Measurement of O_2 in the Combustion Chamber of Apulverized Coal Boiler

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Abstract

Operational measurements of the O_2 concentration in the combustion chamber of a pulverized coal boiler are not yet common practice. Operators are generally satisfied with measuring the O_2 concentration in the second pass of the boiler, usually behind the economizer, where a flue gas sample is extracted for analysis in a classical analyzer. A disadvantage of this approach is that there is a very weak relation between the measured value and the condition in specific locations in the fireplace, e.g. the function of the individual burners and the combustion process as a whole. A new extraction line was developed for measuring the O_2 concentration in the combustion chamber. A planar lambda probe is used in this approach. The extraction line is designed to get outputs that can be used directly for diagnosis or management of the combustion in the boiler.

Keywords: O_2 measurement, Lambda probe, Pulverized coal boiler.

1 Introduction

The aim of this study was to obtain more detailed information about the combustion process in pulverized coal boilers. The volumetric concentration of O_2 in the combustion chamber provides important information about the burn-out ratio, the combustion quality, and the space distribution of the flame. Simultaneous application of several classical O_2 analyzers for making measurements in multiple places in the combustion chamber is too expensive for ordinary industrial operation. Another disadvantage of classical types of O_2 analyzers is that a flue gas sample cooler needs to be used, which makes the entire measurement system complicated and delays the delivery of the acquired information. A new analyzer device has been developed for making simple and affordable measurements in the combustion chamber of a pulverized coal boiler [1]. It consists of an extraction line, an oxygen sensor, suction pump, and a periodic cleaning system. A wide range λ-sensor is used as the O_2 measurement element. This is a type of sensor that is widely used in the automotive industry. Mass production reduces the price of the whole analyzer. The flue gas is drawn by the pump directly through the extraction line of the analyzer, without using the cooler, and then the flue gas passes by the λ-sensor. The sensor measures the O_2 concentration directly, i.e. in the wet flue gas. Under suggestion that the combustion process is finished, the air excess ratio can be determined by Eq. 1

$$\alpha = \frac{21 + \omega_{O_2}^{wet} \cdot \nu \left(\frac{V_{FlueGasWet\min}}{V_{AirWet\min}} - 1 \right)}{21 - \omega_{O_2}^{wet} \cdot \nu}, \qquad (1)$$

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

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

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

2 Description of the analyzer

The measurement sensor is a BOSCH LSU 4.9 wide-range (planar) sensor. This sensor [2, 3] 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 gasses 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 combustionas well. The extraction line of the analyzer is equipped with periodic blow-through periodical cleaning by compressed air.

Figure 1: The extraction line and the head of the λ-sensor

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 unfavorable condensation. The sample transport within the analyzer is executed by a chemically resistant air pump.

The present design of the analyzer with the extraction line (Figure 1) is the result of development work based on test measurements performed at the Mělník 1 power plant. The analyzer itself is installed in an isolated, temperature-controlled box. The aim was to develop a compact structure for the analyzer. Several different structural solutions were abandoned because they did not provide the anticipated properties. A former manner of the sample transport was provided by the air driven ejector. The tests in the power plant revealed the problem of the ejector getting blocked by a mixture of ash and condensed liquids from the flue gas. Another disadvantage was the high consumption of compressed air. The extraction pipe inserted in the combustion chamber is made from high-temperature resistant kanthal material. The velocity of the flue gas in this pipe should be slow, in order to take advantage of the gravitation setting of the prevailing part of the ash. This settled powder is blown away by the periodic cleaning. The compressed air for cleaning is stored in a 5-litre pressure vessel. The cleaning period of 10 sec every hour is activated by opening an electromagnetic valve. The valve is governed by a programmable logic controller (PLC).

3 Calibration and test measurements

Several tests were performed in the laboratory with the extraction pipe and the LSU 4.9 sensor. The sensor has its own calibration function between the measured electric current and the volumetric O_2 concentration. The purpose of the laboratory tests was to find the properties of our extraction line with the sensor. We tested the absolute value of the O_2 concentration, and the time response to the change in concentration. For the reference measurement, we used a paramagnetic analyzer PMA12 (M&C). Both analyzers measured the same gas sample (a mixture of N_2 and air) at the same time. The uncertainty detected during the tests was lower than 2 % of the measurement range for the expected operation measurement. This uncertainty is acceptable for this analyzer.

The time delay is in the order of seconds, depend on the pump performance and the optimum flue gas velocity in the extraction pipe. For O_2 concentrations higher than 15 %, the time response is longer, but this condition is, in general, outside the desired operational condition in the combustion chamber.

More attention was paid to the tests in the power plant. In a laboratory, it is difficult to simulate the same conditions as in a combustion chamber, especially the high temperature of the dewpoint and the high concentration of solid particles in the flue gas. The measurements were mostly carried out at the Mělník 1 power plant. These measurements focused on the reliability of the entire analyzer and tests of the periodic cleaning of the extraction pipe. The heating system of the analyzer was also tested.

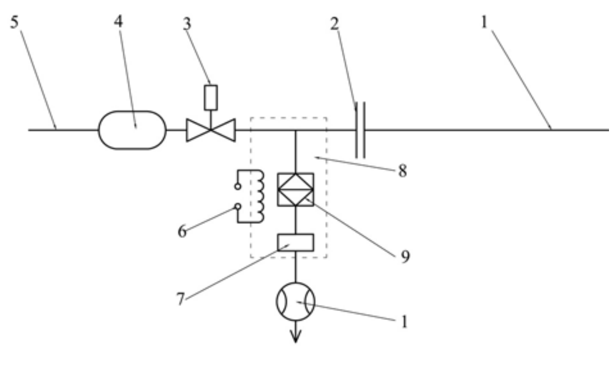

Figure 2: Scheme of the extraction line and the analyzer: 1 – air pump, 2 – connection port, 3 – electromagnetic valve, 4 – air vessel, 5 – connection to the compressed air line, 6 – PID-controlled heater, 7 –λ-sensor, 8 – isolated box, 9 – filter

Figure 3: The inlet to the extraction pipe after a one-day test

Figure 3 shows the inlet part of the extraction pipe after a one-day test. This test showed the good efficiency of periodic cleaning. Without cleaning, the tip of the extraction line became blocked by ash. After this measurement, no trace of unfavorable condensation inside the analyzer was detected.

