EUROSIM 2016

Simplified mechanistic model of the Multiple Hearth Furnace for control development

Gomez Fuentes J. V., Zakharov A., Jämsä-Jounela S.-L.
Aalto University, School of Chemical Technology, Research group on Process Control and Automation,
P.O.Box 16100, FI-00076, Aalto, Finland (e-mail: jose.gomezfuentes@aalto.fi)

Abstract

This work presents the simplified mechanistic model of a Multiple Hearth Furnace (MHF), developed for process control implementation. The detailed mechanistic model of the MHF and its solving procedure are introduced. Based on the detailed model, the simplified model is developed in the nonlinear Hammerstein-Wiener form, which defines a specific type of nonlinear state space models suitable for example for Model Predictive Control (MPC) implementation. The simplified model aims to preserve the key physical-chemical phenomena taking place in the furnace and to reproduce the nonlinear dependencies between the input and output variables. Finally, the paper presents the simulation results to compare the mechanistic and the simplified models. The comparison confirms that the dynamics of the simplified model accurately follows the mechanistic model outputs.

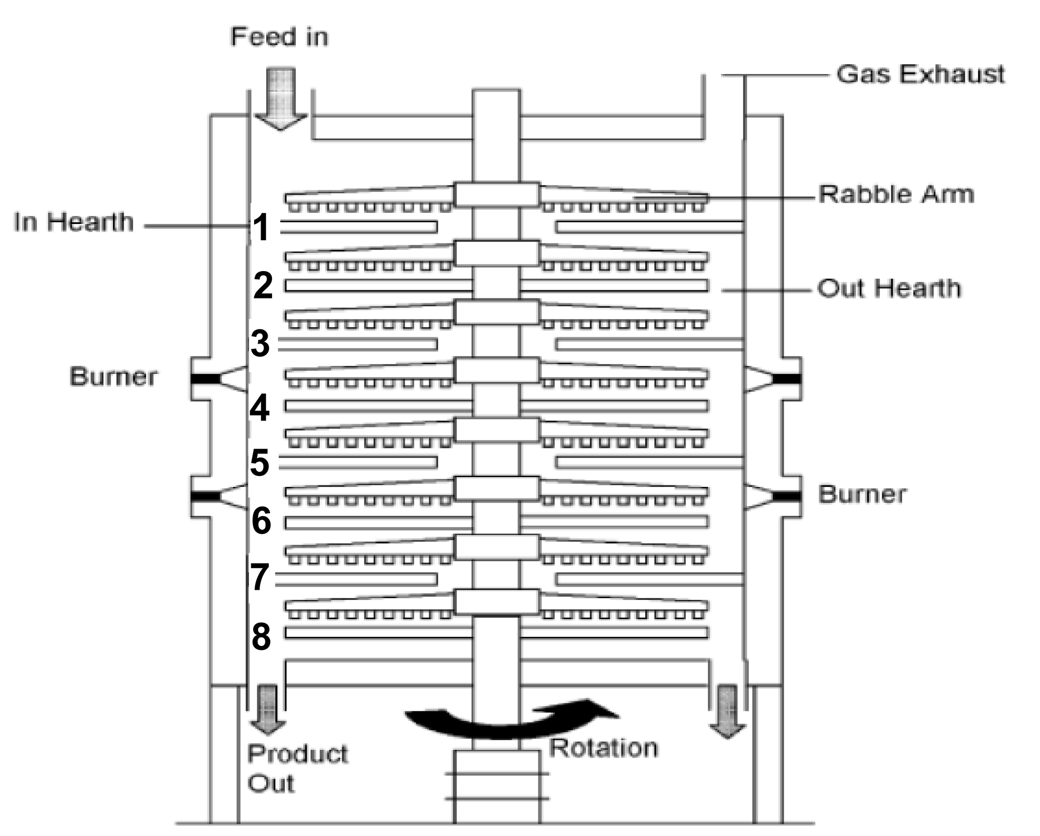

Figure 1. Cross-sectional picture of the Herreschoff calciner with direct fire burners

Process Description

This work considers a multiple hearth furnace used for kaolin calcination (Figure 1). The furnace has eight hearths, and eight burners located in hearths 4 and 6. The temperature of the solid increases as it travels down through the furnace and reaches its maximum in Hearth 6. Kaolinite transforms to metakaolin at the temperature between 400-700 °C. The metakaolin is released from hearth 5 at a temperature of 800 °C. In hearth 6, the transformation of metakaolin to the Al–Si spinel phase occurs at 925-1050°C.

Mechanistic Model

The modeling equations are developed for the six parts of the MHF: the gas phase, solid bed, central shaft, walls, rabble arms, and the cooling air. The model comprises the calcination reaction kinetics, the mass and energy balances, the transport phenomena inside the MHF, as well as additional equations describing the temperature dependent parameters.

Model Simplification

The simplified model is expressed as a Hammerstein-Wiener model (HWM). With the following structure:

$$x_{t+1} = \alpha x_t + (1-\alpha)F(u_t)$$
$$y_t = G(u_t, x_t)$$

$F(u_t)$is a static nonlinear function calculating the steady state of the furnace using the process input values, which are compiled previously from the mechanistic model as a look-up table. The second function $G(u_t, x_t)$, calculates the gas temperature profile next to the walls in the Hearths based on the current furnace state x_t (temperature of the solids and the internal wall temperature in the hearths) and the process inputs u_t (kaolin feed rate, gas flows to the Hearths 4 and 6). The function $G(u_t, x_t)$is implemented by solving the energy balance for the gas phase derived from the mechanistic model.

