

CO_e-Sensor Control for Optimisation of the Burning Process of Burners in the Range of Small and Middle Power.

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Summary

The biggest part of the anthropogenic emitted pollutants on earth is generated by burning processes in industrial and domestic applications and in combustion engines. The main part of the emitted pollutants is the product of an imperfect combustion, like soot, CO, H₂, and unburned hydrocarbons C_nH_m. The minimization of these pollutants is possible by the use of an intelligent process operating. In automotive and power plant application, the use of the Lambda probe is realised. In case of the high system costs of the lambda probe they are not used in domestic burner systems and in application up to the power rating of 200kW. The next captures are describing a new CO_e-sensor system and the optimal control strategy to use it.

I The Problem

The trend with domestic burner systems is going to infinitely variable Systems, which can operate modular over a wide power range. Another trend is going to burners which are independent of the air around the burner and which can directly be installed in the living space. At these systems, the air-flue gas-system has an important influence at the burning process. Other requirements are results of the more and more flexible market for fuels. This open going market brings more and more fluctuations in the quality of the fuel worldwide. In opposition of this fact, we have the need for a combustion that is optimal at every process point and has the maximum efficiency every time at the minimum of the emitted pollutants. To achieve these requirements under permanent changing conditions is nearly a mission impossible, if you do not use an innovative combustion control based on a sensor system that detects unburned parts of the combustion process (picture 1).

Optimisation of the Burners	
Problem	<ul style="list-style-type: none"> ➤ Incomplete combustion ➤ Lower efficiency ➤ High emission of pollutants (CO_e, soot)
Previous Technology	<ul style="list-style-type: none"> ➤ O₂-control
Futur Technology	<ul style="list-style-type: none"> ➤ Binary control of the combustion product (CO_e)
Goal	<ul style="list-style-type: none"> ➤ Continuous control and reduce of the emission pollutants at all firing systems with the application of ceramic gas sensors for CO_e in combination with an self-adaptive rule policy

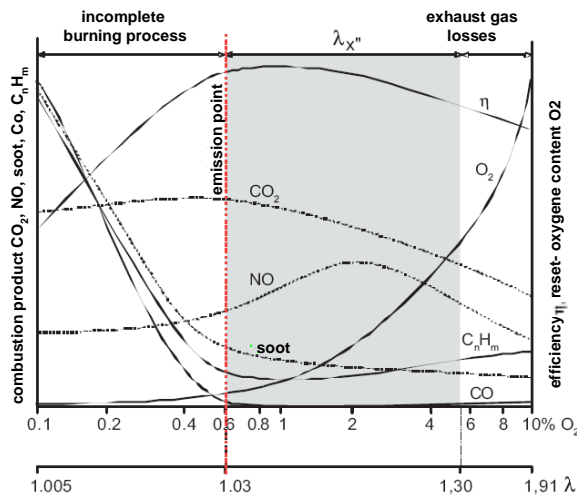
Picture 1 The problem of the optimisation of firing systems

II Optimisation of the Burning Process

2.1 The Burning Characteristics

Picture 2 shows the typical characteristics of the partial pressures of the flue gas in a burner in dependence of the oxygen partial pressure (O₂) or of $\lambda=21/(21-O_2)$. If the burning process is ideal (stiochiometric, $\lambda =1$) the burning process is given exactly the oxygen (from air) needed for the complete burning of the fuel. That means, in the flue gas no oxygen can be found and the burner is working with maximal efficiency. If the oxygen is lower than this case,

the burning process will be incomplete and the emission of pollutants is very high. Too much oxygen in the burning causes high exhaust gas losses because of the higher volume of non-used air.



Picture 2 The burning characteristics

2.2 Available Technology

Fluctuations in the quality of the air (temperature, pressure, humidity), the quality of the fuel (viscosity, calorific value) and changes at the burner system, e.g. defects or wear, accounts a fluctuation of the optimal processing point of the burner. Therefore modern burners are adjusted at a fixed point at $\lambda = 1,3 - 1,4$ to be sure to have a complete combustion at every time. At nominal conditions, the burner is working steadily however with a high distance to the emission point of the burning process and with a lower efficiency during the process.

