Biomass Combustion Control and Stabilization Using Low Cost Sensors

Ján Piteľ, Jana Mižáková, Alexander Hošovský
Technical University of Košice, Faculty of Manufacturing Technologies with a Seat in Prešov, Bayerova 1, 080 01 Prešov, Slovakia
e-mail: jan.pitel@tuke.sk, jana.mizakova@tuke.sk, alexander.hosovsky@tuke.sk

Abstract
The paper describes methods for biomass combustion process control and burning stabilization based on low cost sensing of carbon monoxide emissions and oxygen concentration in the flue gas. The designed control system was tested on medium-scale biomass-fired boilers and some results are evaluated and presented in the paper.

Introduction
The quality and efficiency of combustion process versus air pollution is global problem of economically developed countries, but also poor countries in the world. Currently, the consumption of power includes a high proportion of heat production in some countries.
Small-scale biomass-fired boilers with a fuel in the form of woodchips, possibly sawdust or other secondary woodworking production sources, are often operated uncontrolled or with a very simple control mechanism, mostly mechanical controller. The environmental contribution of such uncontrolled or poorly controlled boilers in comparison with fossils fuels ones can be very small if any [1]. A typical issue is an improperly controlled air-to-fuel ratio during transition states (e.g. boiler lighting, burn-out phase, sudden increase of power demand, etc.) [2]. Such poor control method moves combustion process out of optimal combustion interval and causes significant heat loses and high emission production. Emissions usually consist of solid organic carbon, which in combination with ash is visible part of emissions [3-5]. These problems often appear also in medium-scale biomass-fired boilers.
During the last decade a substantial effort has been spent to improve the biomass boiler design. This resulted in an efficiency increase. However, development of control algorithms ensuring optimality of combustion process is quite behind in the development of the design. One way in the combustion process control algorithm development is to modify a control algorithm used on medium or full-scale boilers and adapt it to small-scale boilers. This approach can be partially used, but it runs against some specifics of small-scale boilers [6-7]. Main differences of small-scale boilers cover [8]:

- faster fluctuation of a combustion process due to a smaller mass of combustion chamber walls,
- higher sensitivity of a combustion process to external influences,
- a poor and non-periodical maintenance due to carelessness of many users,
- unserviced sensors with uncertain measurements,
- a budget for automation of a boiler has to be kept low etc.

In solving of project "Research and development of intelligent control systems for biomass based heat production and supply" we dealt with possibilities of increasing of biomass combustion efficiency by using of low cost carbon monoxide (CO) emissions and oxygen (O_2) concentration sensors instead of common used flue gases analyzer. This analyzer is quite expensive for continuous emission sensing in small-scale and also medium-scale biomass-fired boilers unlike in large-scale boilers, where the price of control system including analyzer is not so important. In order to increase combustion efficiency and to decrease emission production in medium-scale biomass-fired boilers we designed new control algorithms for fuel supply and so to stabilize combustion process. Such control system using low cost CO and O_2 sensing can be used after some simplifications also for control of the small-scale boilers.

1. Materials and methods

1.1 The basis for design of biomass combustion process control system

From theoretical point of view it follows that for realization of nearby complete combustion and for reaching the highest efficiency and the lowest level of CO emissions production the parameter excess air ratio λ is important (Fig. 1), which is usually detected by O_2 concentration measurement with using Lambda probe installed in the flue gas as follows [9]:

