PID control of rotary lime kilns using decoupling control

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Abstract: Calcination in a rotary kiln is a key unit operation in the kraft pulping process, enabling internal regeneration of pulping chemicals through the recausticizing cycle. In this cycle, lime mud—consisting primarily of calcium carbonate ($CaCO_3$)—is thermally decomposed into reactive calcium oxide (CaO), which is subsequently reused to convert green liquor into white liquor. This closed chemical loop is essential for sustained wood delignification and directly links kiln performance to pulp production efficiency, chemical balance, energy consumption, and overall process stability.

The lime kiln consists of a large, inclined, slowly rotating cylindrical reactor. Lime mud is continuously fed at the inlet of the kiln, and is transported by the rotation and incline of the kiln. An oil burner is located at the outlet, and a draft fan positioned near the inlet induces counter-current flow, drawing hot combustion gases through the kiln toward the incoming lime mud. As a result, wet lime mud is dried, heated, and calcined while being transported along the kiln.

Kiln control is commonly achieved using two independent PID controllers regulating the inlet and outlet temperatures, where the manipulated variables are typically burner power and draft fan flow. This control configuration suffers from several fundamental limitations. The inlet and outlet temperatures are strongly coupled, and exhibit non-minimum phase behavior. The system is characterized by very long dead-times due to the large kiln volume and slow material transport. Tuning the controllers is challenging as most experiments take several hours and tend to become riddled with disturbances due to, e.g., feed variability.

As a novel approach, this work introduces a simple decoupling strategy based on transforming the measured inlet and outlet temperatures into their mean and differential components. The coordinate transformation significantly reduces loop interaction and removes the non-minimum phase behavior. As a consequence, the control problem becomes tractable and intuitive. Controller tuning is carried out using step-response experiments on a validated offline process model, thereby avoiding disruptive and time-consuming experiments on the physical kiln.

The proposed control strategy has been implemented in more than ten industrial lime kiln installations at the time of writing. Operational results demonstrate energy savings on the order of 5–10%, improved robustness to varying production rates, and reliable operation across multiple fuel types. In addition to its performance benefits, the approach is transparent and easy to understand for both operators and engineers, and it can be implemented using standard function blocks available in all industrial control systems.

Keywords: PID control, Decoupling control, Pulp and paper, Rotary lime kiln