Biomass for Energy and Industry, 10th European Conference and Technology Exhibition
June 8–11 1998, Würzburg (Germany)

EFFICIENCY IMPROVEMENT AND EMISSION REDUCTION BY ADVANCED COMBUSTION CONTROL TECHNIQUE (ACCT) WITH CO/LAMBDA CONTROL AND SETPOINT OPTIMIZATION

J. Good[2], Th. Nussbaumer[1,2]
[1]Swiss Federal Institute of Technology, ETH Zurich, CH - 8092 Zurich, Switzerland
[2]Verenum Research, Langmauerstrasse 109, CH - 8006 Zurich, Switzerland
Phone: +41 1 364 14 12, Fax: +41 1 364 14 21, Email: verenum@access.ch

ABSTRACT: Efficiency improvement for combustion processes demands low fluegas temperature and low oxygen content. In biomass combustion, the amount of unburnt pollutants is highly influenced by the excess air ratio. The optimum excess air ratio is influenced by the furnace design and the operating conditions, such as heat demand and fuel properties. Nowadays combustion control techniques (flame temperature and lambda control) don't use information about the actual amount of unburnt pollutants and therefore need a setpoint on the save side to avoid incomplete combustion.

The presented advanced combustion control technique ACCT maximizes the efficiency with respect to the emissions of unburnt pollutants for all combustion processes. Basing on CO/Lambda control with selftunig setpoint optimization, it finds the optimum excess air ratio for different furnace designs and operating conditions.

Measurements on a 1 MW understoker furnace equipped with ACCT during a whole heating period showed that the efficiency was above 90 % for the whole range of the heat output. Especially at part load operation the efficiency was improved by up to 5%. CO emissions averaged over one heating period were below 50 mg/Nm^3 which represents a reduction by a factor of 5 compared to flame temperature control. For control with setpoint optimization, there is no need for accurate and stable measurement of CO emissions and lambda. Therefore ACCT can be realized with low cost, in-situ sensors.

For typical fuel costs and an expected efficiency improvement over the whole year of 2 to 4 %, the investments for ACCT are estimated to be repaid in 2 to 5 years.

Keywords: combustion, control, efficiency, emission reduction, selftuning, setpoint optimization

1. INTRODUCTION

Efficiency improvement for combustion processes demands low fluegas temperature and low oxygen content, which is equivalent to a low excess air ratio (Lambda). In biomass combustion, the amount of unburnt pollutants, i.e. CO, HC, PAH and soot, is highly influenced by the excess air ratio. At excess air ratios below a certain optimum value, the unburnt pollutants rapidly increase by a factor of 10 or 100. With increasing excess air ratio above an optimal value, the amount of unburnt pollutants slowly increases [1] (see Fig. 1 and 3).

Control technique on biomass furnaces has progressed very much since the last ten years. While the first generation of automatic wood furnaces were operating only at nominal heat output, the next generation could also run at 50% of the nominal heat output. The standby hours were again remarkably reduced by load control technique being able to vary the heat output between 30% and 100% of the nominal heat output. To operate at high efficiency and low emissions, an adequate combination of load and combustion control technique was necessary.

The most important combustion control techniques used in combination with load control are control of the temperature in the combustion chamber (flame temperature control) [2,3] and control of the excess air ratio (lambda control). These control techniques don't use any information about the actual amount of unburnt pollutants and therefore the settings of the combustion control techniques used today are usually conservative, i.e. the setpoint for the excess air ratio is rather high to avoid incomplete combustion.

The optimum excess air ratio is influenced by the furnace design and the operating conditions, such as heat demand and fuel properties (humidity, specific weight) [4,5]. Experiments on a laboratory furnace showed, that the correlation between CO emissions and excess air ratio shifts to higher excess air with decreasing heat output or with increasing fuel humidity [4,5] (Fig. 1). Therefore selftuning setpoint optimization algorithms [6,7] were developed to find the optimum excess air ratio for different furnace desings and changing operating conditions [4].

Because the operating conditions permanently change, the new generation of combustion control technique should include information about the amount of unburnt pollutants to guarantee a high efficiency and a low emission level without manual interaction. Information about CO emissions can be used alone [8]. However an increase of CO emissions is easier to interpret, if lambda or the flame temperature is also known.

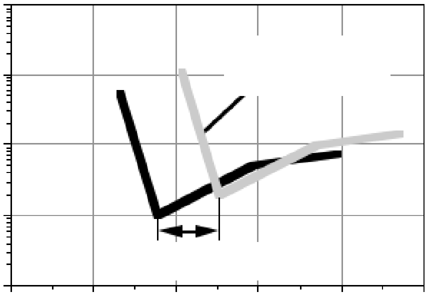

Figure 1: Shift of the correlation between CO emissions and excess air ratio due to changing operating conditions.