$$\lambda = \frac{21}{21 - O_2\%}$$

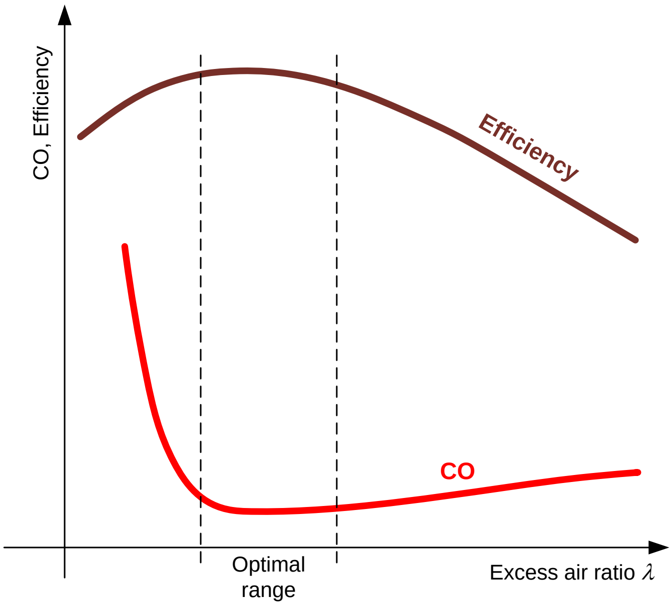

Fig. 1 Efficiency and CO dependence on excess air ratio λ

Generally, optimal interval of O_2 concentration in flue gas is from 5% till 10%, what means that excess air ratio λ should be approximately $\lambda \in \langle 1.3; 2.1 \rangle$. In case when value is on upper boundary of interval (about 2.1) or even $\lambda >> 2.1$, an incomplete combustion occurs and higher amount of oxygen together with produced heat leak through exhaust gas.

For complete combustion and the highest efficiency value of O_2 concentration theoretically should be equal to zero, i.e. $\lambda \approx 1$, what is impossible in real operation of biomass combustion. For that reason the goal is to operate biomass combustion boiler at the lowest air ratio λ (on the left interval border), while simultaneously keeping CO emissions at such value so that it doesn't increase due to a low air ratio. It is common if air ratio rapidly falls (for example due to poor quality of fuel), quality of combustion process worsens and at the same time trend of CO rapidly increases. Maintaining optimal marginal value on the left border is quite difficult and decrease of O_2 concentration under this value can have very negative impact on combustion stability. Values of CO emission can rapidly increase, leaks of CO into air occurs and simultaneously temperature in fire chamber decreases. This state can be eliminated by control of fuel supply on the base of information about tendency of nascent carbon monoxide in the flue gas [10-11].

1.2 Experiment description

The described problem with biomass combustion at the lowest air ratio λ we solved in our experiment by implementation of low cost Lambda probe and CO sensor into biomass combustion control system with new control algorithms [9].

For CO emissions measurement gas sensor TG816 was used in the flue gas. It is a tin dioxide (SnO_2) semiconductor with low conductivity in clean air. In the presence of a detectable gas, the sensor's conductivity increases depending on the gas concentration [12]. A simple electrical circuit converts the change in conductivity to an analog output signal which corresponds to the gas concentration. Such CO probe will serve only for the indicative measurement of CO concentration in the flue gas in regard to that only information about tendency of nascent carbon monoxide (i.e. whether CO emissions are increasing or decreasing) is important for biomass combustion control algorithm. The exact value of CO emissions in ppm or mg/m^3 is not so important and therefore the measuring accuracy 10% of the used low cost CO probe is satisfactory for this application. The special holder (Fig. 2) has to be used for mounting of this CO probe into flue way. It enables positioning of the probe for good input of flue gas to sensor under condition fulfillment of its preservation against damage caused by high temperature in flue way. Simultaneously, this special holder enables simple operative cleaning and maintenance of CO probe [13].

Fig. 2 Two versions of special holder for CO probe [13]

The most common way of O_2 concentration measurement in the flue gas is using a so-called Lambda probe, which is generally an oxygen analyzer working on the principle of electrochemical cell. The wide band Lambda probe LSU 4.2 was used. It is a planar ZrO_2 dual cell limiting current sensor with integrated heater with the main purpose of use in car engines. But its monotonic output signal and good price make it capable to be used as a very useful sensor for combustion monitoring in small-scale and medium-scale biomass-fired boilers too [14].

