Model predictive control utilizing fuel bed height model and moisture soft-sensor for the BioPower plant

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ABSTRACT

The usage of biomass fuel for heat and power production is growing due to an increasing demand for replacing of fossil energy sources with renewable energy. Typical biomass fuel is usually a blend of different batches, for example, spruce bark and dry woodchips with varying moisture content between 30% and 55%. This varying moisture content of the fuel results in uncertainty in the energy content of the fuel and complicates the operation of combustors. One of the latest developed processes, which can burn biomass fuel with high moisture is BioGrate technology developed by MW Biopower. In the BioGrate system, this is achieved by feeding the fuel onto the center of a grate, thus improving water evaporation due to the heat of the surrounding burning fuel and thermal radiation from the brick walls.

An important step in the control strategy development for BioGrate boiler has been to develop a method for estimating the furnace fuel flow and combustion power, as shown in theoretical studies and practical tests by Kortela and Lautala. On-line measurements of oxygen consumption were used when a new cascade compensation loop was built to optimally control the fuel flow. It was reported that the amplitude and the settling time of the response of the generator power decreased to about one third of the original. In addition, advanced combustion control has been applied to control air and fuel. Havlena and Findejs used model-based predictive control to enable tight dynamical coordination between air and fuel to take into account the variations in power levels. The results showed that this approach enabled the boiler to be permanently operated with optimum excess air, resulting in reduced O_2 and a significant increase in the boiler efficiency. Similar results have also been reported for the application of a multivariable long-range predictive control (LRPC) strategy based on a local model network (LMN) in the simulation of a 200 MW oil-fired drum-boiler thermal plant and for a scheme presented by Swarnakar et al. for robust stabilization of a boiler, based on linear matrix inequalities (LMIs).

An important prerequisite for model predictive control of biomass furnace is a simple mathematical model of the system, consisting of as few as as possible low-order ordinary differential equations. The simple model describes reality more approximately, but this does not matter since inaccuracies of the model as well as disturbances are compensated by the controller. Bauer et al. derived a simple model for the grate combustion of biomass based on two mass balances for water and dry fuel. The model was verified by experiments at a pilot scale furnace with a horizontally moving grate at full and partial load. The test results showed that the overall effect of the primary air flow rate on the thermal decomposition of dry fuel is multiplicative. In addition, the test results of Bauer et al. showed that the rate of water evaporation is mainly independent of the primary air flow.To estimate this water evaporation, Kortela and Jämsä-Jounela developed a fuel moisture soft sensor that is based on a dynamic model that makes use of combustion power estimates – which can be calculated based on the furnace's oxygen consumption – and that makes use of a nonlinear dynamic model of the secondary superheater. However, there is a need for a more accurate prediction of combustion power.

This paper presents a model predictive control (MPC) strategy for efficient energy production of a BioGrate boiler. In addition to compensating the main disturbances caused by variations in fuel quality such as fuel moisture content, and fuel flow, the fuel bed height of the grate is modeled and monitored. As a result, the primary air can be adjusted for a needed combustion power, and the power of the boiler can be predicted accurately. Therefore, the efficient stabilization of the plant operations is possible. The performance of the MPC is evaluated by a simulator which is

identified by using the industrial plant data, and compared with the authors' previously developed linear MPC of the BioPower plant. Finally, the results are presented, analyzed and discussed.