2.3 The Industrial O₂-Control

In burners for industrial application the burner control based on an O₂ probe, like you can find in automotive application is state of the art. In using that probe it is possible to adjust the burner system at a fixed λ - value. The Drift of the sensors will be compensated by a standard calibration routine. But at least the measurement of the O₂ partial pressure does not give an idea if the combustion is incomplete or not. For a survey of the unburned parts of the flue gas CO_e-sensor is necessary.

2.4 The Industrial CO_e-Control

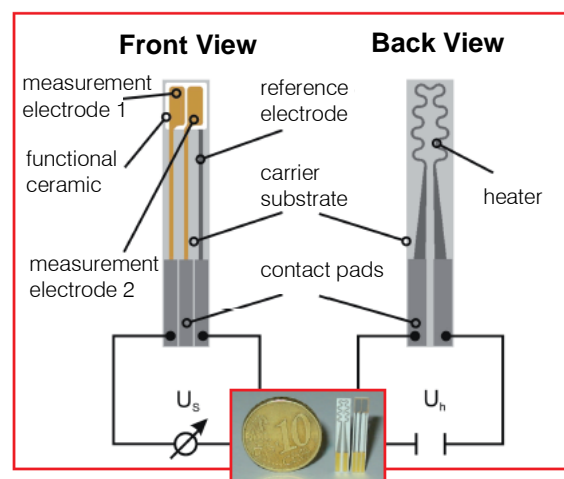
The goal of a modern combustion control has to be the minimization of the exhaust gas lost through the minimization of λ down to the emission point. For that, you have to use a CO_e-probe like the approved KS1 probe of the

LAMTEC Company. The construction is nearly the same like the Nernstian λ -probe. But the signal is a mixed potential where at a minimum of CO_e in the flue gas the voltage output is significant higher than the voltage output of the λ -probe. The KS1-D probe combines both measurements and gives the CO_e- value as well as the O₂ value.

The LAMTEC Company produce electronic control systems and has for industrial burners since 2004 the CO_e-control in addition to the approved O₂-control in the portfolio. In using of this CO_e-control, it is possible to reduce the O₂ partial pressure in the flue gas significant under 1vol. %. In this condition, the combustion will have significant better efficiency and a minimum of CO_e. To get an idea, how much the cost for fuel can be reduced, the brewery Jever made a summary. The result is that they save 12.721,43€ per year at every burner [7].

The CO_e-control got a tribute of the German gas industry at the Innovation price award. In industrial application the O₂-control and the CO_e-control gets more and more importance. Nevertheless, at domestic application it is not possible for the moment to install such sensor systems, because the known one are to expensive and it does not exist an easy control strategy for it although you can find indices in newer literature [4].

To open the way for a more efficient combustion in domestic application and to use there the advantage of a CO_e-controlled burner, a new CO_e-sensor, the CarboSen was developed [1-3].



Picture 3 The CO_e-Sensor CarboSen

III The CO_e-Sensor

3.1 Configuration and Working Principle

The physical principle of the CO_e-sensor (picture 3) is the solid-state electrolysis. The electrolyte is the same like at the λ -probe, yttrium stabilized zirconia (YSZ). YSZ is known for its excellent oxygen ion conductivity in the range of temperature between 400°C and 800°C. Also a advantage of YSZ is the chemical stability. The CO_e-sensor is working on the non-nernstian principle. Different materials for the electrodes allow different adsorption characteristics at the platinum reference electrode and the measurement electrode. On that way it is possible to detect unburned parts in the flue gas. The sensor voltage can be described with

$$U_s = \frac{\mathfrak{R} \cdot T_s}{n \cdot F} \cdot \ln \frac{c_{\text{CO}_e(\text{ad},K)}}{c_{\text{CO}_e(\text{ad},A)}} ,$$

\mathfrak{R} is the universal gas constant, T_s the sensor temperature, $n=2$ the valenz quantity of the oxygen ions and F the Faraday constant. The concentrations $C_{\text{CO}_e(\text{ad},A)}$ and $C_{\text{CO}_e(\text{ad},K)}$ represents the adsorbed CO_e at the electrodes.

The sensor voltage U_s has a logarithmic characteristic with an excellent resolution in the lower measurement range. The origin of the characteristic is defined and without drift at 0mV. The response time of the sensor element is less than 1s. The robustness and the low response time of the sensor element as well as the high dynamic allow establishing a robust monitoring or control of dynamic combustion processes based on the principle of the emission point control.