On the base of theory mentioned above the automatic control and remote monitoring system of biomass combustion was designed and realized (see in Fig. 3). The basis of this system is an industrial modular process control system ADiS which is monitored by SCADA system Promotic. There are implemented in process control system a procedure for communication with heat meter via M-BUS for measurement of power of boiler and procedure for communication with Lambda probe via RS232/485. Process variable sensors (e.g., temperatures, pressures, CO) are connected via analog input module with 10 bits A/D converter. The system was experimentally tested on biomass combustion boilers in real operation of heat production in two boiler plants in Slovakia. Information about process values is used for process control of fuel and air supply and also they are on-line monitored in our workplace via Internet [13].

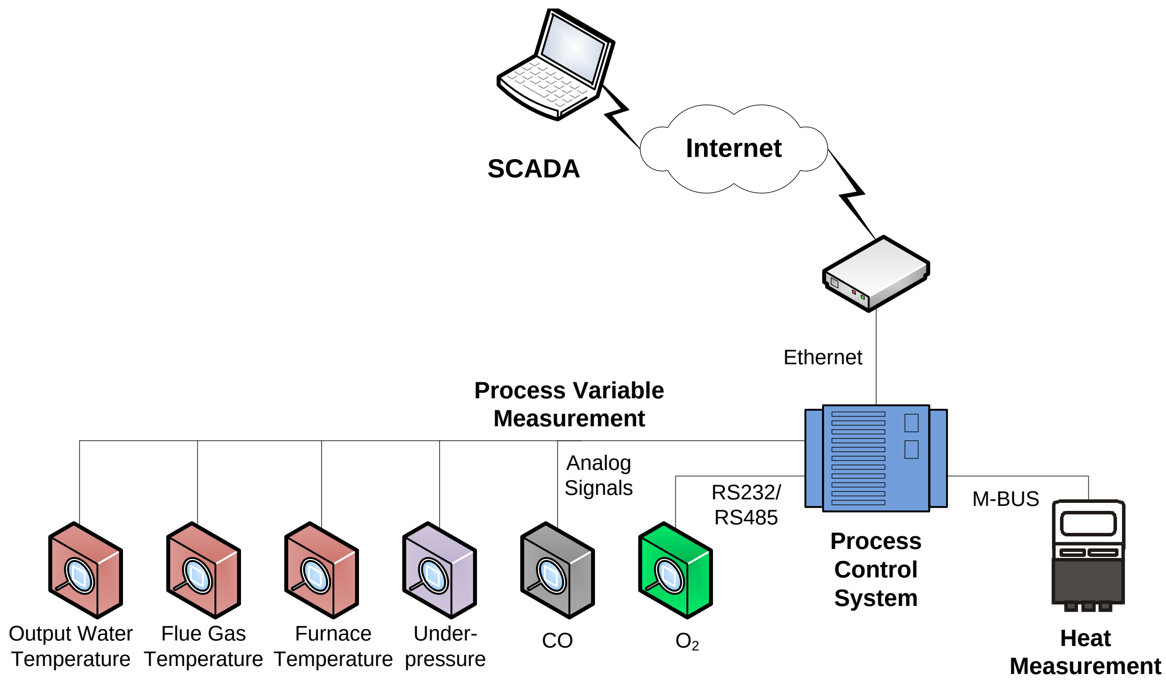

Fig. 3 Process control and remote monitoring system of biomass combustion

2 Results and discussions

Next, we describe obtained results measured in our experiment. Firstly, in Fig. 4 is example of displaying of measured and evaluated CO emissions dependence on O_2 concentration in the flue gas. CO emissions are presented in percent of sensor range, which is approximately 1000 ppm.

It is clear from obtaining dependence, that from 1.1.2013 09:53 to 2.1.2013 09:53 combustion runs in interval 7% - 10% O_2 concentration in the flue gas. This fact is also confirmed by histogram of samples, where is shown that 13,7% of samples were measured in interval 7-8 % O_2 concentration, 52,0% in interval 8-9% and 27,6% in interval 9-10% O_2 concentration.

