

Modelling and control of small-scale biomass combustion for emission reduction

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1 Introduction

Small-scale, biomass fired combustion units are typically operating under varying process conditions. For example, continuously changing heat demand and fluctuating fuel moisture content (Ruusunen, 2008) complicate the task to produce energy with high efficiency and low emissions. Unlike in large-scale combustion, where sophisticated measurement and control systems are available, lack of cost-effective sensors and automation sets hard limits to small-scale control. This, in turn, usually prevents the real-time minimisation of fuel usage and emission control in boilers having lower than 500 kW heat output. Small-scale biomass combustion has a major contribution to the harmful emissions of energy production sector in Finland.

Automatic control can be regarded as a primary measure for preventing combustion emissions. In this view, the control technology covers broadly the control methods, sensors and actuators for monitoring and controlling combustion. In addition to direct control of combustion process, it can also give tools for condition monitoring and optimisation of total heat consumption by system integration thus reducing the need for excess conversion of energy.

Combustion control is usually applied to achieve targets like steady heat output and constant oxygen level in flue gas. This means that disturbances, changes in fuel quality and heat load, are smoothed by the control actions reducing process variations. The control of the process behaviour is directly related to clean combustion since steady-state conditions in general are favourable for achieving lower emissions.

One of the main aspects for successful combustion control is the feedback from the process state. This may include direct (Good et al., 1998) or indirect measurements (Ruusunen, 2001; Ruusunen et al., 2004; Ruusunen, 2006a) from the variables to be monitored and controlled. With control algorithms, sophisticated air and fuel supply strategies can be then realised, as typically present in larger than 1 MW combustion units.

2 Objectives of the research

This research concentrates on modelling and control of decentralised biomass combustion processes. The main objective is to design reliable indicators for the quality of combustion by modelling and data-analysis. This enriched information is then utilised in development of model-based control strategy for small-scale combustion systems. The research is focused on combustion processes using wood chips, wood logs and pellets as a fuel.

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3 Results

Results of the investigation have been carried out using design of combustion experiments, process data analysis, including model and control development. Testing of constructed models and control strategy has been performed with several small-scale, grate fired units intended for heat production.

3.1 Analysis and simulation of biomass combustion

The capability of indirect measurements, namely process temperatures, for features indicating combustion quality and absolute values of variables was studied with the method similar to procedure presented in (Ruusunen et al., 2006b) and (Ruusunen, 2008). Several indicators have been found to be used in boiler efficiency approximation and fuel moisture content modelling, as well as to emission monitoring. For example, certain temperature differences can be utilised to estimate real-time boiler efficiency without the need for extensive and continuous gas analysis (Figure 1).

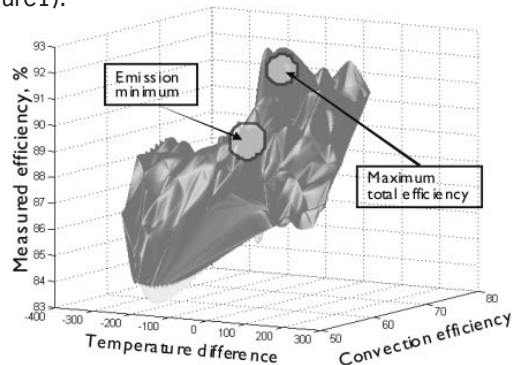


Figure 1 Boiler efficiency as a function of two extracted features by combustion data analysis (Ruusunen et al., 2007).

Dynamic behaviour of a grate fired combustion process has been studied by constructing a combination of mathematical models. Motivation was to have a tool for testing preliminary control strategies using simulator instead of a real process experiments. It can be concluded that accuracy of the simulator is satisfactory. More importantly, the process delays and dynamic behaviour in general are almost fully accounted by the models in this case, enabling the detailed study of the process behaviour.

3.2 Real-time modelling and control experiments

The developed and demonstrated control concept utilises data-based modelling approach for combustion state monitoring. The information is further integrated with the feedback control strategy, where knowledge of optimal operating conditions and instant heat output levels are used for stabilising the burning rate and excess air. This soft sensor approach has been chosen to explore possibilities to replace more complex, slower or expensive measurements needed for proper boiler control automation at distributed energy production. Results for fuel moisture content and oxygen models are presented in Figure 2.