2. ADVANCED COMBUSTION CONTROL TECHNIQUE ACCT

The presented advanced combustion control technique ACCT is considered as an additional control loop to the existing combinations of load and combustion control technique.

ACCT is based on a CO/Lambda control algorithm. With the use of additional information by measuring CO emissions, the setpoint of the lambda control loop is permanently optimized (Fig. 2,3).

One possibility of setpoint optimization is to reduce the lambda setpoint until an increase of CO emissions is detected. Another is shown in Fig. 3. Inside a certain range around the actual setpoint lambda control does not change the secondary air. Data of lambda and CO emissions are permanently measured. With exponential forgetting factors, new data are stronger weighted than older data. The shifting of the correlation between CO emissions and excess air ratio due to changing operating conditions can be detected and the setpoint will be adapted. Therefore ACCT maximizes the efficiency with respect to the emissions of unburnt pollutants [9].

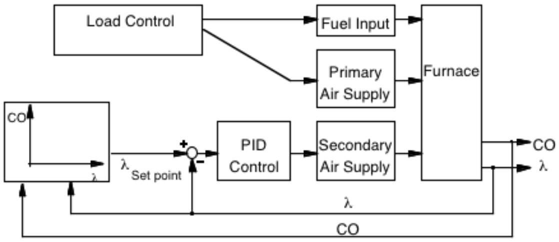

Figure 2: CO/Lambda Control with setpoint optimization [10].

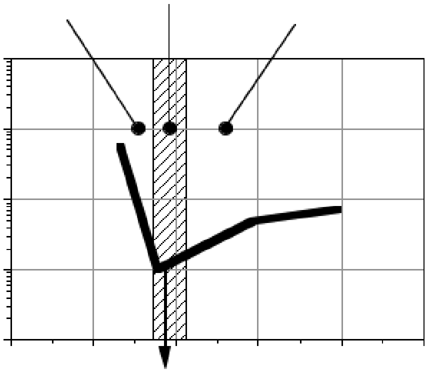

Figure 3: Principles of the controllers action [10].

3. EXPERIMENTAL

ACCT was applied to a 1 MW understoker furnace equipped with load control and flame temperature control (Fig. 2,4). Measurements of emissions and efficiency were done during a whole heating period.

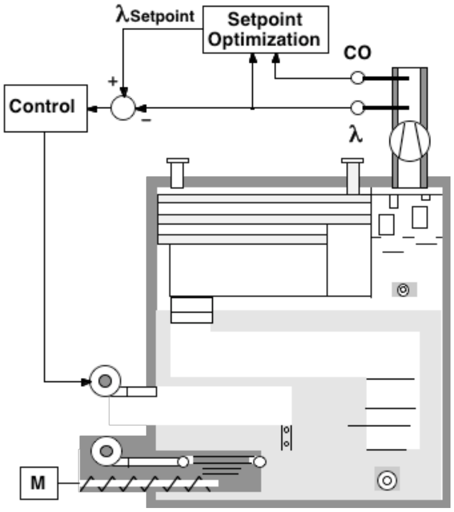

Figure 4: Schematic of a 1 MW understoker furnace equipped with ACCT [10] (TIBA-MUELLER AG).

CO/Lambda control and the setpoint optimization were first performed by reference measurements of O_2 and CO emissions with paramagnetic and infrared analyzers. In a second step ACCT was performed by the use of low cost, in-situ sensors detecting CO emissions and excess air ratio. The gas sensor detecting CO emissions is a solid-state, semi-conductor sensor mainly composed of sintered tin dioxide (SnO_2) which detects gases through an increase in electrical conductivity when reducing gases are absorbed on the sensor's surface, heated at 400 °C (Fig. 5). The lambda sensor is based on zirconium dioxide (ZrO_2). At temperatures above 500 °C the zirconium dioxide as a solid-state electrolyte becomes a conductor of O_2 ions. The porous internal and external platinum cell coatings act as electrodes. If the oxygen partial pressure of the sample gas differs from that of the reference gas, an electromotive force (EMF) is produced that is proportional to the temperature and log-proportional to the oxygen content. As the temperature effects the EMF, it is regulated at a constant value (Fig. 6).

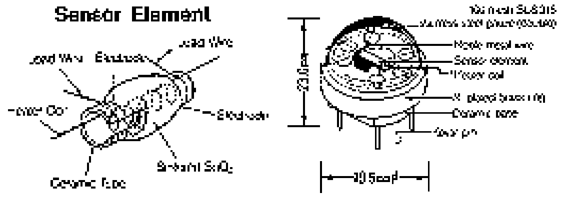

Figure 5: CO sensor (Figaro Inc.).