Figure 4 presents an example of the measured data from a pulverized coal boiler at the Mělník 1 power plant. After 3 minutes, the analyzer was placed in the boiler. In the 16th minute, the cleaning event by the compressed air blow through can be seen.

4 Results

When the final design of the analyzer was settled, a second analyzer was manufactured. For the verification of analyzers were used opportunityto measure the off-design operation of boiler K6 at Mělník 1, in collaboration with I&CEnergoCompany. During these tests, the data from the analyzers was compared with the operational measurement of the O_2 concentration in the second pass of the boiler. This verification measurement was considered successful, because the new analyzers follow all changes to the boiler setting. Further verification tests will be made and operational experience with the analyzer will be gained.

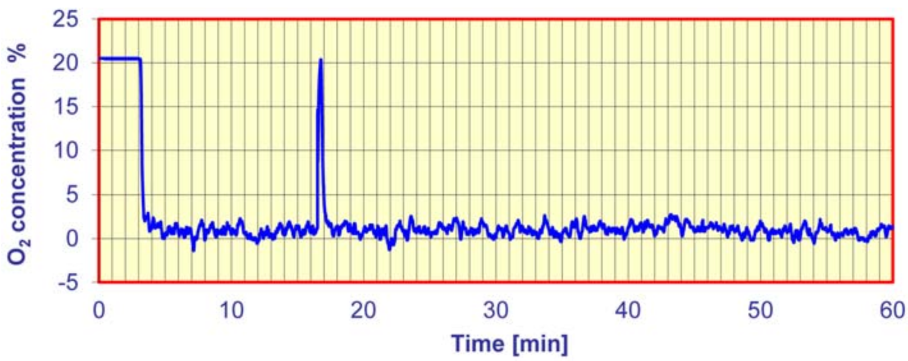

Figure 4: Acquired data example of O_2 concentration

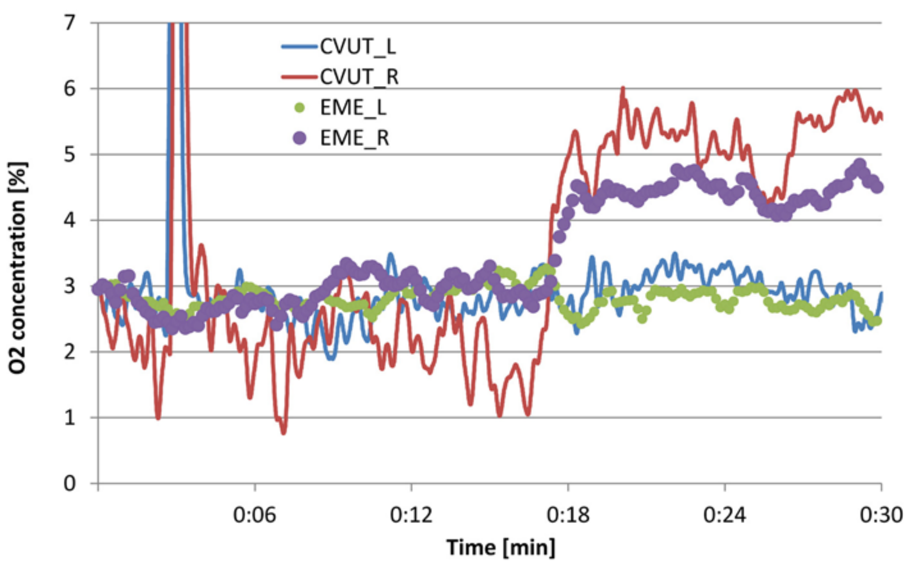

Figure 5: Acquired dataexample from the left and right side of the boiler measured by the boiler control system and by the tested analyzers

An example of the measurements is presented in Figure 5. The label CVUT denotes the new analyzer, and EME denotes operational measurements of the boiler. L and R refer to the left and right side of the boiler. In the 18th minute of this test, the amount of air in the right side of the boiler increased rapidly, while the left side remained stable. The operational measurement is placed behind the combustion chamber and the information is blurred by the mixing of the flue gas behind the combustion chamber.

5 Conclusion

The new O_2 analyzer was developed, tested and used for practical measurements. The main advantage of the analyzer is that it provides immediate information about the O_2 concentration at the place of measurement. This information can be used in the boiler control system to optimize some imbalances in the combustion chamber. The new analyzer was developed for pulverized coal boilers, but it can also be used for other types of boilers. T analyzer costs less than classical analyzers, which raises the question of the possibility of using the same analyzer or a similar analyzer to control boilers with lower performance. Also biomass combustions systems offer a broad field of potential applications.

If the combustion process is not finished, measured value provides cumulative information about the amount of as yet unburned fuel and the excess air ratio. These two parameters can be distinguished only with additional information about the combustion. We expect that the analyzer will be able to provide accurate results only in the region when combustion is finished.

The present development focuses on reliability enhancement, especially on the external side of the extraction pipe. The outer surface can be covered by melted ash; this layer can increase until the weight of the stuck ash bends the extraction pipe. Periodic mechanical cleaning of the outer surface is currently under development.

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