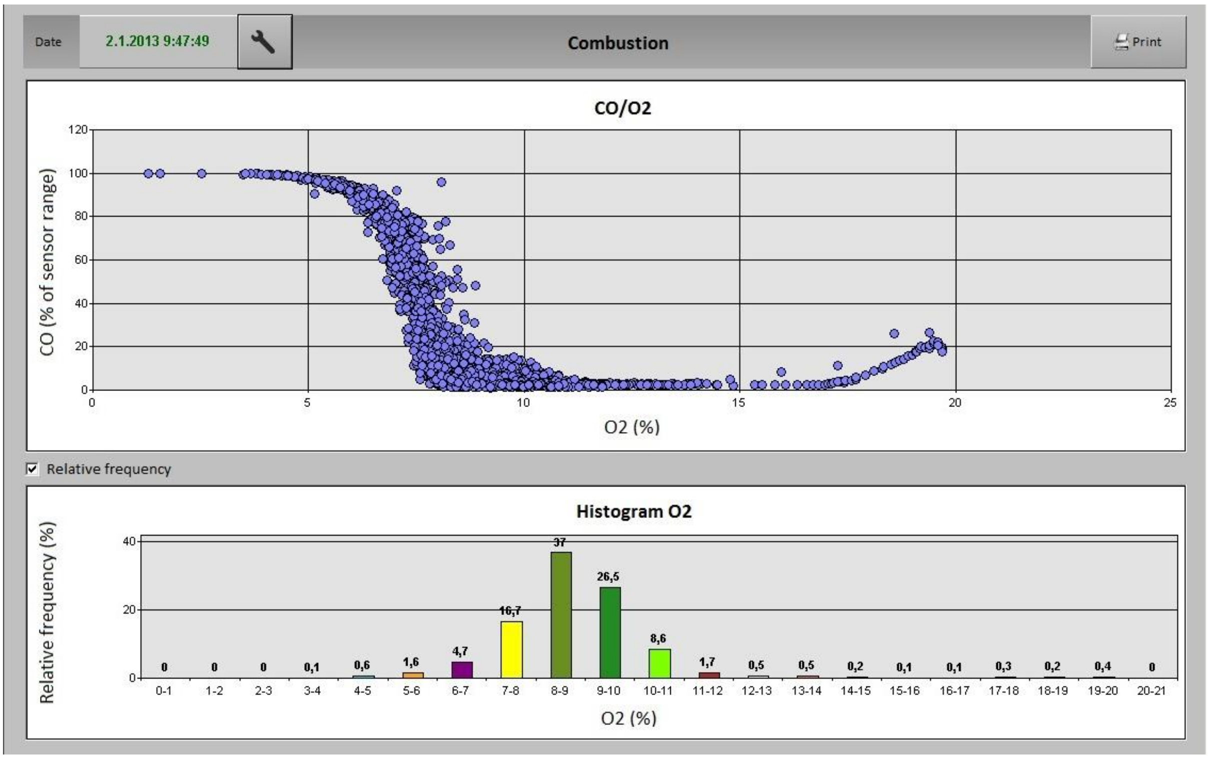

Fig. 4 Example of using of the designed system for on-line evaluation of CO dependence on O_2 concentration in the flue gas

Secondly we can analyze measured data in more detail. There are in Fig. 5, Fig. 6 and Fig. 7 some measuring results obtained 26.1.2013. In graphs displayed in the upper part of figures the values of oxygen concentration (in %) are on left *y* axis and the values of carbon monoxide emissions (in percent of sensor range) are on right *y* axis. In graphs displayed at the bottom of figures the fuel supply is recorded, which is expressed as ratio of filling time to filling time plus stop time in percent.