3.2 Sensor Housings

The planar sensor elements are produced in a clean room at the ESCUBE Company in thick film technology. This kind of production allows a high quality performance at a high quantity. After finishing the sensor elements, they will be integrated in application specific or customer specific housings.

Picture 4 shows the CarboSen1.000 in standard housing for application up to 200°C flue gas temperature with 100% relative humidity. In Case of an easy mechanical mechanism, the sensor can be assembled easily in a drilling between 11,5mm and 12,0mm. The lower illustration in picture 4 shows the housing for high temperature application up to 450°C flue gas temperature.

The CarboSen HT is integrated in a stainless steel housing (8mm diameter) which can be

customised in length up to 1000mm. The assembly into the burner can be done easily with standard compression couplings. With the integrated electronics, the CarboSen ST has his optimum in industrial applications, e.g. monitoring of boiler casing in coal power plants.



Picture 4:
The CarboSen 1000 in standard housing (upper) and in housing for high temperature application with and without integrated sensor electronics

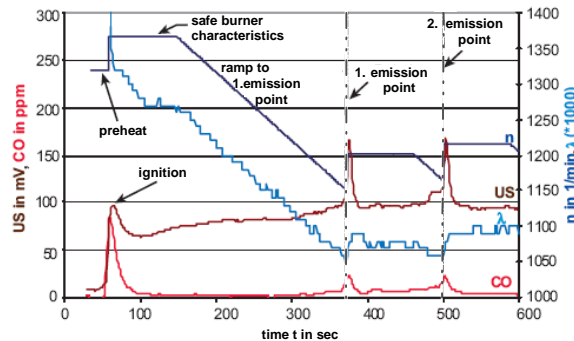
IV CO_e-Control Strategy

In the last two years at the HLK mbH, in cooperation with the Friedrich-und-Elisabeth Boyesen-Stiftung, the CO_e-control strategy of industrial burners became modified and enhanced for smaller burners in domestic application. The burner was a modular working oil blue burner of the company HERMANN on a 20kW boiler of the company Rotex [6].

The sensor CarboSen1.000 is placed directly in the flue gas of the burner. The sensor electronics converts the sensor voltage in to an analogue output. This analogue output will be compiled to a control signal for the fan rotation. Picture 5 shows a typical optimisation cycle at the emission point.

- 1) The burner starts after a long downtime at the safe burner characteristics ($\lambda = 1,3 - 1,4$). The quantity of the oil (controlled over the frequency of the oil pump) depends on the demanded of needed heating power.
- 2) After a fixed time interval, e.g. $t = 50s$, the fan speed will be reduced with a fixed rate dn/dt . The frequency of the oil pump is constant. This means, that λ will be reduced and the efficiency of the burner is increasing.
- 3) The emission point of the burner ($\lambda = 1,05 - 1,1$) will be found by the sensor by a high gradient of the sensor voltage U_s and dU/dt respectively. The optimal working point will be set by a small increasing of the fan speed.

This procedure can be repeated as much as needed. Between two interval of optimisation the burning process will be controlled on fast and slow increasing of the emission.



Pictunre 5 A typical cycle of the CO_e -control

In case of the combination of controlling the sensor voltage U_S , the gradient of the sensor voltage dU_S/dt and the changes in the dependence of the sensor voltage and the control values dU_S/dS_i effects of degradation and drift can be compensated. A calibration of the sensor system is not necessary. A self-test of the sensor system in combination with some plausible values of the burner system gives a maximum of safety of the burner.

V Results

The using of adaptive sensor controlled burner with the emission point strategy allows the reduction of the exhaust gas loss down to the minimum and the reduction of the emission of the pollutants. If all burner systems for domestic application in Germany would have a 1% lower exhaust gas loss, we could save 397 million litre oil and 478 million m^3 gas. The emission of CO_2 could be reduced about 1,9 Million tonnes per year [4]

In additional to the cost reducing of the burning process the in-situ measurement of the CarboSen directly in the flue gas allows a continuous diagnostic of the burner system. In that way, changes can be found before the process will be in a critical state. An intelligent diagnostic monitoring allows reducing the service maintenance just on need. On that way, the using of the sensor system CarboSen increase the reliability and the reduction of service and repair cost.

VI Literature

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