ISSN 1848-0071
662.6+683.97=111
Recieved: 2015-01-19
Accepted: 2015-07-31
Professional paper

FUZZY CONTROLLER FOR MEDIUM-SCALE BIOMASS BOILER

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The combustion in biomass boilers is classified as a non-homogeneous combustion process. This phenomenon is known as difficulty controllable by common control algorithms due to its inappropriate properties e.g. non-linear static characteristics, limitation of control variable quantity, transitions with a time delay or even behavior similar to non-minimal phase systems. Due to these properties the usage of traditional linear controllers leads to unsatisfactory results. The authors decided to use fuzzy controller with behavior similar to PID controller but with adaptation to most problematic properties of combustion process. The results were experimentally verified on a 100 kW biomass combustion boiler.
Key words: biomass, combustion, control.

Neizraziti regulator za kotlove na biomasu srednjih veličina. Izgaranje u kotlovima na biomasu je klasificirano kao nehomogen proces izgaranja. Ovaj fenomen je poznat kao teško kontrolirani algoritam s uobičajenim kontrolnim algoritmima upravljanja zbog njegovih neprikladnih svojstava npr. nelinearnih statičkih karakteristika, ograničenja količine kontrole varijable, prijelazima s vremenskim zakašnjenjem ili čak ponašanju sličnom neminimalno-faznom sustavu. Zbog tih svojstava uporaba tradicionalnih linearnih regulatora dovodi do nezadovoljavajućih rezultata. Autori su odlučili koristiti neizraziti regulator s ponašanjem sličnim ponašanju PID regulatora, ali uz prilagodbu za većinu problematičnih svojstava procesa izgaranja. Rezultati su eksperimentalno verificirani na 100 kW kotlu za izgaranje biomase.
Ključne riječi: biomasa, izgaranje, kontrola.

INTRODUCTION

Biomass is one of the basic renewable energy sources. The biomass combustion has been for long history a significant energy source in most countries. The combustion of the biomass in a form of chopped wood, woodchips and wood or herbal pellets is still widely spread nowadays. Automatic biomass combustion boilers range from small-scale sizes intended for residential heating through medium-scale boilers for heating of larger workshops to full-scale boilers for heating of a whole neighborhood or villages. [1]

To be able to benefit from biomass potential to be environmentally friendly, the control algorithms used in automatic boilers have to be properly done. The control algorithm must be able to constantly attain optimal combustion conditions regarding to maximum efficiency and minimal emissions of noxious flue gases. The control algorithm must also be able to adapt to changes of fuel or boiler parameters. It has to be also reliable and immune to user mistakes. [4]

The biomass combustion is difficult to control in its principle. Main reason for that is unfavorable behavior of combustion process from the control point of view. The heterogeneous combustion (mixing of solid fuel with gas oxidizer) is quite chaotic process. Almost all variables measured near combustion process are weighted by a distinctive noise. The noise is problematic not only by its high amplitude, but also by its frequency spectrum reaching the close proximity of measured variables working frequency spectrum. The process is also sensitive to difficultly measurable disturbances as i.e. small pressure changes due to a wind outside a chimney, changes in a fuel density or grate sweeping etc. Some of the measured variables show behavior similar to systems with time-delays (i.e. temperature difference between hot and cold water) or non-minimum phase systems (i.e. response of combustion chamber temperature to a change in a primary air flow). Most of static characteristics measured in causal relationships of studied variables shows distinctive non-linear behavior. The parameters of the boilers tend to drift in time (i.e. clogging of heat exchange surfaces) so the combustion process has to be also considered as a system with time-invariant parameters.

According to those properties is the usage of classical PID control algorithm unsuitable. The implementation possibilities of PID controllers for small-scale and medium-scale biomass boiler control with experimental verification can be studied in a reference [6].

The usage of control methods working with an internal model hits a snag in a non-existence of a proper process model. A lot of effort has been invested in developing of such a model, but no one is sufficiently accurate and general to be able to describe the process in longer run. [7]

Basis for our control algorithm was PID control algorithm which we extended for a couple of non-linearities using a fuzzy logic. This non-linear behavior of control algorithm allows for elimination of PID control algorithm issues and extended control algorithm abilities for a continuous realization of some safety functions.

COMMON CONTROL METHODS

The main goal of the small to medium-scale boiler algorithms is reliability. It is mainly due to the specifics of the boiler operation conditions. These are usually neglected maintenance, unsuitable service of unqualified operators (end-users) and cheap instrumentation. Due to these reasons the control algorithm is based mainly on open-loop control, based on heuristically or experimentally acquired interpolation tables. See the Figure 1 for an example of such realization used by one of the Czech boiler manufacturers. The merit of this control algorithm is reliability, however it is the trade-off for quality of control. The transitions speed is, in comparison with reliability, unimportant for the manufacturer. The distinctive drawback of this control approach is inability of the control algorithm to adapt to gradual change of process parameters. If for example the primary air supply drops due to the clogged grate the combustion process would suffer from lack of combustion air. The open-loop control algorithm does not recognize this state and maintain the combustion process out of an optimal working point.

