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MEASUREMENT OF O_2 IN COMBUSTION CHAMBER WITH AN ANALYSIS OF THE BURN OUT RATIO

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An aim of this experimental research work was to achieve more detailed information about the combustion process in pulverized coal boilers. An O_2 analyser was developed and manufactured for the measurement of O_2volumetric concentration directly in the combustion chamber. The volumetric concentration of O_2 in the combustion chamber is important information about the burn out ratio, quality of combustion and the space distribution of the flame. The uniformity of the flame or the even distribution of the combustion parameters could be a possible way how to move to satisfy new emission limits. Measured parameters of the combustion process could be used for the control system of the boiler.
The O_2 analyser was manufactured for the permanent measurement with acceptable results. The measurement of the air excess ratio in the combustion chamber shows that for the left and right side of the combustion chamber could be highly non-uniform. For correct interpretation of the air excess ratio measured in the combustion chamber is necessary to know local amount of the unburnedcarbon in the position of the measurement. Therefore a new extraction line with an isokinetic probe was installed in the boiler for an extraction of the particles from the combustion chamber. The extracted sample was analysed in the laboratory and in the position where the combustion process should be terminated was measured from 3-12% of the flammable substance in the analysed sample.
Key words: O_2-measuremet, lambda probe, pulverized coal boiler.

Mjerenje O_2 u komori za izgaranje s analizom produkata izgaranja. Cilj ovog eksperimentalnog istraživanja bio je dobiti detaljnije informacije o procesu izgaranja u kotlovima na ugljen u prahu. O_2 analizator je razvijen i proizveden za mjerenje volumenske koncentracije O_2 izravno u komori za izgaranje. Volumenska koncentracija O_2 u komori za izgaranje je važan podatak o produktima izgaranja, kvaliteti izgaranja i prostornoj raspodjeli u plamenu. Mogući način zadovoljavanja novih granica emisije mogli bi biti: uniformnost plamena ili ravnomjerna raspodjela parametara izgaranja. Izmjereni parametri procesa izgaranja mogu se koristiti za sustav kontrole kotla.
O_2 analizator je proizveden za trajno mjerenje s prihvatljivim rezultatima. Mjerenje pretička zraka u komori za izgaranje na lijevoj i desnoj strani komore pokazuje da može biti neuniformnost izmjerenih vrijednosti. Za točno tumačenje pretička zraka izmjerenog u komori za izgaranje, potrebno je znati lokalni iznos neizgorenog ugljika u položaju mjerenja. Stoga je instalirana nova linija ekstrakcije s izokinetičkom sondom u kotlu za ekstrakciju čestica iz komore za izgaranje. Izvađeni uzorak je analiziran u laboratoriju i na njemu je, u položaju u kojem se proces izgaranja treba završiti, izmjereno 3-12% zapaljive tvari (neizgorenog ugljika).
Ključne riječi: mjerenje O_2, lambda sonda, ugljena prašina kotla.

INTRODUCTION

A worldwide effort to enhance efficiency of the electricity production is forcing operators to increase the efficiency of the existing power-plants. A possible way to reach this goal is to enhance the control system of the combustion in the boiler. This work is focused on the pulverized coal boilers. Temperature, air excess ratio and

other parameters are within a common operation in a certain non-uniform state across the combustion chamber. This non-uniformity can cause the operational state where in a certain place in the furnace is lack of the air and in the other is the excess of the air. The control system mostly has only integral information about the combustion from the second pass of the boiler. The measurement of these parameters directly in the combustion chamber can be used together with the combustion chamber model for the active control of the burners and mainly the air distribution into the combustion chamber to reduce this non-uniformity. The air excess ratio or the O_2 content was determined as the most suitable parameter for the boiler's control. The position of the O_2 analyser was chosen at the end of the combustion chamber where the combustion process should be terminated. This position for the analyser is compromise between the precision of the measured data and a condition suitability at the position of the extraction pipe. The measurement inside the combustion chamber has some difficulties due to high temperature and moreover the data from the analyser could be shifted by the amount of the unburned fuel at the position of the measurement. The measurement behind the combustion chamber is easier due to lower temperature but the measured values are blurred by the flue gas mixing.