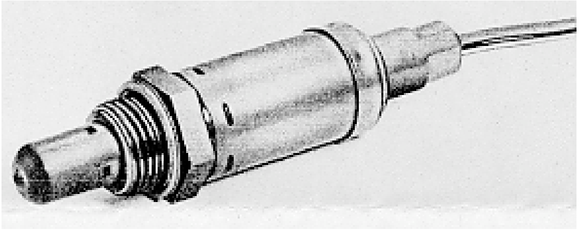

Figure 6: O_2 sensor (Bosch GmbH).

4. RESULTS AND DISCUSSION

Measurements on the 1 MW understoker furnace equipped with ACCT during a whole heating period showed that the efficiency was above 90 % for the whole range of the heat output (Fig. 7). Especially at part load operation the efficiency was improved by up to 5% compared to flame temperature control.

CO emissions averaged over one heating period were below 50 mg/Nm^3 which represents a reduction by a factor of 5 compared to flame temperature control (Fig 8).

Fig. 9 shows, that the selftuning setpoint optimization leads to lower excess air ratios, thus resulting in higher efficiency and lower CO emissions.

It has been seen that there is no need for accurate measurement of CO emissions and lambda. ACCT can therefore be realized by application of low cost, in-situ sensors. They can be used for control and monitoring purposes over long-term periods without calibration and maintenance. Signal drifting of the sensors has no negative effect on the setpoint optimization algorithm. Fig. 10 and 11 show the O_2 sensor measurements in comparison to the O_2 reference measurements and the CO sensor being able to detect CO peaks.

For typical fuel costs and an expected efficiency improvement over the whole year of 2 to 4 %, the investments for ACCT are estimated to be repaid in 2 to 5 years.

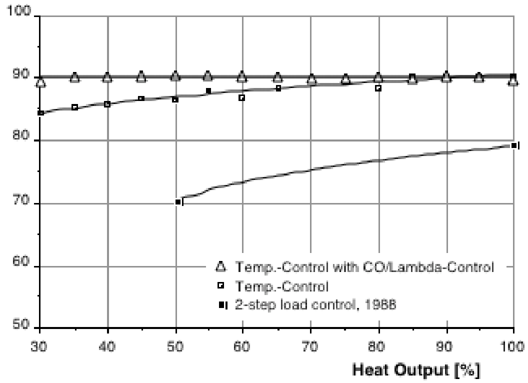

Figure 7: Efficiency versus heat output, averaged over one heating period [10].

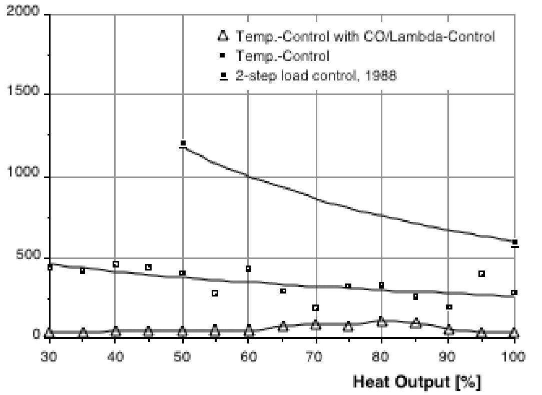

Figure 8: CO emissions versus heat output, averaged over one heating period [10].

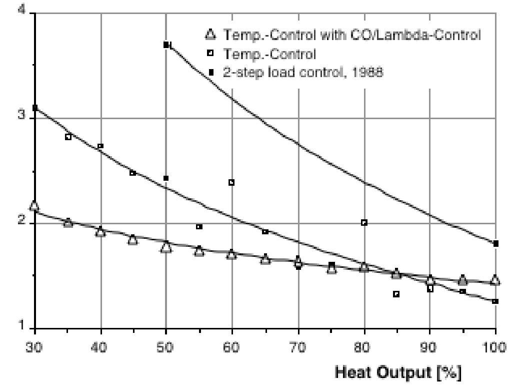

Figure 9: Excess air ratio Lambda versus heat output, averaged over one heating period [10].

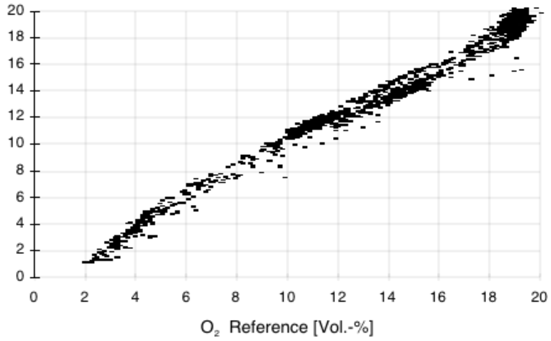

Figure 10: Signal of the O_2-sensor versus O_2-reference.