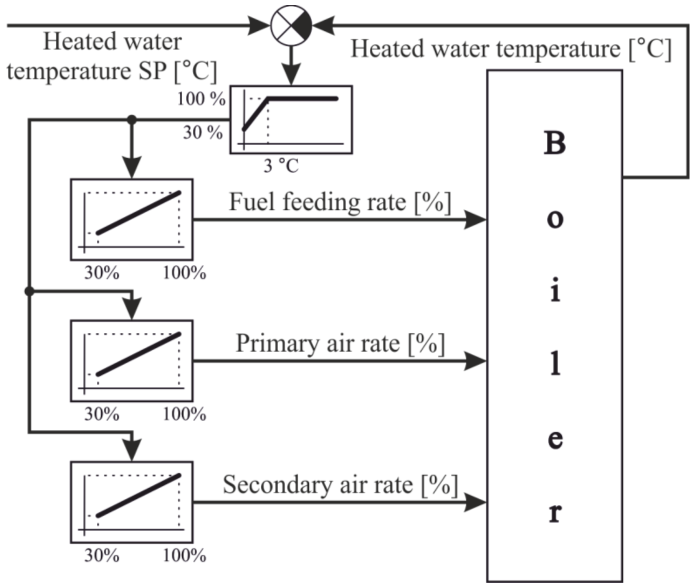

Figure 1. Scheme of a common method of small-scale
Slika 1. Shema uobičajene metode kontrole umanjenjih kotla na biomasu.

Particular solution to the problem can be use of PID controllers similarly as it is used in full-scale boilers (see Figure 2). The disadvantage of this solution is close link to working point and the immediate vicinity due to strong non-linear behavior of the controlled process. It is possible to use this algorithm for full-scale boilers because demanded control range is narrower, dynamics slower, the control algorithm may be much more complex and the process is operated under supervision of skilled operator. [3, 5]

Usage of PID algorithms for small and medium-scale boiler proved to be considerably problematic. Non-linear behavior, time-delays together with non-minimal phase behavior forced us to tune PID parameter very conservatively. The control process transitions then took unacceptable long time. More to this problem is in [6].

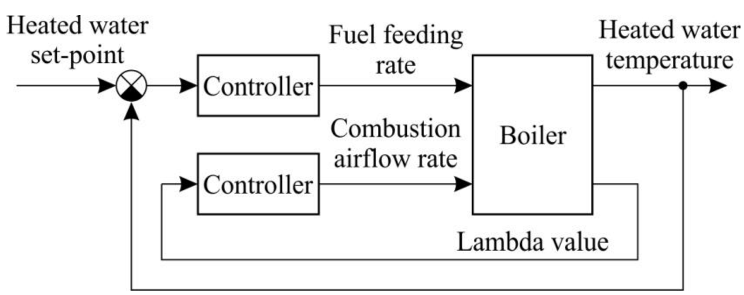

Figure 2. Standard PID control circuit used in full-scale
Slika 2. Standardni krug PID regulatora korištenog za kotao stvarne veličine.

FUZZY CONTROLER

The reason for using fuzzy controller is extension of PID control algorithm for logical operations. Fuzzy logic allows influencing control process without disturbing it by step changes. Fuzzy logic implements primarily:

safety limitation of flue gases temperature inside the combustion chamber,

prevention of fire burning out while there is a request for minimal heat output,

continuous change of controller integrative component coefficient,

reaction to combustion chamber temperature and hot water temperature rate of change.

The inputs of the fuzzy controller are heated water temperature, temperature of flue gases in the combustion chamber and rates of their changes (their time derivations). The output of the fuzzy controller is then the normalized value of fuel feeding rate (non-linear analogy to direct proportional gain of PID controller proportional component) and multiplicative coefficient of an integrative constant of integrator influencing the fuel feeding rate. The block scheme of the algorithm using the fuzzy controller is in the Figure 3.

We have experimentally found out that the integrative component of PID controller does not markedly influence the heat output response to change of set point. On the contrary, during the long transitions (i.e. during lighting the boiler), the integrator often integrated so large value, that when reached set point the integrator caused long lasting oscillating response. Usually this behavior is prevented by using anti-windup rules. Unfortunately, the anti-windup rules need to know minimal a maximal values of the integrator output. But those limiting values cannot be used, because the integrator is used for permanent control deviation elimination. The integrator value range is large due to wide range of used fuel calorific values. Using so large limiting values for the integrator would render the anti-windup rule useless.