EXCESS AIR RATIO MEASUREMENT

The O_2 concentration in any boiler is measured to the determined the air excess ratio, which is the crucial parameter for the description of the combustion process. The O_2 concentration is mostly measured behind the combustion chamber from several reasons:

- The combustion process is definitely terminated and the flue gas contains mainly CO_2, H_2O as the main products of the combustion and some remaining O_2 and N_2 (a volumetric contents of NO_x and SO_2 is negligible). In the case of the complete combustion, without CO production and remaining carbon the air excess ratio can be determined by Eq. 1

$$\alpha = \frac{0.21 + \omega_{O_2}^{wet} \cdot \upsilon\left(\frac{V_{FlueGasWet\,\min}}{V_{AirWet\,\min}} - 1\right)}{0.21 - \omega_{O_2}^{wet} \cdot \nu} \quad (1)$$

Where **ω** denotes concentration and **V** denotes volume. Ratio **ν** is defined as

$$\upsilon = \frac{V_{AirWet\_\min}}{V_{AirDry\_\min}} \quad (2)$$

The ratio $\frac{V_{FlueGasWet\_\min}}{V_{AirWet\_\min}}$ varies from 1.1 to 1.25, and has to be taken into consideration.

- The measurement of the volumetric concentration of the O_2 or the flue gas sampling is not difficult because there is not a problem with high temperature in the combustion chamber.

In the case of the in-complete combustion (inside of the combustion chamber) the flu gas contains additional species CO come hydrocarbons and the carbon. The excess air ratio determination requires knowledge of two more entry, e.g. the volumetric concentration of the CO_2 and the amount of the unburned carbon. In this case the air excess ratio can be determined by the equation (3)

$$\alpha = \frac{e_1.\omega_{O2} + e_2.\omega_{CO2} + e_3}{c_4.\omega_{O2} + c_5.\omega_{CO2} + c_6} \quad (3)$$

Where the coefficients e_1, e_2, e_3 are functions of the ratio of the unburned carbon. The relations for this coefficients and constants c_4, c_5, c_6 are described in [1].

The measurement of the volumetric concentration O_2 with the flue gas sample extraction is difficult due to the high temperature. The extraction pipe which is exposed in the combustion chamber is in the environment with the temperature higher than 1000°C. A ceramic material cannot be used due to itself brightness and when the slag is falling down from the superheater could be simply broken. A metallic material can be used up to the temperature 1000°C because they have in this temperature unacceptable low limit of the strength in creep. This fact causes the long term deformation of the extraction pipe. In this project a Kanthal APM was used as the extraction pipe material. This sintered material is an alloy of the FeCrAl. The strength limit at the temperature 1000°C is 2MPa and the deformation after 1000 hours is 1%. Any alloy on a base of CrNi is not possible to use without cooling.

A partially melted ash which create a slag crust on the outer surface of the extraction pipe and it produce an additional bending moment, which multiply the deformation speed of the extraction pipe. The long-term test requires some protection against the slug crust formation. A slug scraper was use in this project, other slag removing ways possible to use are a water or steam jet, vibration technique, etc.

Description of the analyser O_2

The new analyser of the volumetric concentration of O_2 was developed for the need of the long-term measurement of O_2 concentration inside of the combustion chamber of the pulverized coal boiler. The volumetric O_2 concentration is determined by the lambda wide-range (planar) sensor Bosch LSU 4.9. This sensor [2] is based on the principle of two ZrO_2 electrochemical cells. The first cell measures the O_2 concentration in the testing volume. The second cell is the inverse electrochemical cell, and it removes (or adds) oxygen ions, to held the air excess ratio in this volume equal to one. The oxygen concentration in the flue gas is determined from the electric current flowing through the second electrochemical cell. An advantage of this sensor is that it can determine the air excess ratio in a wide range of values. This sensor can also identify sub-stoichiometric combustion as well. The extraction pipe of the analyser is equipped with periodic blow-through periodical cleaning by compressed air. The sensor itself is protected by a high-capacity stainless steel filter. Without this cleaning, ash and coal powder can block the extraction pipe within a few hours. The temperature along the entire extraction line is controlled to avoid unfavourable condensation. The sample transport within the analyser is executed by a chemical resistant air pump.