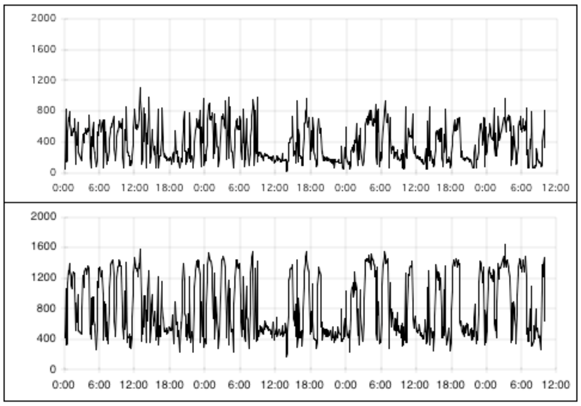

Figure 11: CO-reference and CO-sensor over a period of 3.5 days [10].

5. CONCLUSIONS

In biomass combustion the fuel properties, such as density, water content and heating value can vary in wide ranges. A selftuning combustion control technique is needed to guarantee a high efficiency and low emission level at changing operating conditions. Therefore the advanced combustion control technique ACCT basing on CO/Lambda control with setpoint optimization is proposed.

Measurements on a 1 MW understoker furnace equipped with ACCT during a whole heating period showed that the efficiency was above 90 % for the whole range of the heat output. Especially at part load operation the efficiency was improved by up to 5%. CO emissions averaged over one heating period were below 50 mg/Nm^3 which represents a reduction by a factor of 5 compared to flame temperature control. For typical fuel costs and an expected efficiency improvement over the whole year of 2 to 4 %, the investments for ACCT are estimated to be repaid in 2 to 5 years.

ACCT was also successfully applied to a handfired log wood furnace [11].

Another field of application for ACCT are furnaces with staged combustion used as primary measure for NO_x reduction. One of the parameters for a relevant NO_x reduction is the primary excess air ratio which is expected to be about 0.7 – 0.8. To meet this condition, it is important to operate the furnace at the optimum excess air ratio.

For biofuels with low ash melting points such as grass, miscanthus or urban waste wood, ACCT can be extended in order to avoid an exceeding of the ash melting temperature.

Beside the presented application for wood combustion, ACCT also offers a potential for efficiency improvement and emission reduction for other combustion processes with varying combustion conditions. ACCT can be applied to the combustion of solid fuels like municipal solid waste as well as it can be used for improved fossil fuel combustion.

REFERENCES

[1] Nussbaumer, Th. (1992). Schadstoffbildung bei der Verbrennung von Holz, PhD Thesis ETH Nr. 8838, Zurich.

[2] Leiser, O. (1990). Mit Flamm-Control wird Energieholz zum umweltfreundlichen Brennstoff, HeizungKlima 3 1990, p. 120.

[3] Kerschbaumer, D. (1989). Regelung einer Stückholzfeuerung, PhD Thesis Universität Neuenburg.

[4] Good, J. (1992). Verbrennungsregelung bei automatischen Holzfeuerungen, PhD Thesis ETH Nr. 9771, Zurich.

[5] Good, J. (1994). Combustion Control for Automatic Wood Firings, In: Advances in Thermochemical Biomass Conversion, Blackie Academic & Professional, London, ISBN 0 7514 0171 4, p. 590 – 604.

[6] Föllinger, O. (1976). Regelungstechnik, Elitera Verlag, Berlin,, 6. Auflage.

[7] Unbehauen, H. (1989). Regelungstechnik I und II, Verlag Vieweg, 5. Auflage, Braunschweig und Wiesbaden.

[8] Padinger, R., Novy, M,, Spitzer, J. (1990). Emissionsminderung durch Verbrennungsregelung. In: 1. Holzenergie-Symposium, Bundesamt für Energiewirtschaft, Bern.

[9] Good, J., Nussbaumer, Th. (1995). CO/Lambda-Regelung einer automatischen Holzfeuerung, Amt für Bundesbauten, Bern.

[10] Nussbaumer, Th., Good, J. (1995). CO/Lambda-Regelung mit Sollwertoptimierung zur Wirkungsgradverbesserung und Schadstoffminderung bei Holzfeuerungen, Holz-Zentralblatt Nr. 117, Stuttgart.

[11] Good, J., Nussbaumer, Th. (1993). Regelung einer Stückholzfeuerung mit unterem Abbrand, Bundes-amt für Energiewirtschaft, Bern.