In Fig. 5 we can see typical response of control system to change of woodchip quality or fuel amount in fire chamber. For example from 6:36:20 value of oxygen started decreasing and value of carbon monoxide started increasing due to inappropriate fuel. Control system has responded by reduction of fuel supply time, i.e. less woodchip fuel was supplied into fire chamber. At time 6:38:20 values of CO and O_2 were stabilized again. Supplying of fuel was not interrupted completely, because of CO was stabilized very quickly. On the other hand there was a lack of fuel in fire chamber at 6:42:20 and control system gradually increased woodchip supply so to reduce amount of O_2 in the flue gas.

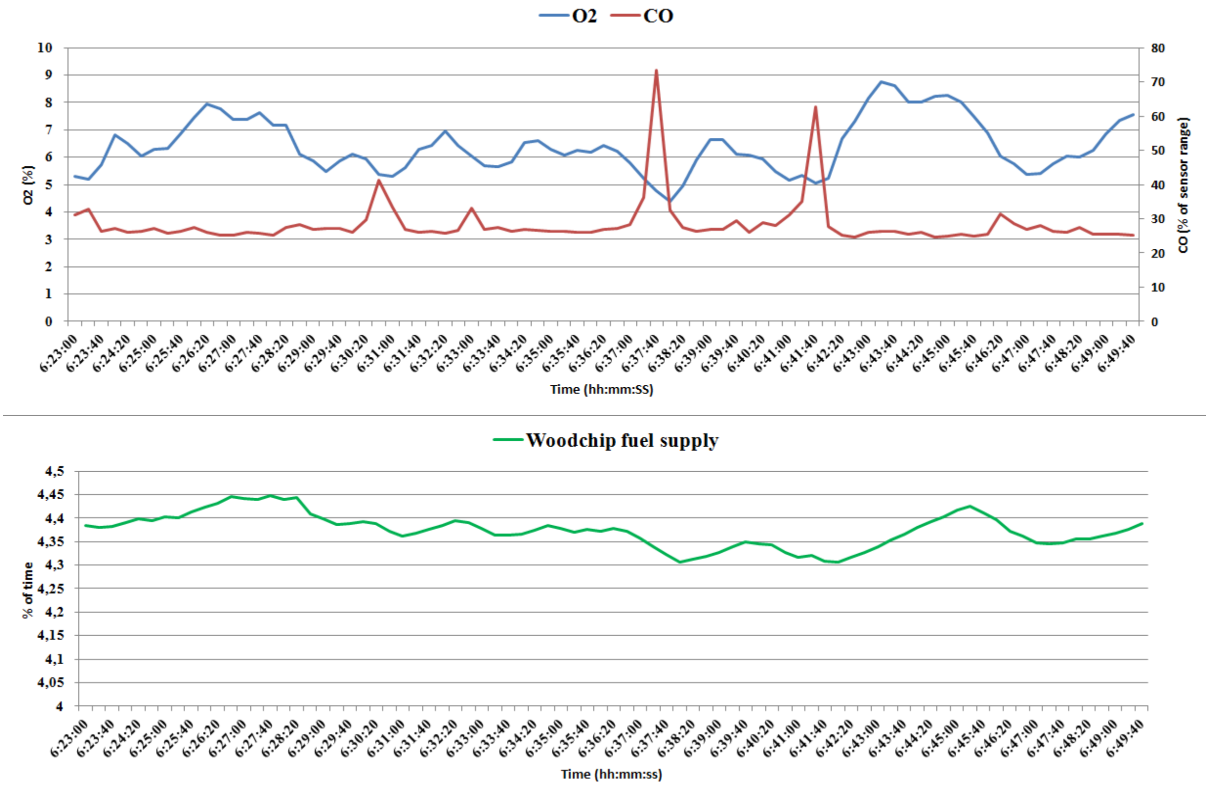

Fig. 5 Woodchip fuel supply according to CO emissions and O_2 concentration

In Fig. 6 it can be seen that due to some disturbance amount of O_2 in the flue gas suddenly decreased at 7:46:20 (it was out of common interval 5% - 10%) and at the same time CO emissions rapidly increased. Woodchip fuel supply was practically stopped and it was renewed after combustion stabilization at 7:48:20.