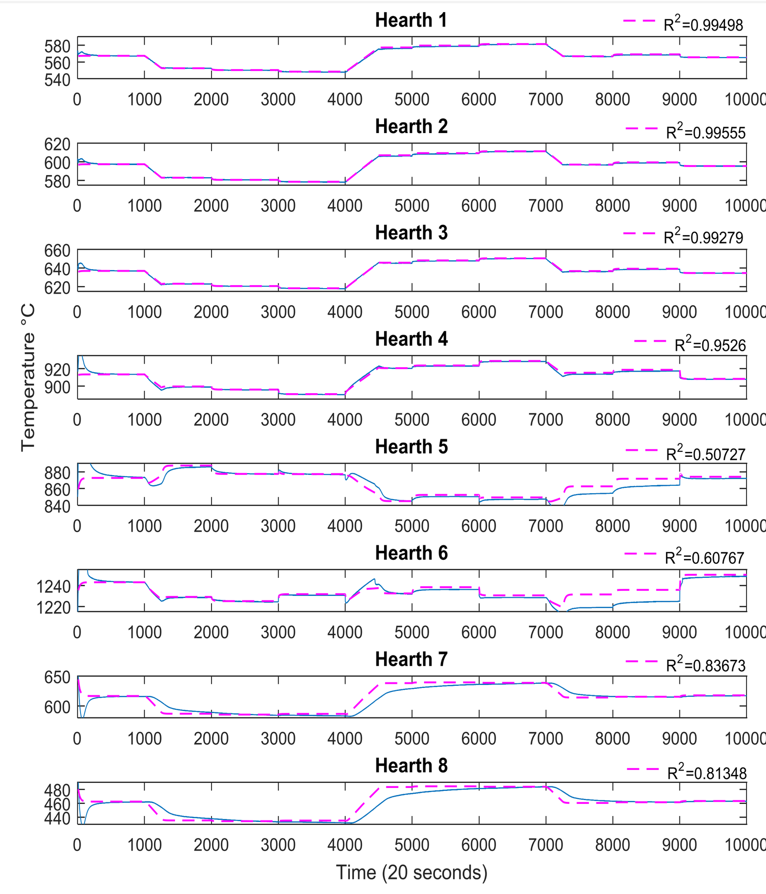

Figure 2. Comparison of models gas phase temperature

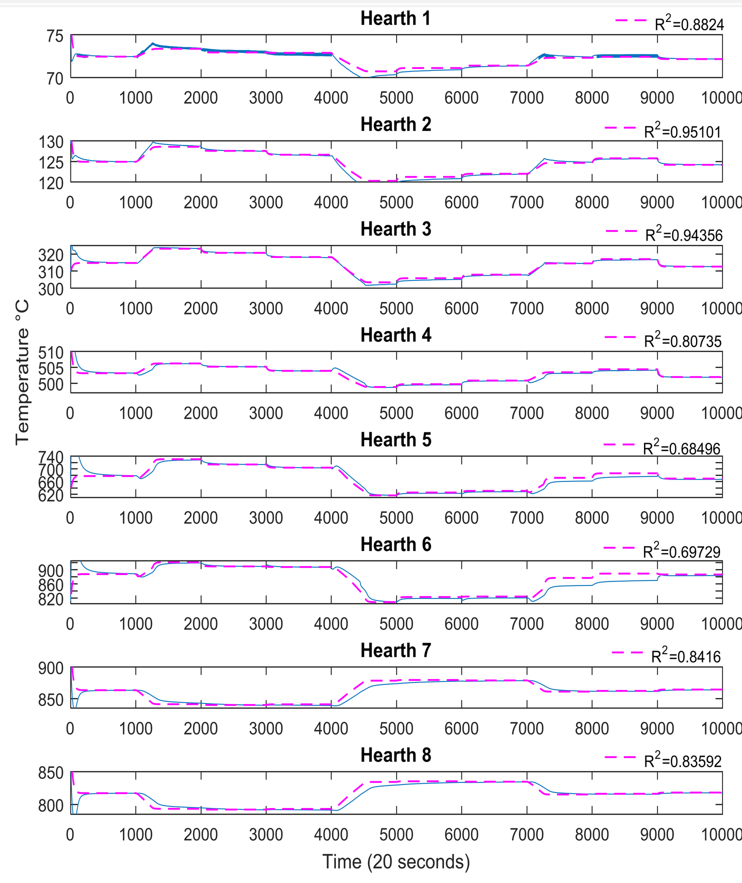

Figure 3. Comparison of models solid phase temperature

Results

The simulation study has been conducted to evaluate the performance of the simplified model by comparing its predictions with the results of the detailed mechanistic model. The results of the simplified model are shown as dashed lines. With step and ramp inputs to process, the comparison of the model predictions (Figures 2 and 3) shows excellent simplified model accuracy for all hearths, specifically in hearths 1 to 4 and 7-8.

References

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Acknowledgments

The research leading to these results has received funding from the European Commission under the 7th Framework Programme (FP7/2013-2016) under Grant Agreement number 310645