The present design of the analyser with the extraction line (Fig. 1.) is the result of development work based on test measurements performed at the Mělník1 power plant. The aim was to develop a compact structure for the analyser.

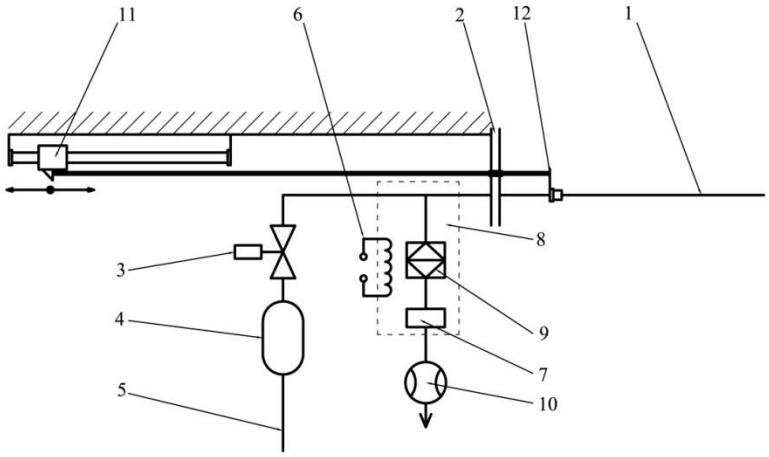

Figure 1. Scheme of the entire O_2 analyser. 1 – extraction pipe, 2 - connection port, 3 – electro-magnetic valve, 4 - air storage vessel, 5 - connection to the compressed air line, 6 – PID - controlled heater, 7 - λ-sensor, 8 - isolated box, 9 – filter,10 – air pump, 11- linear drive unit, 12 – slag scraper

Slika 1. Shema cijelog O_2 analizatora. 1 – cijev za ekstrakciju, 2 – priključni dio, 3 – elektro-magnetski ventil, 4 - Spremnik za zrak, 5 - priključak na liniji za komprimirani zrak, 6 - PID-kontroliran grijač, 7 - λ-senzor, 8 - izolirana kutija, 9 - filter, 10 - pumpa za zrak, 11 - linearni pogon, 12 – strugalo za šljaku

Figure 2. The analyser mounted on the wall of the boiler

Slika 2. Analizator montiran na zid kotla

Several measurement campaigns were performed with the new analyser in duration 1 day to 2 weeks; some of them are mentioned in the [3] or [4]. The purpose of these campaigns was to verify all new components and overall design of the analyser especially the periodical cleaning of the extraction line outer surface. The lambda probe itself was tested as the O_2 volumetric concentration measuring device before in series of short one-day measurements. The most of these measurements were done in the power-plant Mělník on the boilers K6 and K4, on the floor level +22 a +24 m (Fig.2). At this position in the boiler the combustion process should be terminated but in the next step was necessary to verified this assumption and evaluate its dependence on the analyser output data.

Determination of the particle size distribution function and the local amount of the unburned carbon in the flue gas

The measurement of a size distribution function of the particles at the end of the combustion chamber was used an extraction line which was developed especially for the higher temperature and higher due point of the flue gas (Fig.3). The temperature of the extracted flue gas in the measurement position is in the range of 800˚C - 1200˚C. Furthermore, the temperature along the extraction line was continuously controlled to avoid a vacuum pump overheating. In the case of high flow rate, when the temperature of the flue gas was high the flue gas was dissolved with an ambient air. The analyser of the size distribution function of the particles in the flue gas was an industrial facility Spraytec produce by Malvern Comp. The results are achieved by the light scattering of the laser beam.