As prevention of integrator winding we created a special fuzzy logic rule. The rule watches the value of heated water control deviation and its rate of change. When the temperature of heated water changes faster than predefined value, then almost zero value is sent to the integrator input. But when the hot water temperature rate decrease under predefined value the rule consider actual control deviation as permanent and start the integration process by raising the value sent to integrator near one. Moreover, if the control deviation is small, the rule raise the integrative gain to three to compensate for the small influence of proportional component due to a small control deviation.

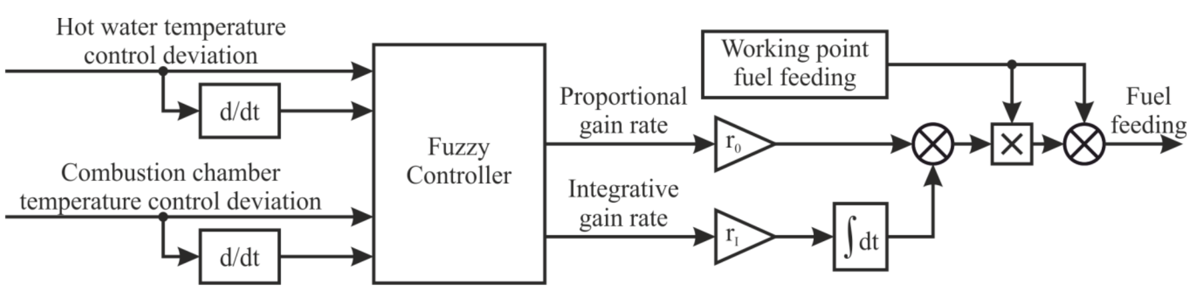

Figure 3. Block scheme of control algorithm using fuzzy controller
Slika 3. Blok shema regulacijskog algoritma korištenjem neizrazitog regulatora

The introduction of fuzzy controller also allows using non-linear but continuous safety logics intervention. When combusting some fuels, mostly those based on herbaceous mass, it is necessary to control the combustion process in a way that the temperature of burning fuel layer does not exceed a melting temperature of the fuel ash. [2] When exceeding this temperature, even for a short time period, the burning fuel bakes together rendering the layer impervious to combustion air. Fuzzy controller thus watches the temperature in combustion chamber and the rate of its change. If the temperature comes near the melting temperature of an ash, the controller reduces the fuel feeding rate. Moreover, if the temperature in combustion chamber rises rapidly, the fuel feeding rate reduction is even stronger.

Fuzzy controller also watches the temperature in the combustion chamber during heat output demand drop to minimal value. If the temperature in combustion chamber lowers under a limit value, the fuel could burn out and would not be able to light up just by start of fuel feeding. If the temperature drops to set value the fuzzy controller limit the fuel feed decrease despite of other rules. The combustion process is then controlled on its minimum heat output. If such a state remains longer than set time limit, a standard logic shuts the boiler down and let it burn out.

Another rules takes care of limiting rate of change. It is analogy to derivative component of PID controller. If the temperature of heated water or the temperature in the combustion chamber change faster than set in the fuzzy rule, the rule affect the fuel feeding in a way to reduce the rate of change. This rule prevents choking the combustion chamber by too much fuel fed in a short time period.

The outputs of the fuzzy controller range from zero to one (from zero to three for the output to the integrator). The physical values of fuel feeding rate are computed by multiplying of the fuzzy controller outputs by working point value. Fuzzy controller just governs the ratio of fuel feeding in comparison with working point. The integrator is not restricted in its limits. If the working point is set incorrectly, the integrator moves the working point to the region that matches actual fuel properties and the boiler parameters state.

The Figure 4 shows a simulation of the set point tracking control process. In the time of zero the heated water set point is set to 50 °C and in 80th minute it is changed to 65 °C. The temperature in the combustion chamber must not rise above 800 °C. Tuning of the fuzzy rules was carried out using simulation on an approximate analytical model. The model is based on commonly known analytical equations tuned and extended for a dynamics measured on a real boiler. Our experiences show that the simulation model is more forgiving than a real boiler. For that reason the values of proportional gain r_0 and integrative gain r_I were set with a safety margin.