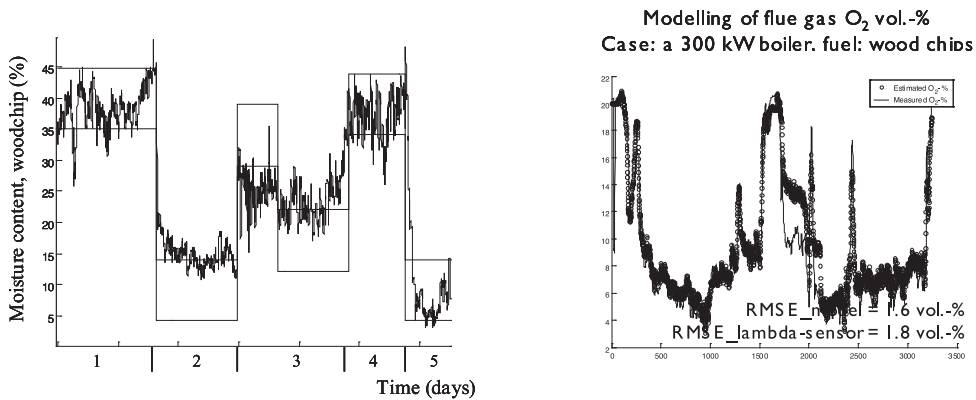


Figure 2 (a) measured (dashed box) and modelled (solid line) moisture content in woodchips (Ruusunen, 2008); (b) measured and modelled oxygen concentration (Ruusunen, 2006a).

Simulations and practical test result with a 300 kW commercial biomass boiler indicate significantly higher total efficiency and at the same time somewhat lower emissions in different operating conditions, when comparing typical set point control methods to the developed model-based control strategy (Figure 3).

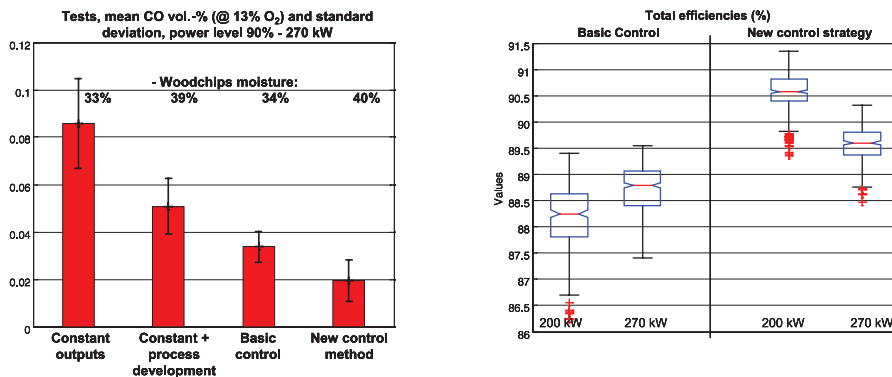


Figure 3 Comparison of the developed control strategy and conventional techniques in small-scale biomass fired boiler. (a) Carbon monoxide levels, (b) total efficiency with full and partial heat outputs (Ruusunen et al., 2007).

The disadvantage of model-based monitoring and control system is the need for accurate models, and usually a more complex design procedure. Deeper insight and understanding of the process is also required as well as representative data for model parameter identification. However, more efficient modelling procedures and analysis tools have been developed in this research to overcome difficulties that are present especially in small-scale biomass boiler environments.

The structure of the new control method has also portable properties that are needed for the concept to be applicable to variety of different combustion units. According to results, the combination of the presented model-based monitoring methods can also help to avoid time delays and compensate sensor failures in control.

4 Relevance of the research

Automatic control has already shown its potential in small-scale solid biomass combustion. Still mostly unrealised advantages of control are the adaptation to changes in combustion conditions (fuel, environment, device, user) and the continuous optimisation of the air/fuel ratio. Modern control technology also covers combustion condition monitoring, process diagnostics, and the higher level optimisation of the energy consumption with system integration. The results of this research can further help to design cost-effective control systems that continuously monitor and optimise combustion conditions in small-scale boilers. These primary measures can maximise the overall efficiency, enabling a significant reduction in fuel consumption and total emissions per small-scale combustion unit, continuously at the annual level.

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