PROCESSING OF DISPERSED PHOSPHORITE IN THE PLASMA REACTOR WITH MULTI-JET MIXING CHAMBER

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ABSTRACT

The suggested mathematical model allows computer calculation of heat transfer of the dispersed phosphorite moving the multi-jet plasma reactor. The calculated and experimental degrees of the phosphorite conversion are in good agreement.

1. INTRODUCTION

The experimental data for plasma chemical processing of natural phosphates (1) show that the degree of P_2O_5 exhaust from phosphorite is primarily determined both by the plasma and phosphate ore parameters for the initial reactor cross section and by the plasma reactor design. The mathematical modelling and numerical calculation are advisable because the experimental investigation over a wide range of the plasma and phosphate ore parameters is complex and needs much time.

2. MATHEMATICAL MODEL

The equations for heat balance and particle motion are written in a general form elsewhere (2,3). These equations are supplemented with the expressions for dispersed material processing in the multi-jet plasma reactor:

$$G_g dH_g = h_p(T_g-T_p)S_p d\tau + q_{wp} dF_w \qquad (1)$$

$$h_p(T_g-T_p)S_p d\tau = c_{p1}G_p dT_{p1} + L_m dG_p +$$

$$+ c_{p2}G_p dT_{p1} + K_p \Delta H_R k dG_p \qquad (2)$$

$$m(dv_p/d\tau) = 0.5C_d\rho_d(v_g-v_p)^2F_d + mg \qquad (3)$$

$$St_1 = 10.7\ Re_{x1}^{-0.86}\ Pr_1^{-0.67} \qquad (4)$$

$$\varepsilon_{wp} = 0.945(\beta\ .\ 10^4)^{-0.125} \qquad (5)$$

$$q_{wp} = q_w \cdot \varepsilon_{wp} \qquad (6)$$

$$Nu = 2(\lambda_s/\lambda_g) + 0.78\ Re_p^{0.5}\ Pr^{0.33}(\rho_g\mu_g/\rho_s\mu_s)^{0.2}\varepsilon_\beta \qquad (7)$$

$$\varepsilon_\beta = 7.82\ .\ 10^{-8}\ \beta^{-2.1} \qquad (8)$$

$$\beta = (G_p\ {}_g v_g D^2)/(G_g \rho_p v_p D_c^2) \qquad (9)$$

$$K_p = Q_{p4}/\Delta H_R k G_p \quad . \qquad (10)$$

Here G_g and G_p are the mass flow rates of gas and phosphorite, respectively; T_g and T_p the bulk temperature of gas and particles, respectively; v_g and v_p the bulk velocity of gas and particles, respectively; S_p, F_w, F_d the surface area of particles, reactor channel and midcross section of particle, respectively; H_g the gas enthalpy; ΔH_R the thermal effect of decomposition of tricalcium phosphate heated to a decomposition temperature, T_R; L_m the latent fusion heat; C_d the drag coefficient for particle; τ the time; q_w, q_{wp} the heat flux from the plasma to the channel wall without and with particles in the gas; d_p the particle diameter; m the particle mass; ρ_s , μ_s ,λ_s the density, viscosity and thermal conductivity of a gas at the temperature equal to the bulk temperature of particle; ρ_g,μ_g,λ_g the same at the bulk temperature of gas; D the reactor channel diameter; D_c the particle scattering cone diameter; c_{p1}, c_{p2} the specific heat of solid and liquid particle, respectively; K_p the phosphate conversion degree; k the part of tricalcium phosphate in natural phosphate; Q_{p4} the amount of heat consumed for thermal decomposition of tricalcium phosphate; h_p the heat transfer coefficient for particle and plasma; β the volume particle concentration in gas; ε_β,$\varepsilon_{w\beta}$ the corrections for the concentration effect.

Expression (4) governs heat exchange between air plasma and multi-jet reactor channel walls (4); expression (5) allows for the effect of the dispersed phosphorite concentration on heat exchange between plasma and channel walls (5). Relation (7) enables calculation of the heat transfer coefficients for particles moving in the plasma flow, with varying thermophysical gas properties in the boundary layer and volume particle concentration being taken into account. As is shown in (6), according to expression (8), the correction for the volume concentration contribution should be allowed for at $\beta > 4.\,10^{-4}$ m^3/m^3.

