The deviation of the moisture content prediction in the oulet solid using PFBM model compared to the pilot data is less than 5%. The developed mathematical model was used to study theoretically the influence of some process variables, such as the flow rate of solid particles, air flow rate and drying air temperature on the performance of rotary dryer.

Finally, this work developed a mathematical model of rotary dryer to dry the fertilizer ammonium sulfate particles with non-uniform particle size by combining the drying processes model with particle size distribution model. Particle size distribution models used are Rosin-Rammler model and Gamma distribution model. For simplicity, the model of drying processes of solid particles in the rotary dryer was developed by assuming of uniform air conditions (temperature and humidity) along the rotary dryer as in the entry conditions. The resulting differential equations were solved analytically.This work has studied the effect of particle size distribution on ratary dryer performance, expressed as the profile of moisture content in solid along the dryer. Using Gamma function distribution, the study showed that for the value of the coefficient of varience less than 0.5, particle size distribution does not have significant effect on dryer performance. For the value of CV greater than 0.5, the dryer performance increase (or outlet solid moisture content decrease) with increasing the value of CV. The application of Rosin-Rammler model gives lower prediction of outlet solid moisture content compared to the application of Gamma function model.

Key words: Rotary dryer, ammonium sulfate, drying process, particle size distribution, Rosin-Rammler, Gamma function, coefficien of varience.