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Chapter 7. Monitoring the fuel combustion process based on actual measuring of oxygen concentration in the air

1. Introduction

Combustion process notably determines the reliability and efficiency of the boiler unit. One of the major purposes of the process of furnace operation is combustion control which provides support of the required power and efficiency of the unit.

Typically, the characteristic that determines the efficiency of the combustion process while burning any types of fuel in different flue devices is the excess air coefficient (EAC, α). While the operation in different modes of formation it`s necessary to maintain the optimal EAC in which the summary loss of heat with gases and losses from chemical incomplete combustion is minimal.

However, it`s necessary not only to support EAC, but also check its value periodically. Determination of the EAC, is usually determined by the composition of the combustion products, including the residual O_2 concentration in the outgoing flue gases:

$$\alpha = \frac{21}{21 - [O_2]_{out}}, \tag{1}$$

where $[O_2]_{out}$ — is the volume concentration of oxygen (VCO) in the outgoing flue gases, %.

For the efficient quality control of the combustion process it`s possible to use various types of gas analyzers, their principle is mostly based on the formula (1), which states the VCO in the ambient air at level 21%.

However, it`s indicated in the number of studies[1] that this level may vary depending on several parameters: temperature, pressure and humidity. Thus, the considered method for EAC determination in the gas analyzers contains a significant systematic error.

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[1] Методика расчета количества кислорода в атмосферном воздухе на основе метеорологических

Error characterizes the imperfection of measurements (caused by inaccuracy of the measurers, the incompleteness of our knowledge about the phenomenon, difficulty of taking into account all incidental factors affecting the measurement). Their positive feature is accuracy.

The accuracy is the quality of measurements that reflects the closeness of the results to the actual value of the measured value. In metrology accuracy is usually characterized incidentally because of the measurement error — the more accurate is measurement, the lower is it`s error.

In this work, by increasing the accuracy of EAC measurement it`s necessary to understand the increasing of the proximity degree of the EAC value founded by the way of the indirect measurements EAC value with its real (conventionally true) value.

2. Analysis of the existing methods

Currently, there is a number of known methods for the determination of gaseous substances in the products of combustion boilers[1]. They are divided into three categories: physical, chemical and physico-chemical (Fig.1). The use of mechanical methods to control gas mixture, despite the selectivity, universality and simplicity, is not acceptable because of the low accuracy, low sensitivity and a considerable length of the analysis time. The range of magnetic methods application is narrowed to the analysis of gases, which have paramagnetic properties (for example O_2, NO).

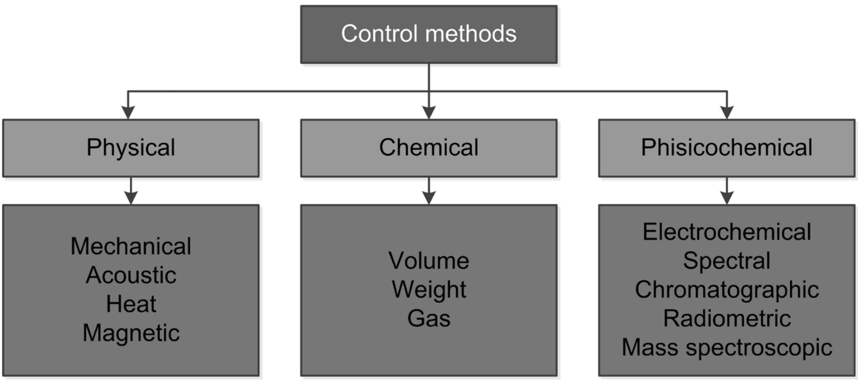

Figure 1. Classification of the methods of controlling the composition of gaseous substances

параметров с целью прогнозирования метеопатических эффектов атмосферы: [метод. рекомендации]/ Гл. упр. лечеб.-профилакт. помощи; сост. В. Ф. Овчарова. – М.: МЗ СССР. – 1983. – 13 с.

[1] Kouprianov, V. I. Applications of a cost-based method of excess air optimization for the improvement of thermal efficiency and environmental performance of steam boilers/V. I. Kuprianov//Renewable and Sustainable Energy Reviews. – 2005. – Vol. 9, Issue 5. – P. 474–498; Kouprianov, V. I. Optimization of excess air for the improvement of environmental performance of a 150 MW boiler fired with Thai lignite/V. I. Kouprianov, V. Tanetsakunvatana//Applied Energy. – 2003. – Vol. 74, Issue 3–4. – P. 445–453.

Thermal methods of analysis are characterized by non-linearity calibration characteristics, electric dependence of thermal conductivity on the ambient conditions (temperature of the gas environment, atmospheric pressure fluctuations, velocity of the gas exchange, etc.) and large inertia.

