Controlling the temperatures during the calcination of aluminum hydroxide in rotary kilns

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Abstract. Processing 4.1 to 4.2 tons of nepheline concentrate mixed with limestone produces 1 t of alumina, 0.8 t of sodium carbonate, 0.3 t of potash, and 10 tons of cement. The costs of producing these from nepheline are significantly lower than the costs of individual production from conventional raw materials by conventional technology. Unlike the traditional ammonia-based method, the nepheline technology of producing soda ash is environmentally friendly and does not require costly sludge fields. Using belite sludge as the raw material for making cement improves the performance of kilns and reduces the fuel consumption by over 40% compared to the conventional technology. Making alumina with a specific content of $\alpha$-$\text{Al}_2\text{O}_3$ and $\gamma$-$\text{Al}_2\text{O}_3$ requires an automated process control system (APCS). In an industrial setting, only automatic controls enable maintaining a technologically healthy process. This paper presents a summary of the aluminum hydroxide calcination process that occurs in tubular rotary kilns. The research team has synthesized a dynamic control object model to plot curves of the target-parameter acceleration as induced by stepwise disturbances in air flow, charge flow, and fuel flow in order to compute the basic dynamic characteristics of the control object. A control parameter has been selected for the prospective single-loop control system. On the basis of the obtained characteristics, the research team has selected a controller for their single-loop kiln temperature stabilization system. The paper presents curves of the control-channel and disturbance-channel transients in the target parameter.

1. Introduction

Russia and the CIS have very limited natural reserves of the fundamental aluminum raw materials (high-quality bauxites with an A/S ratio of 12 or above) manufacturable with the easy and cost-effective Bayer method [1-7]. It is only the Northern-Ural Bauxite Mine (the SUBR) that meets these requirements, albeit hardly.

This is why since its very infancy, the Russian aluminum industry has been using non-bauxite raw materials (nephelines, alunites) as well as low-quality bauxites with a high content of harmful silica impurities (the A/S ratio of such bauxites is about 3.0). Russian scientists have developed efficient methods for processing low-quality aluminum materials; these methods have gained worldwide recognition. Nephelines (ores and concentrates) undergo a unique integrated zero-waste treatment, which consists in sintering nepheline-limestone charge to produce alumina, soda ash, potash, potassium sulfate, Portland cement, while also extracting gallium from the aluminate solutions [1-4, 7].
The main challenge of the calcination process is to control the temperatures in the $\gamma$-$\text{Al}_2\text{O}_3$ and $\alpha$-$\text{Al}_2\text{O}_3$ calcination zone, which is the subject matter of this paper.

2. Statement of Problem
Calcination is intended to minimize the cost of alumina while keeping high quality.

The quality of alumina is evaluated over a certain sintering kiln runtime, e.g. 24 hours. The operator monitors the temperature of the material leaving the sintering zone (subject to criterial optimization) over a certain kiln runtime; the temperature is then averaged for this time $T$. Therefore, the recommendable quality control criterion is variance, as the quality of alumina is a function of the material temperature in the calcination zone, which changes over time.

The smaller the variance, the smaller the temperature variation, the less time it takes to establish a nominal temperature, the more efficient the stabilizing system is.

Therefore, the parameter that could serve as the ACS quality criterion is the variance in the material temperature in the sintering zone or the proportional cumulative squared error written as [8-10]:

$$J = \int_0^T \Delta^2(t) \, dt \quad \text{or} \quad J = \int_0^T (\Delta^2(t) + \gamma^2 \cdot \Delta(t)) \, dt$$

where $\Delta(t)$ - the error signal (misalignment) and $\gamma$ - the weight factor. The control is intended to stabilize temperature.

3. Plotting Target-Parameter Acceleration Curves
The control object has been described in MathCad on the basis of heat and mass balances. To simulate the control system by disturbance and control channels, one needs to assign each channel type. The channels under analysis are the air flow, the charge flow, and the fuel flow.

In order to find which channel could be used as the disturbance channel, and which — as the control channel, it is necessary to find the amplification factors for each channel, see Figures 1 and 2, for example, acceleration curves. The control channel is the one with the largest amplification factor; the disturbance channel features the lowest factor.

![Figure 1](image-url)
4. Synthesizing a Single-Loop Control System

The optimal quality criteria for such system are: minimum adjustment time; minimum cumulative error; and appropriate control action, which affects the controller settings [2, 9, 10].

This paper uses the minimum cumulative squared error as the only criterion, as the calcination process runs continuously. The chosen controller is a PI controller. Figure 3 shows the block diagram of the control object.

**Figure 3.** Block diagram of a single-loop deviation-stabilizing system.

**Legend:** CO is the control object (tubular rotary kiln); $\Delta G_{O_2}$ is the disturbance (air flow); $\Theta_{\text{main}}$ is the output parameter (temperature upon leaving the calcination zone); $\Theta_{\text{conf}}$ is the configured output-parameter value; $\Delta G_{\text{fuel}}$ is the control signal; $W_{G_{O_2}-\Theta_{\text{main}}}$ is the CO transfer function for the disturbance channel; $W_{G_{\text{fuel}}-\Theta_{\text{main}}}$ is the CO transfer function for the control channel; $W_{\text{controller}}$ is the controller; $\Delta \Theta_{\text{main}}$ is the controller input error.

The control input error is the difference between the actual and the configured output-parameter values:

$$\Delta \Theta_{\text{main}} = T_{\text{real}} - T_{\text{conf}}.$$

Figures 4 and 5 present curves of the control-channel and disturbance-channel transients in the target parameter.
5. Conclusions
Adjustment time for the process conditions is 260 seconds for a transient with a stepwise configuration; 280 seconds for a transient with a stepwise adjustment in the disturbance-channel signal. Since the material spends about 70 minutes within a kiln on average, the controller response time is satisfactory in both cases. The objective here is to stabilize temperature; given that the controlled parameter does not deviate from the configured value by more than 5%, the objective is deemed to be attained.

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