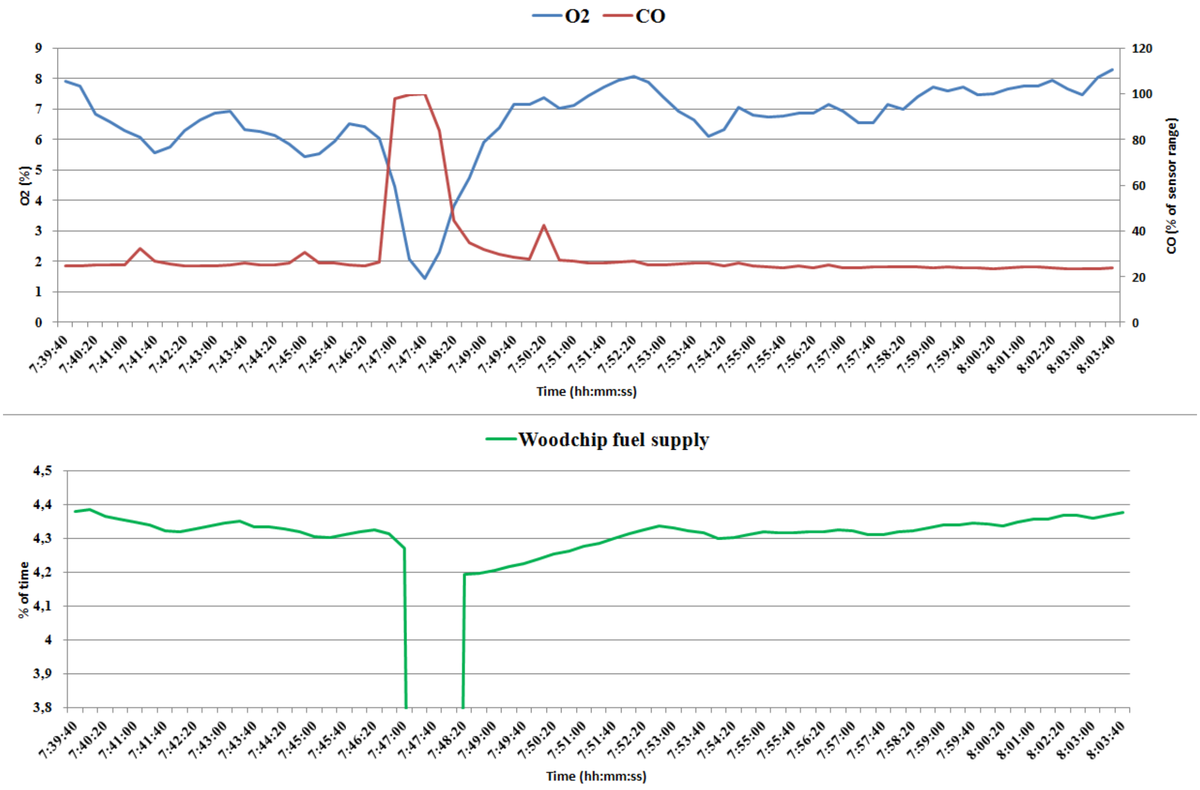

Fig. 6 Woodchip fuel supply according to sudden O_2 decrease and CO increase

Tested control system measures also other process variables, for example temperatures as furnace temperature, flue gas temperature, boiler output water temperature. In Fig. 7 we can see example of woodchip supply stopping due to high boiler output water temperature. When woodchip supply was stopped at 3:14:40, burning gradually has been finished too, O_2 values were shifted beyond right boundary of optimal interval and CO emissions increased. When supplying was renewed at 3:27:00, the control system stabilized combustion after few minutes.

