Modelling and Optimization of Peroxide Pulp Bleaching Process

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***Abstract*—The wood pulp industry has been around for a long time, but new higher quality pulp require more advanced solutions to old processes. One of these processes is the complex peroxide (PO) bleaching process, which is the last of a whole chain of bleaching processes at the Mörrum pulp processing plant. In this thesis a novel hybrid model was developed to accurately predict the brightness of the outgoing pulp. The hybrid model uses a combination of kinetic reaction and Gaussian Process Regression (GPR) models. With this hybrid model the PO process was able to be optimized in simulations to lower chemical usage and obtain the correct pulp brightness.**

***Index Terms*—Wood pulp, bleaching, peroxide, Gaussian processes, optimization.**

I. Peroxide Pulp Bleaching Process

This thesis was conducted with the help from Södra Cell and focuses on the peroxide bleaching process (PO-stage) at their pulp plant in Mörrum. The purpose behind the PO-stage is to raise the pulp brightness using the chemicals H_2O_2 and $NaOH$. Thus, the thesis' goal was to develop a model that is able to predict the pulp brightness after the PO-stage and use the model to optimize the chemical dosages.

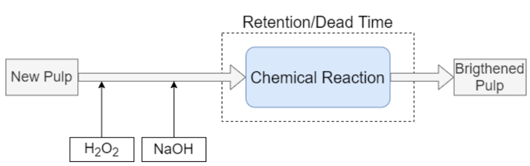

Fig. 1. Simplified schematic of the peroxide bleaching process.

Figure 1 shows a simplified chart of the PO-stage. Retention and dead time are in this case the same, which is the time between new pulp entering the process and obtaining the brightness results of that pulp. The dead time being a few hours long causes a few difficulties and after initial tests the problem of modelling the process could be divided into two main parts:

- The nominal chemical reaction of the peroxide bleaching process.
- The change in bleachability as the pulp properties change with new pulp coming into the process.

The second part is the results of the dead time being so long and pulp properties constantly changing. A chemical reaction model will not be able to be accurate if the pulp properties have changed and the change doesn't show up in the results until a few hours later. Additionally, the dead time changes with the production speed of the plant, which adds more uncertainty for implementation on the real process. Predicting the dead time, however, was skipped in favor of focusing on the peroxide process, as predicting production speed of a whole plant is another type of problem entirely.

II. Methodology

The main part of the thesis work consisted of creating and testing process models. However, only the most accurate brightness model will be shown here, which is the C8 GPR model. The C8 GPR model is a combination of two models: a kinetic bleaching model and a Gaussian Process Regression (GPR) model. To understand how the C8 GPR model works, a bit of information of the two individual models are needed.

The kinetic bleaching model is a kinetic reaction model that models the chemical reaction of the peroxide pulp bleaching. It was developed and tested at a sister-mill to Mörrum [1]. The model uses chemical dosages, brightness, temperature and retention time as inputs, and then predicts the output brightness after the PO-stage. Exactly how it works would take too much time to explain, but it consists of three differential equations representing the chemical reactions. One detail which is important for the hybrid model, is the C8 parameter of the kinetic bleaching model, which represents the maximum brightness the pulp can achieve for the PO-stage.

The GPR model is a well known machine learning model that uses conditional probability and training data to make predictions of the future output [2]. The training data are past values of the GPR models input and output. In this case the input is a collection of chosen measurements prior to the process and the output is the aforementioned C8 variable of the kinetic bleaching model.

A. C8 GPR Model

The idea behind the model is to let the GPR model predict the pulp properties of the incoming pulp, and then use this prediction to improve the kinetic bleaching model. The GPR model does this by making a prediction of the C8 variable, which represent the bleachability of the pulp. The prediction is based on a selection of different input features. Then, the kinetic model can use this newly predicted C8 variable along with the usual inputs to make a brightness output prediction.