3. NUMERICAL CALCULATION

Three plasma jets are radially injected into the vertical cylindrical reactor channel. The phosphorite particles are axially injected from above into the reactor. Therefore, a one-dimensional model can be adopted. The two-dimensional particle motion is allowed for by varying particle scattering cone diameter. The time step is $\Delta\tau=10$ s. The initial parameters of the main regime are: plasma temperature $T_g=6000$ K; reactor channel wall temperature $T_w=2000$ K; air flow rate $G_g=0.007$ kg/s; mass particle concentration in the gas $\mu_p=0.5$ kg/kg; particle velocity $v_p=10$ m/s; particle size $d_p=100$ µm; reactor channel diameter $D=0.050$ m; particle scattering cone-to-reactor diameter ratio $D_c/D=0.5$; initial reactor cross section power $N_1=105$ kW.

Several calculations involving modified parameters are shown in Fig. 1. The form of the relations in Fig. 1a and 1b is attributed to the effect of volume concentration on heat exchange between plasma and reactor channel walls as well as between plasma and phosphorite particles. This concentration contribution can be determined from expressions (5) and (8). The optimum initial volume concentration ($\beta=5.10^{-4}$) can be found from expression (9).

4. EXPERIMENTAL

Experiments are performed in the multi-jet plasma reactor with the channel diameter D=50 mm. The initial reactor cross section power is $N_1=50\text{-}70$ kW; total air flow rate, $G_g=0.005\text{-}0.008$ kg/s; bulk plasma temperature, $T_g=3800\text{-}5300$ K. In the reactor, P_2O_5(28%)-containing phosphorite is processed and the particle size varies from 100 to 160 µm.

Plasma processing of phosphorite yields liquid slag and condensed calcium phosphates shaped as fine particles less than 10 µm in size. These particles are trapped with the filter. The phosphorite conversion degree is determined from the chemical analysis of slag and phosphate ore as the mass relation of P_2O_5 exhausted from phosphate to P_2O_5 in the phosphate ore.

5. COMPARISON OF CALCULATION AND EXPERIMENT

The calculated value of the phosphorite conversion degree is determined by:

$$K_p = 3600(\psi_1 - \Delta\psi_3) / K\Delta H_R \qquad (11)$$

where ψ_1 and $\Delta\psi_3$ are the total energy consumption and the part of the energy consumption for phosphorite heating up to a decomposition temperature, T_R=3200 K, respectively. Figure 2 shows the theoretical conversion degree versus energy consumptions when there are no heat losses to the reactor channel walls, Q_{wp}, and heat losses with the exit gas, Q_{ex}. These losses are available during experiment and allowed for in numerical calculations. Therefore, the total experimental energy consumptions are much greater than the theoretical ones. The data in Fig. 2 indicate that the calculated values of dispersed phosphorite processing in the plasma reactor coincide well with the experimental ones. Thus, the mathematical modelling can be applied to evaluate the effective processing of dispersed phosphorite in the multi-jet plasma reactor under the assigned initial and boundary conditions.

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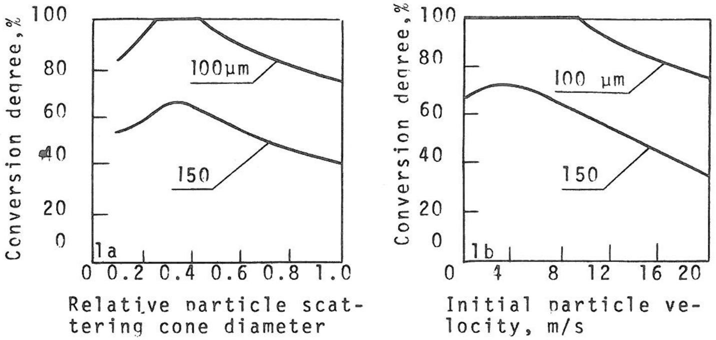

Fig. 1 Phosphorite conversion degree as a function of the initial relative particle scattering cone diameter (1a) and initial particle velocity (1b).

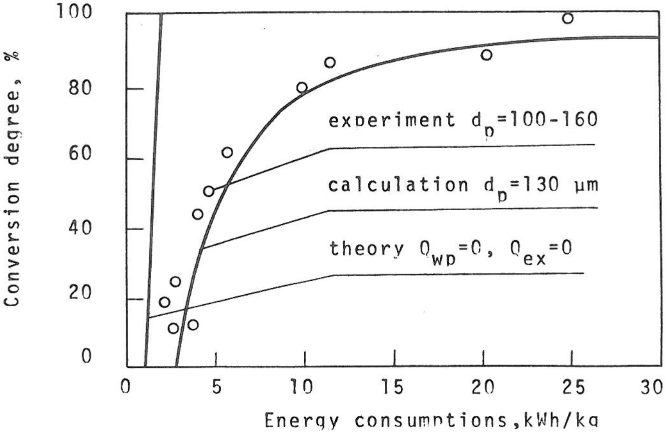

Fig. 2 Conversion degree versus energy consumptions