Control Strategy for Small-Scale Wood Chip Combustion

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Abstract: The purpose is to control small-scale (< $1MW_{th}$) wood chip combustion in an inexpensive and durable way. Therefore, a hierarchical control concept is presented. The main task of the fuel feed control system, which is based on temperature and lambda measurements, is to settle the fuel feed to air feeds and to compensate for the temporary fluctuations in the fuel feed. The task of the air flow control is to set the primary and secondary air flows suitable for the power level and for the fuel moisture content. Test results of a 200 kW commercial system are presented. The process experiments indicate that the high level control system is able to adapt to varying combustion conditions and to maintain low emission levels. The control concept is adaptable also to existing systems.

Keywords: Combustion control, cascade control, fuzzy control, sensors, biomass, wood chips

1. INTRODUCTION

By combusting wood in the form of pellets, chips and logs, inexpensive and CO_2 neutral energy can be exploited. Therefore, significance of small-scale (10–1000 kW) biomass fired systems have increased over the last years. However, wood chip combustion in small scale is challenging due to extensive process fluctuations. The main source of fluctuations is irregular fuel feed. This is largely due to the variation in the degree of filling of the feeding screw. Additionally, the energy density and moisture content of the chips may vary significantly. These variations disturb the combustion, with the result of increased emissions, loss of efficiency and fouling of heat surfaces and sensors. Therefore, active control actions have to be made to compensate for the fuel feed fluctuations. However, to maintain the inexpensiveness of small-scale combustion systems also with better controllability, instrumentation should be kept on reasonable level. Moreover, robustness of sensors used must be such that the sensors last in the challenging combustion environment without defects or drifting. This work aims to provide an inexpensive and comprehensive control solution for these challenges also to existing combustion systems.

Small-scale wood combustion produces significant amount of fine particles and hence causes health hazards (Tissari *et al.*, 2007). Good combustion in CO and OGC (organic gaseous compound) point of view also reduces fine particle emission compared to the poor combustion (Tissari *et al.*, 2007). The CO and OGC emissions correlate well with each other as a function of excess air in the small-scale combustion systems (Eskilsson *et al.*, 2004). Hence, the natural goal of the control system is to minimize the CO emissions. However, the optimum in the emission point of view is not exactly the same as in the efficiency point of view (Ruusunen, 2006), because the efficiency optimum is got when the CO and OGC emissions are slightly increased due to lack of excess air. Therefore, enough excess air must be provided to reduce emissions with price of lower efficiency. On the contrary, NO_x emissions slightly increase as the excess air increases (Eskilsson *et al.*, 2004). Altogether, a suitable excess air level for the combustion system must be found and maintained at every heat output level in order to satisfy these conflicting requirements.

Lambda sensor is a widespread sensor used for feedback control in modern wood chip fired systems. However, the durability and long-term accuracy of the lambda measurement might not be optimal, especially if the sensor is exposed to highly unclean gas. This is in particular the case with discontinuous combustion with iterative start-ups, shut downs and pilot flame (Tissari, 2007). Hence, the better the quality of combustion, the longer lifetime is expected for the sensor.

Temperature measurements are common as a part of combustion control system in wood pellet fired systems, as temperature measurement is a reliable and inexpensive measurement. Its measurement signal has a good negative correlation with the flue gas oxygen content, if suitable amount of excess air is guaranteed. Unfortunately, the temperature measurement signal does not describe reliably the absolute value of the oxygen content. This is the case if the fuel quality and especially the moisture content (Ruusunen, 2008) of the fuel vary. Therefore, the temperature measurement by itself does not suit with the wood chip combustion as well as for the wood pellet combustion. In an earlier work (Korpela *et al.*, 2008), a soft sensor (e.g. Ruusunen & Leiviskä, 2004) framework was presented, in which the positive properties of temperature and lambda sensors were joined. The paper also covered passive stabilization methods and a low-level control strategy for the fuel feed control. This paper, instead, focuses on how to utilize the low-level system as a part of a comprehensive control strategy including fuel and air feed controls.

2. EXPERIMENTAL SET-UP

Combustion tests were carried out with a commercial system including a Säätötuli 200 kW stoker burner, which is not originally equipped with feedback combustion control. The burner is designed primarily for wood chip combustion, but it can also be used with other solid biomass fuels as well. Therefore, it is equipped with grate sweepers. Grate sweepers are metal rods, which are used to move the ash away from the grate and to equalize the fuel pile. Grate sweeping, however, causes significant disturbances to combustion, which can be e.g. compensated by reducing the primary air and increasing the secondary air around the sweeping (Korpela *et al.*, 2008). Therefore, compensations were used at trial runs illustrated in this paper. The idea of compensation is to damp momentarily the speed of pyrolysis and to provide extended amount of secondary air for increased amount of combustion gases due to the sweeping. As the grate sweeping compensation interfere the operation of a feedback control system, the control has to be locked during and straight after the compensation.

