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Advanced control strategy for rotary lime kilns based on the real time measurement of nodule particle size distribution

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Abstract— Process automation and control improve industrial processes by increasing productiveness, effectiveness and safety, which is needed for corporations to remain relevant in a competitive and demanding scenario. Rotary lime kilns are energy intensive equipment used in the pulp and paper industry to process lime sludge and recover reburned lime; nonlinearities, slow dynamics and long time delays make it a challenging process to control. From manual control to PID-based to MPC and expert system strategies, many previous efforts from the literature have contributed to improve the operation of rotary kilns, and in this work we present how the online measurement of nodule particle size distribution can drive the process performance even further. In particular, we discuss how the operating variables kiln rotation speed, flue gas temperature and lime temperature impact the nodule size distribution. We also discuss ideas for further research aimed to understand the fundamental chemistry in the formation of reburned lime at high temperatures.

I. INTRODUCTION

Rotary lime kilns are an energy intensive equipment in the pulp and paper industry, however they are essential to recycle the lime sludge created in the caustizing process by producing reburned lime. It is expected that the reburned lime has a high and consistent reactivity, that it is produced at the required flowrate and that the process is as energy efficient as possible while complying to environmental legislation on emission of pollutants. The lime reburning process is a complex, multivariable and nonlinear control problem with slow dynamics, or in other words, a process that greatly benefits from advanced control strategies. For example, the strategy presented in [1] reports that simple PID controllers can decouple the effect of energy supply to the oven (usually the flowrate of fuel) and the flowrate of flue gas on the temperature of lime sludge inside the kiln the heat transfer between flue gas and lime sludge in the kiln, respectively. [2] developed an expert system based on neural network models to keep the flue gas exit temperature from the kiln and furnace oil flowrate between given limits and claimed that such strategy would perform better than PID-based control. Similarly, [4] used an expert system control approach, based on a Takagi-Sugeno fuzzy model to control a grate-kiln.cooler for iron ore pellets, but the choice of controlled and manipulated variables resembles the one in [1], as the aim is to decouple heat suply and heat distribution. A MPC-based strategy was developed in [3], in which linear models for the relationships between inputs (fuel gas flowrate, percentage opening of the induced draft damper) and output (front-end and back-end temperatures in the kiln) were obtained using Taylor approximation. A review study summarizing control strategies for rotary kilns was also published [5].

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In this contribution, we present the main results from the research project Effective control of rotary kilns using particle size measurements (original title in Swedish ”Energieffektiv mesaugnsstyrning genom partikelstorleksmätning”) and discuss directions for further development and research, aiming towards decreased energy consumption, decreased emissions to the environment and increased lime quality.

II. METHODOLOGY

The objectives of the project were to investigate how nodule particle size distribution can be used as a controlled variable in control design of the lime reburning process, and in particular investigate how kiln rotation, flue gas temperature and lime temperature affect nodule particle size distribution. In order to meet these objectives, several campaigns were run in the lime reburning circuit from Södra Cell in Mönsterås, Sweden, in which each of the studied variables were varied between different values, while the other studied variables and as many as the other variables that affect the process were kept constant. The nodule particle size distribution in the kiln was measured online using Optimation Advanced Measurement AB's 3DPM.

III. RESULTS AND DISCUSSION

It was observed that the 3DPM camera performed well, even in a challenging environment. Particle sizes were measured down to 2 mm, and no unexpected stops were reported over a period of 13 months. An obvious advantage is that, compared to sieve tests ran in a laboratory, online measurement of particle size distribution enables it to be used actively in control algorithms. Furthermore, results of the operation campaigns showed that the lime temperature has a strong correlation with nodule particle size distribution (see Figure 1), while rotation speed of the lime kiln and flue gas temperature have insignificant and weak correlation, respectively.

However, the data collected from rotation speed and flue gas temperature campaigns showed that both kiln rotation speed and flue gas temperature have a strong impact on heat transfer. The rotation speed and bulk

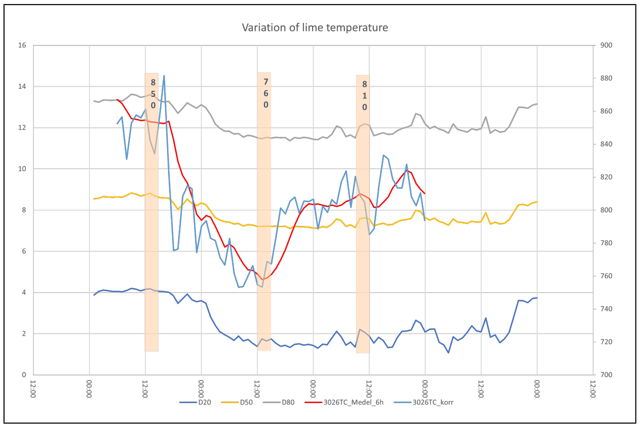

Fig. 1. D_{20}, D_{50}, D_{80}, Filtered temperature and measured temperature over time for different lime temperature setpoints.

density of material in the kiln define the heat transfer area between flue gas and lime sludge, and the larger the heat transfer area, the less fuel is required to reach a given lime temperature. The bulk density of material is in turn dependent on the nodule particle size distribution, and in particular the amount of fines, that cause high dust content. It was observed that a 20% content of fines in the kiln reduced its filling grade by 20% and its heat transfer area by 8%, resulting in a 5% increase in the fuel flowrate, compared to normal dust conditions (around 2% fines). On the other hand, a reduction of 25% in the kiln rotation speed is equivalent to a increased heat transfer area that corresponds to a difference of 100°C in the flue gas inlet, which in turn corresponds to energy savings around 5%.

IV. CONCLUSIONS AND FUTURE WORK

Results from previous work have shown the potential of on-line nodule particle size distribution measurements in designing advanced control strategies for the lime reburning process. Particle size distribution information can be analyzed in a combination with factors that were not tacked in the original study, for example flowrate of external lime or alternative fuels (metanol or wood). In particular, metanol can introduce sulfur in the reburning process which can react with vestiges of sodium from the causticization process to produce components that have high melting or vaporization points. These components accumulate in the reburning process and might have a negative effect on energy efficiency. Fundamental research to understand how sulfur components affect heat transfer and formation of fines (lime dust) in the kiln contributes to a deeper understanding of the process and might lead to design of better control strategies. To the best of our knowledge, no research has been done in this field. Flame analysis using cameras, either as a source of images [7] or videos [6], has been reported in the literature, but its results have not incorporated in control design. It can be interesting to investigate how flame shape or behavior in a rotary kiln correlate to the agglomeration of nodules, and in turn the degree and consistency of reburned lime's reactivity.

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