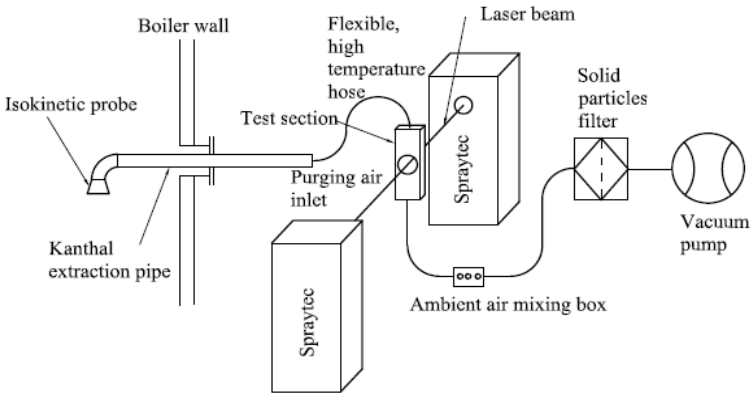

Figure 3. Scheme of the extraction line forparticles sampling from the combustion chamber
Slika 3. Shema linije za ekstrakciju uzoraka čestica iz komore za izgaranje

The extraction line is suitable to export continuous data from Spraytec, the solid particles are further collected in the filter. For the verification of the system the sieve analysis was performed for the determination of the size distribution function. The average value of Sauter diameter was determined D_{32}=14.3 μm for the particles at the end of the combustion chamber with standard deviation 0.8 μm. This value can be expected as typical particle size from measurement port during the test.

The Fig. 4 shows good agreement between the size distribution function achieved by the analysis with the Sprayec measurement and the function given by the sieve analysis. Both were determined from the same sample position in the combustion chamber where the temperature is around 1000˚C.

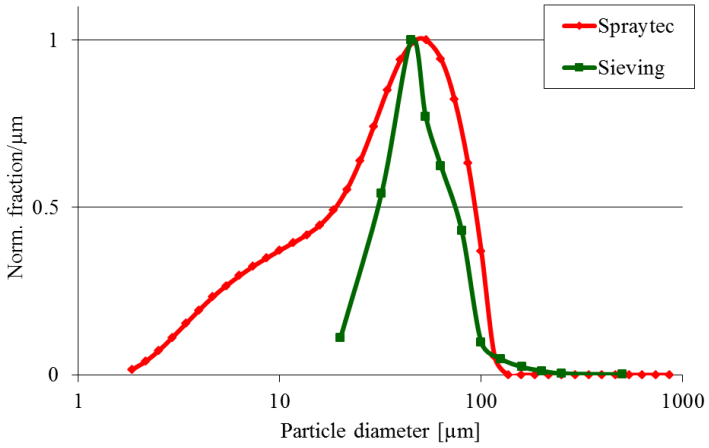

Figure 4. Size distribution functions yield by the Spraytec and sieving analysis
Slika 4. Funkcije raspodjele veličine čestica pomoću Spraytec i analize prosijavanjem

The particle sample captured in the filter of the extraction line was tested to determine amount of the unburned carbon at the position of the measurement. The amount of the sample was not sufficient for standard statistical analysis so only two couples of sample were tested. Average values of these samples are shown in the Table 1 below.

Table 1. Average values of samples A and B
Tablica 1. Srednje vrijednosti uzoraka A i B

Sample	W^r	Unburned carbon in the dry sample
A	0,46%	11,26%
B	0,51%	3,59%

CONCLUSION

The measurement of the volumetric concentration O_2 inside the combustion chamber is a possible way for the verification of the combustion models of the pulverize coal boilers. In this case when is the measurement of the local volumetric concentration O_2 used for governing of the combustion process in the boiler it would be necessary to know the local amount of the unburned carbon as well.

For this purpose were developed on the CTU in Prague a new O_2 analyser and a new extraction line for sampling the particles from the boiler. Both were tested in the common lignite burning pulverized coal boiler in the Mělník power-plant. The tests confirmed the non-uniform O_2 concentration distribution across the combustion chamber and the fact that the combustion process is not terminated at the end of the furnace. This cause the uncertainty 0,4-1,2% of the measured O_2 concentration. The solution to avoid this uncertainty is to place the measurement ports behind the combustion

chamber in the position of the steam superheaters or find the way how to on-line evaluate the local amount of the unburned carbon together with the measurement of the volumetric concentration of the O_2 in flue gas.

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