Two separate blowers fed primary and secondary air to the burner. Primary air was fed trough the grate upwards. Secondary air was fed from the roof downwards, from the back of the burner to boiler direction and from the sidewall to the opposite wall. The walls and the roof of the combustion space of the burner were made of paste. The fuel feed was realized continuously with an inverter control. The burner was installed in a commercial Arimax Bio 250 SP boiler with nominal capacity of 250 kW. A 24-m^3 fuel storage was equipped with back and forth moving rod dischargers. The system was pressure controlled by pressure measurement and by exhaust fan to a fixed 25 Pa underpressure level.

A control and measurement system was implemented in the LabVIEW environment. Some measurements were collected with a DT9806 data acquisition system. Some instrumentation of the commercial installation based on OMRON logic was utilized via an OPC connection. Flue gas analysis was made with Testo 330-2 flue gas analyzer, which was equipped with O_2, CO and NO measurements. 1.5 mm thick K type sensors for temperature measurements and a lambda system by Motec PLM for O_2 measurement were used. Additionally, air flow velocity sensors by Produal IVL 10 in air feed pipes were used. The velocity measurement values from the middle of the pipe were compensated to effective velocities according to the flow profile (e.g. Halttunen, 2007).

3. LOW LEVEL CONTROL

Korpela *et al.* (2008) presents a low-level control system based on temperature measurement from the upper part of combustion chamber. The goal of the low-level control system is to stabilize the fuel feed in prevailing conditions. In the case of typical fuel feeding disturbance, less fuel is fed to the burner compared to the normal level. As a result, the size of the fuel pile on the grate decreases and the combustion starts to fade. This can be observed e.g. with temperature measurements. As the temperature measurement signal starts to go down, the size of the fuel pile has already decreased. Therefore, fast and powerful control is required. Hence, nonlinear fuzzy controller of Mandani approach was generated. A block diagram of the implemented low-level control system is presented in Fig. 1. In addition, the grate sweeping compensation described in chapter 2 is included.

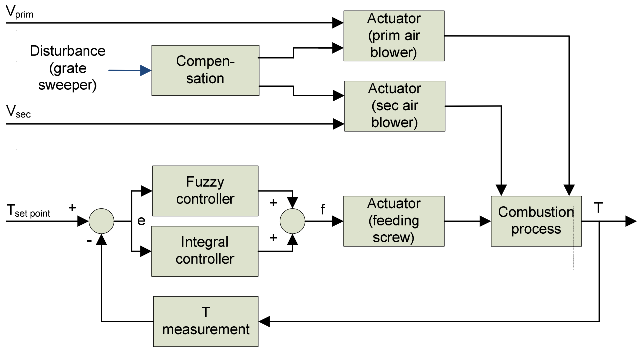

Fig. 1. Low level control loop, in which fuzzy controller and integral controller are in parallel. Air feeding signals are user defined, but air feed ratio is changed to compensate for the disturbances generated by the grate sweeping.

The fuzzy controller infers the compensation requirement based on temperature error signal and its rate of change. These both are divided into five regions, so there are 25 rules that define the status of the temperature. Based on the rules, inference is made between five compensation levels, whether to keep the normal feeding level or to change it. Descriptions of the rules are presented in Table 1. A detailed discussion of the fuzzy controller is presented in Korpela *et al.* (2008).

Table 1. Rules of the fuzzy controller. Vertical and horizontal headings stand for error signal (*e*) and its rate of change (Δ*e*), respectively. Headings: N=negative, P=positive, S=small, L=large, Z=zero. Content: S=subtract, A=add, B=base, S= small, L=large. E.g. If *e* is Positive Large AND if Δ*e* is Positive Small THEN Add Large.

e/Δe	NL	NS	Z	PS	PL
NL	SL	SL	B	B	B
NS	SL	SS	B	B	B
Z	B	B	B	B	B
PS	B	B	B	AS	AL
PL	B	B	AS	AL	AL

As the fuzzy controller compensates for the fast and intensive fuel feed changes, it is beneficial to set an integral controller in parallel with the fuzzy controller. It provides the control system to follow the slow fluctuations of the system. Additionally, the integral controller provides the possibility for the system to follow the operator defined temperature set point.

4. HIGH LEVEL CONTROL

4.1 Operation principle

An essential part of the low-level control is the selection of the appropriate temperature set point, which depends on several factors (Korpela *et al.*, 2008). The set point defines the operation point of the system. If the set point is too high, too much fuel is fed to the burner, and vice versa.

When the primary and secondary air feeds are kept constant, changing the temperature set point changes the excess air level, as the low-level control stabilizes the combustion by fuel feed. This feature enables the oxygen measurement by lambda sensor to provide fundamental knowledge about the