MATHEMATICAL MODELING OF THE PROCESS OF SINTERING IN TUBULAR ROTARY FURNACES

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This article examines the essence of the process of sintering a charge to obtain clinker for the production of Portland cement. The application package ReactOp is used to construct a model of the rotary furnace employed for this operation. Relations are found for the concentrations of the main components of the charge along the furnace and the overall change in the main mass flows.

Rotary kilns are widely used in the production of alumina and ceramics, in the cement industry, and in other areas of commerce. Among the distinguishing characteristics of kiln operation in these cases are the use of high sintering temperatures, the long time that the charge remains in the furnace, and the high velocities of gas flow in the unit. Sintering is accompanied by significant changes in the chemical composition of the reacting phases and an increase in the overall volume of the gas phase. Most of the processes which take place in sintering furnaces are endothermic and require a substantial amount of heat, which comes from the combustion of different types of fuel [1]. Natural gas is the fuel used most often in Russia. Natural gas supplies the necessary amount of heat without the formation of solid products from the fuel’s combustion. The end product is of higher quality and the sintering operation is controlled more easily than when other fuels are used. Decarbonization is involved in the main furnace processes that take place upon introduction of the charge when cement is being made or when sintering is being done as part of alumina production. Carbonates of calcium and magnesium are decomposed during decarbonization, which takes place in addition to drying of the materials in the furnace and the removal of water from crystallohydrates. Various schemes are now being devised to realize these processes [2]. In addition to sintering – in which all the processes involved in transformation and sintering of the charge take place in one rotary furnace – there are schemes that entail the use of multiple pieces of equipment to transform the charge materials in different stages. To determine the optimum conditions for performing these operations, it is necessary to use a mathematical model that describes the main physicochemical transformations which take place [3–5]. Such a model will make it possible to quantitatively describe the entire course of these transformations over the length of the furnace, determine the optimum conditions for the different stages of the process as a whole, and determine the optimum automation scheme and system to maintain the chosen optimum operating regime [6].

We will examine the construction of a mathematical model to describe sintering in a tubular rotary furnace. As an example, we will use the sintering of a charge to obtain clinker components in the production of Portland cement. The model

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was constructed using the systems of reactions that occur in obtaining the components of clinker. The software employed was the programming complex ReactOp, developed at the Applied Chemistry Russian Science Center in St. Petersburg [7]. This application package has a bank of models describing reactors characterized by different hydrodynamics and heat-exchange conditions. It can be augmented by a special system of chemical transformations. The automated system in the complex provides for synthesis of the mathematical model in an editor along with the system of chemical changes just mentioned. In standard models, mathematical models are synthesized for single-phase flows with the reaction phases and heat carrier moving in one direction. The new complex modifies the standard models with the use of the algorithmic language Fortran, which makes it possible to construct a nonstandard model of a multiphase counter-current reactor adapted for specific operating conditions.

In obtaining the clinker components at the plant Metakhim, the following reactions occur in accordance with the mineralogical composition of the initial charge:

\[
\begin{align*}
\text{CaCO}_3 &= \text{CaO} + \text{CO}_2, \\
\text{MgCO}_3 &= \text{MgO} + \text{CO}_2, \\
\text{Al}_2\text{O}_3\cdot(\text{SiO}_2)\cdot\text{H}_2\text{O} &= \text{Al}_2\text{O}_3\cdot(\text{SiO}_2) + 2\text{H}_2\text{O}, \\
\text{Al}_2\text{O}_3\cdot(\text{SiO}_2) &= \text{Al}_2\text{O}_3 + 2(\text{SiO}_2), \\
2\text{CaO}\cdot\text{MgO}\cdot2\text{SiO}_2 + 2\text{CaO} &= 2(2\text{CaO}\cdot\text{SiO}_2) + \text{MgO}, \\
\text{CaO}\cdot\text{MgO}\cdot\text{SiO}_2 + \text{CaO} &= 2\text{CaO}\cdot\text{SiO}_2 + \text{MgO}, \\
2\text{CaO}\cdot\text{Al}_2\text{O}_3\cdot\text{SiO}_2 + \text{CaO} &= 3\text{CaO}\cdot\text{Al}_2\text{O}_3 + \text{SiO}_2, \\
2\text{CaO} + \text{SiO}_2 &= 2\text{CaO}\cdot\text{SiO}_2, \\
2\text{CaO}\cdot\text{SiO}_2 + \text{CaO} &= 3\text{CaO}\cdot\text{SiO}_2, \\
3\text{CaO} + \text{Al}_2\text{O}_3 &= 3\text{CaO}\cdot\text{Al}_2\text{O}_3, \\
4\text{CaO} + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3 &= 4\text{CaO}\cdot\text{Al}_2\text{O}_3\cdot\text{Fe}_2\text{O}_3.
\end{align*}
\]

With allowance for the equations describing heat exchange between the phases and heat losses to the surrounding medium, the equations of the mathematical model for the processes that take place in the sintering of a charge to obtain clinker can be represented as follows for the steady-state regime of furnace operation:

\[
\begin{align*}
\frac{dc_{ij}}{dl} &= \frac{1}{u_s} \left( \sum_{j=1}^{M_t} w_{ij} \pm m_{igs} \right), \\
\frac{dc_{ig}}{dl} &= \frac{1}{u_g} \left( \sum_{j=1}^{M_g} w_{ijg} \pm m_{igs} \right), \\
\frac{dT_s}{dl} &= \left( \sum_{j=1}^{M_t} w_{ij} Q_j + K_{ip}(T_s - T_R) \right) / \left( u_s c_s d_s \right), \\
\frac{dT_g}{dl} &= \left( \sum_{j=1}^{M_t} w_{ij} Q_j - K_{ip}(T_s - T_R) - \frac{4K_T}{d_{ap}}(T_g - T_0) \right) / \left( u_g c_g d_g \right).
\end{align*}
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