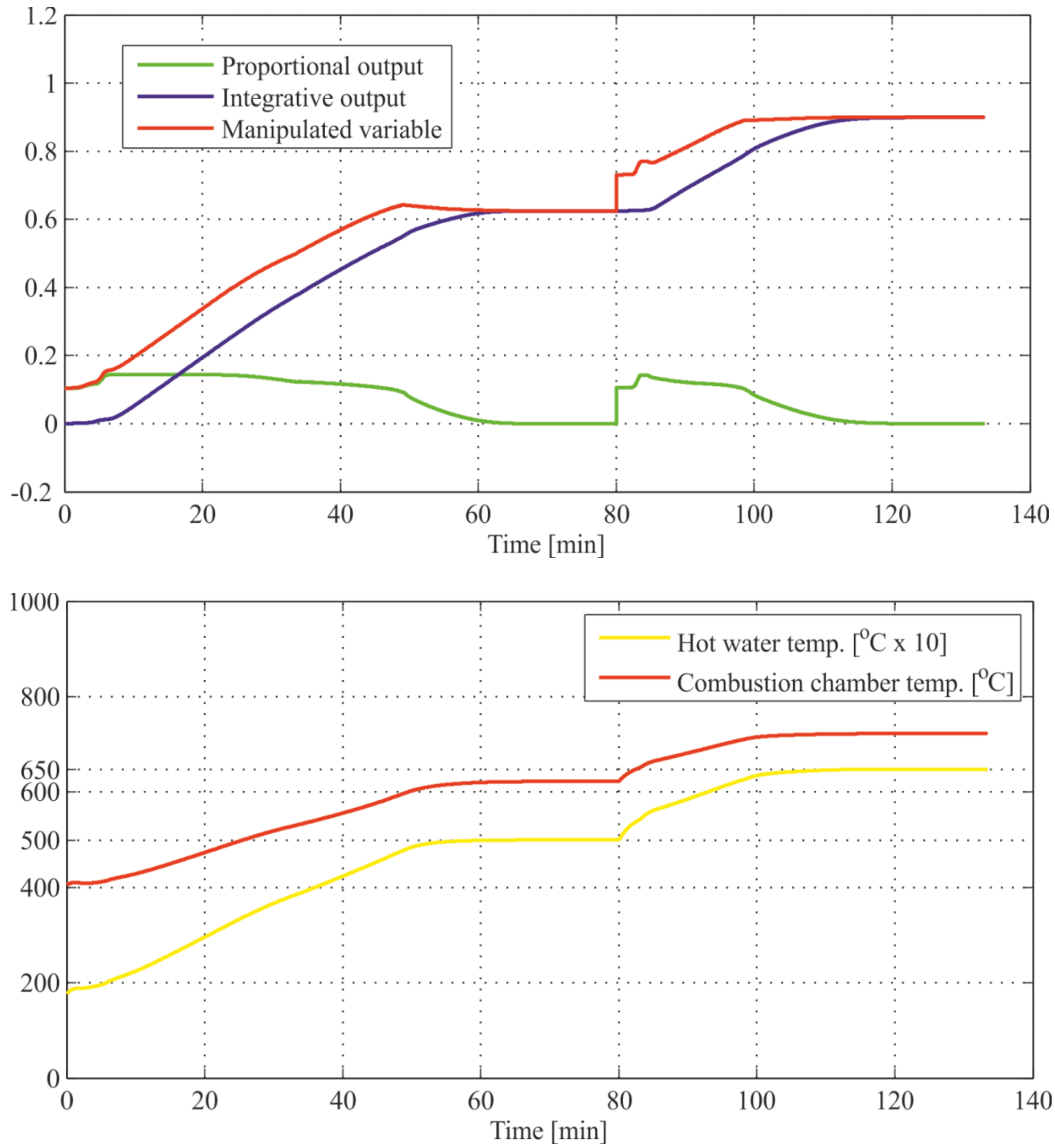

Figure 4. Simulation of set-point tracking control
Slika 4. Simulacija praćenja potrebnih vrijednosti regulacijskog procesa.

CONCLUSION

The aim of this submission is to show of the possibilities how to control the heated water temperature in a medium-scale biomass boiler. The original factory control algorithm fulfill its task, however it does not adapt to fuel properties change or a change in parameters of a boiler. The use of PID control algorithm is able to eliminate a close relationship of an algorithm to the fuel calorific value but for a safety measures the PID parameters have to be tuned very conservatively rendering the control process very slow. The fuzzy controller in combination with proportional, integrative and derivative behavior combines the advantages of PID algorithm with a possibility of continuous implementation of limiting logics.

The further works will verify the described algorithm at the 100 kW boiler in our disposal from the Fiedler company. The proposed algorithm controls fuel feeding rate only. For a real implementation of the algorithm to market boiler another control task have to be realized, such as excess air combustion air, underpressure in combustion chamber control etc.

The next way of our development will lead to usage of Model Predictive Control for heated water control with a limiting of manipulated variable. It remains questionable however, how much is MPC dependant on the accuracy of an internal process model, because in the case of biomass combustion the model will be always very rough.

Acknowledgements

Project TA02020836 is supported by Technology Agency of the Czech Republic.

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