B. Optimization

Very little time was spent on the optimization part, and instead the focus was on developing an accurate model. Nonetheless, the goal attainment method [3] was used on the kinetic bleaching model. The method balances output brightness with H_2O_2 and $NaOH$ dosages to either obtain a high brightness or save on chemicals depending what goals are set.

III. Simulations

To properly test the C8 GPR model, simulations used 12-days worth of logged data directly from the Mörrum plant. In the figure below, the prediction of the model can be seen to be accurate for the large slow changes in output brightness. But, the difficult part is predicting the fast changes in pulp bleachability, which is up to the GPR part of the model to handle.

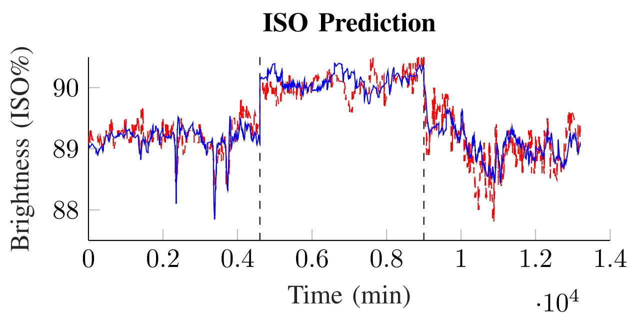

Fig. 2. The figure shows the output brightness prediction of the C8 GPR model for the complete data set. Model prediction (blue lines) is compared to measured values (red lines). The dashed vertical lines mark the change in data sets.

With the decent working model from above, the chemical dosages could be optimized make the output brightness reach a certain target value, 89.5% in this case. Below, Figure 3 shows how the optimization lowers the brightness when it is over the target and raises it when it is below. This can both save chemicals and prevent the pulp from being unusable due to low brightness.

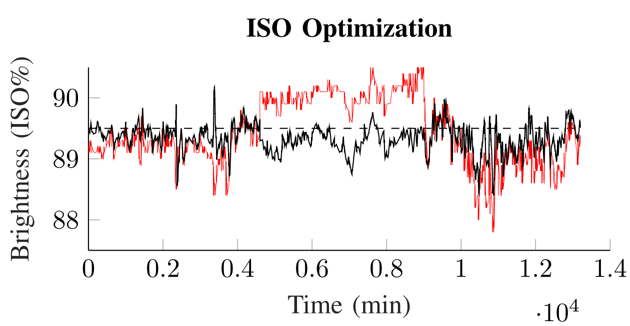

Fig. 3. The figures show the output brightness prediction of the C8 GPR model for the complete data set. Model prediction (blue lines) is compared to measured values (red lines). The dashed horizontal line mark the desired brightness of 89.5%.

IV. Conclusion and Future Work

One of the key findings of this thesis was that the long dead time and variable pulp properties cause a fundamental limitation for the kinetic bleaching model. The GPR model having moderate success in predicting the changing pulp properties is another takeaway from this thesis.

While the optimization part was not studied extensively, it did show how the model could be used to improve the process. The optimization part is also an area which require further research. Testing more optimization methods or go more in a control system direction. Although the results show promise, the C8 GPR model is far from ready to be applied on the real process at a pulp plant. Improvements can be made in many different ways: adding more sensors throughout the process, using larger data libraries for the GPR model and using measurements from earlier bleaching stages. Additionally, robustness is a critical part of any industrial model implementation, which was not tested in the simulations here.

Acknowledgment

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References

[1] L. Alberth, "Experimentell studie av kinetiken för peroxidblekning av pappersmassa," vol. 4, no. 9, 2011.

[2] C. E. Rasmussen and C. K. I. Williams, *Gaussian processes for machine learning*. Cambridge, Mass. : MIT Press, cop. 2006, 2006.

[3] F. Gembicki and Y. Haimes, "Approach to performance and sensitivity multiobjective optimization: The goal attainment method," *IEEE Transactions on Automatic Control*, vol. 20, no. 6, pp. 769–771, 1975.