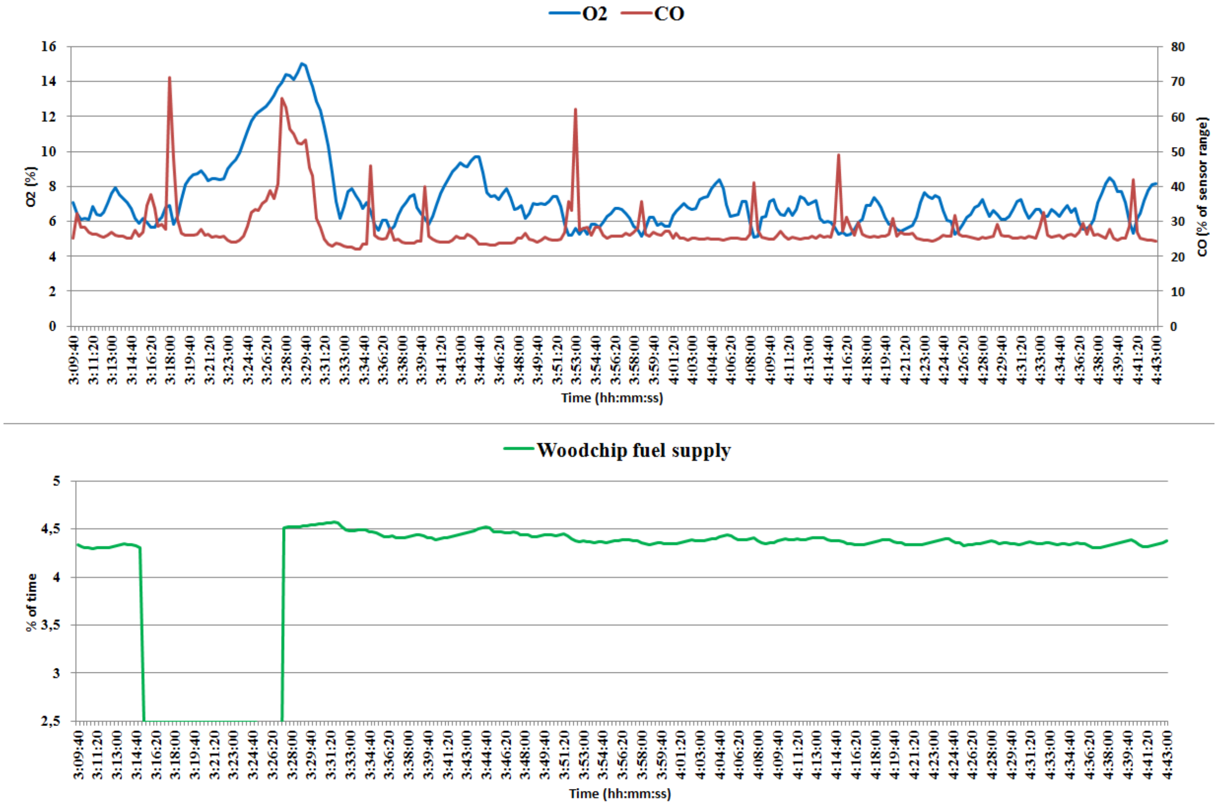

Fig. 7 Stabilization of combustion after fuel supply stopping

Conclusion

The goal of experiment was to design and test cost effective control system of medium-scale biomass-fired boilers based on the information not only about oxygen concentration in flue gas but also about values of carbon monoxide emissions. This is the most significant difference of the tested control system to the so far used in practice, which usually use only Lambda probe in medium-scale biomass-fired boilers and often even no information about the combustion quality in small-scale biomass-fired boilers. Another important difference is in new control algorithms using information about tendency of nascent carbon monoxide for biomass combustion control and stabilization. This new idea will be published in more detail in the future after patenting.

It was proved that low cost wide band Lambda probe and simple CO sensor can be used for biomass combustion control and stabilization in medium-scale and after some simplification also in small-scale biomass-fired boilers. The designed and verified control algorithms based on low cost O_2 and CO sensing can achieve increased effectiveness, higher produced heat and lower emissions. They are suitable for combustion stabilization when combustion starts or is interrupted due to some disturbances and they can also compensate varying woodchip parameters.

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