Control Potential of Different Operating Methods in Small-Scale Wood Pellet Combustion (COPECOM)

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Project Summary

COPECOM – *Control potential of different operating methods in small-scale wood pellet combustion* was a research project funded by ERA-NET Bioenergy. The project consortium consisted of Tampere University of Technology (Finland), University of Oulu (Finland), Växjö University (Sweden), HT Enerco Oy (Finland) and MBIO Energiteknik Ab (Sweden). The duration of the project was 1.4.2007–30.9.2008, and the budgets of Finnish and Swedish partners were 146 900 € and 950 000 SEK, respectively.

The background for the project was that in small scale solid biomass fired systems the most fatal disturbance is the fluctuation of energy content in the fuel feed. So far no cost effective feed forward solution for this disturbance has been presented. The remaining solution is then to manage the combustion by active feedback control. The potential for a fast and exact feedback control is highly determined by the possibilities for adequate observation and impact of the process.

The goal of the project was to compare control potential of domestic wood pellet burners (<20 kW) based on direct combustion and gasification and to develop cost effective control solutions for them by means of data based and physical modelling. The comparison was done both in theory and in practice with use of state of the art feedback control. The possible benefits were defined in perspective of cost effectiveness, burning efficiency and emissions. A minor objective was to clear out in theory if the small-scale gasification could be utilized also for minor power production.

The role of Finnish partners was to investigate the operation and control potential of the different types of combustion systems by extensive measurement procedure and modelling. It was observed that parameters affecting the cleanliness and efficiency of combustion were draught, fuel feeding period and both the amounts of fuel and air feeds. It was noticed, however, that the combustion properties and parameter values vary significantly between the two burners. It was confirmed that by active control the variations in combustion conditions can be compensated to some extent, but a controllable process and proper instrumentation are required. Finally, the emission and efficiency requirements determine the required automation level.

The role of Växjö University was to develop a statistic on-line mixing model, which gives a connection from design and process parameters of burner and combustion chamber geometry to emissions. The model was developed and tested in comparison with experimental data. In spite of the fact that both burners operated far outside the normal combustion interval, the model seems to be able to predict reasonably well the variations in CO-emissions. The experiments fully support the fundamental model assumption – that it is the imperfect mixing in the gas phase that is responsible for the high emissions of unburnt hydrocarbons and unburnt fuel as measured by CO, not the overall residence time in the combustion chambers in commercial, domestic scale boilers. As a result, automatic control measures to improve the combustion behaviour should concentrate on the addition of burnout air with respect to its momentum and its direction. The model generated seems to be able to support such a control system.

At the beginning, reference tests according to EN 303-5 standard were performed with both systems and analysed also by mathematical modelling. The generated model based on physical and chemical phenomena gave useful results, when the measurements were used as inputs. The goal of the model was to calculate the efficiency losses due to sensible heat (flue gas, excess air and steam) and due to unburnt particles (solid char, CO, CH_4 and H_2) based on O_2, CO, flue gas and indoor temperature measurements, fuel properties and unburnt char estimate. Additionally, the air and flue gas flows were determined indirectly. The model gave good results when compared to reference test, so the model is a useful tool for small scale combustion.

Analytical redundancy was utilised in this project by modelling important quantities of the combustion, namely O_2 and CO. The analysis procedure for data-based modelling was based on finding the most valid temperature sensor that is dependent on the O_2 and CO levels in case of both burners. Based on the analysis, the flame temperature was found to have the most potential dependency on carbon monoxide and oxygen. This way, CO and oxygen values can be produced inferentially, giving the real-time information about combustion quality and acting as inputs for the mixing model.

The mixing model and data-based models generated during the project can be integrated with a model based on physical behaviour of subprocesses in wood combustion. The dynamical combustion model then provides e.g. dynamic connections between fuel feed, primary and secondary air feeds, temperature of primary zone and total power generated in combustion. Together with the combination of the mixing model and data-based inferential models, a comprehensive monitoring method for small scale wood pellet combustion is achieved.

Combustion optimisation based on design of experiments (DOE) results was studied to explore optimal combination of the four control factor values. The optimised factors were fuel power, fuel feeding period, draught and combustion air flow. The results were compared to reference tests with both burners. It can be concluded that the boiler output was decreased as the air and fuel feeds were cut down. As a result of changed operation point, the oxygen level lowered a bit and the CO emission level was reduced significantly to a very low level. Moreover, the fact that the efficiency optimum is not reached at nominal power can be considered as a benefit. Then, the burner can operate close emission optimum most of the time, so the operation periods of the burner become long. By this, the unclean start-ups and shut downs can be reduced, and the total emission levels remain low. After the optimised control environment was achieved, the combustion control was applied. With burners equipped with a combustion air fan and fixed primary/secondary air feed ratio, the excess air stabilization does not work as desired. Therefore, power stabilization is suitable control strategy for Biona and Velmax burners. Several control methods, including oxygen trim fuel feed control were implemented and tested during the project. It was shown that with active control combined with optimised control environment variables, more stable operating conditions can be reached. If the primary and secondary air feeds were separated, there would be more degrees of freedom when designing control strategy for the system.

Altogether, a future control framework was developed, which is based on the research work done by the project partners. The foundation of the control framework is the temperature measurement information enriched by mathematical modelling. The enriched information can be used to determine emissions and efficiency of the system. This information can also be used with statistic mixing model to gain information, in which direction the process should be driven. As a result, there is a combination of models, which provides upgraded information on how to control the process to achieve higher efficiency with minimised emissions.

In general, one should note that the combustion properties vary with different systems. Therefore, constructing a control system the entire system must be considered. Hence, system design must be done in a way that the process is controllable. Additionally, proper instrumentation is required. Also the operation point of the system can be changed to a more suitable one. Ultimately, the emission and efficiency requirements determine the disposable automation level, which in turn determines the sensors, actuators and hence control strategies that can and must be applied. The automation level that is required to meet the emission limits will increase in the future.

As a conclusion, the requirement for cost-effectiveness is dominant in small scale applications, which sets hard limits to on-line measurement and control instrumentation in sold applications. A comprehensive solution is to enrich data of simple measurements. This enriching of sensor information can be done by a combination of physical and data based models. Such models were developed in this project. By the generated models, the oxygen and CO levels could be determined based on temperature measurements. By these estimates, efficiency, flue gas and air flow estimates can be calculated. Using the same input information, the mixing model describes the direction in which the combustion should be headed. As a result, there is a combination of models that require and support each others. The sensor information and model based knowledge forms the foundation for control. Still, a lot of work is undone in order to use such a concept in commercial combustion units, but this project served as a needed step for that direction.