Acoustic methods are based on measuring the absorption or velocity of sound propagation and ultrasonic waves in a gas mixture. This method is not selective, and is usually used only to determine CH_4, O_2, H_2 in binary and pseudo binary blends.

Thus, the use of physical methods class is impractical in the gas analysis in the determination of the wide range of materials (especially at low concentrations).

Determining the quantitative characteristics of weight and volumetric methods of chemical analysis sometimes causes difficulties, the main of them are:

• the necessity of prior separation of the analyzed substance from impurities;

• low sensitivity that limits the definition of small concentrations of test material;

• long duration of analysis (especially in a weight method).

Physicochemical methods (Fig. 2) differ with a high sensitivity and selectivity, that`s make it possible to use them in determination of extremely low concentrations of these substances. Among the advantages of such methods is also no need to use indicators, selectivity and small sample analysis[1].

Thus, physical and chemical methods differ by expressivity, selectivity and high sensitivity, allowing to apply them for determination of flue gas using gas analyzers.

Today with a large number of electrochemical methods of gases analyze the most widely used are conductometric, polarographic, potentiometric and coulometric.

Conductometric method of gas analysis is based on the change of the electrical conductivity of the solution due to selective absorption of a specific element from the controlled mixture. During the analysis (before and after the absorption of the corresponding element) the electrical conductivity of controlled mixture of χ is measured.

Conductometric analysis is characterized by the need to build a calibration characteristics of the solution conductivity characteristics from the concentration the studied gas in it.

The dependence of conductivity from temperature is determined by the equation:

$$\chi = \chi_0 \cdot (1 + A \cdot t + B \cdot t^2), \quad (2)$$

where χ_0 — electrical conductivity of the solution at 0 °C; A, B — factors that depend on the nature and concentration of the electrolyte; T — temperature.

Conductometric method of analysis is sufficiently accurate, rapid and objective. The relative error of some electrolytes by this method is ±1%, and with titration — no more than ±2%.

[1] Апаратно-програмне забезпечення моніторингу об'єктів генерування, транспортування та споживання теплової енергії: Монографія/В. П. Бабак, С. В. Бабак, В. С. Берегун та ін.; за ред. чл.-кор. НАН України В. П. Бабака/ – К., Ін-т технічної теплофізики НАН України, 2016. – 352 с

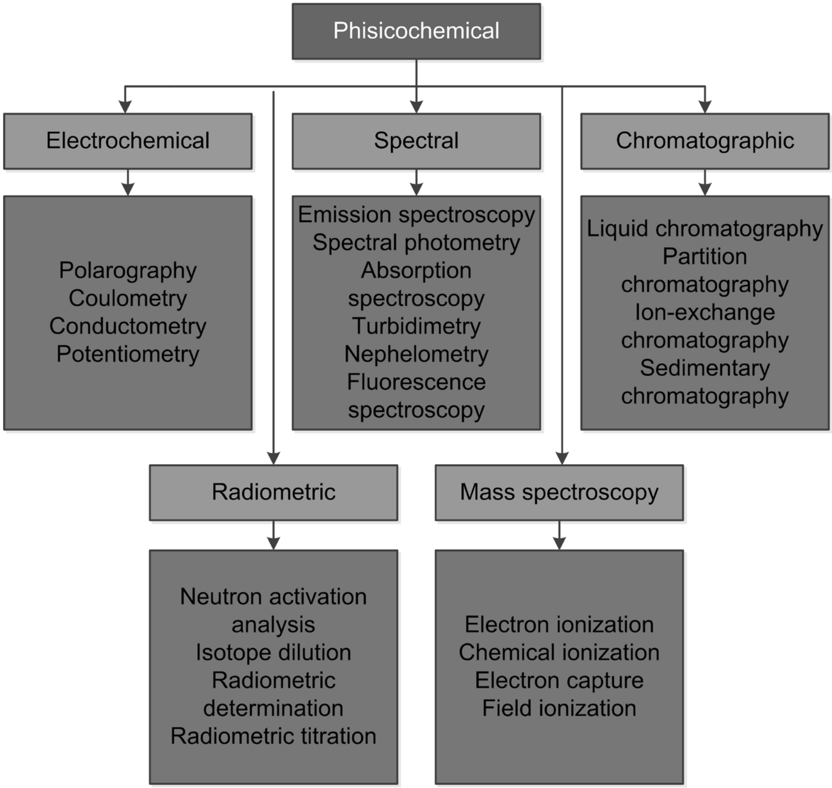

Figure 2. Classification of physicochemical methods of controlling the composition of gaseous substances

However, the application of the method is limited by the fact that the electrical conductivity depends on the concentration of all the electrolytes that are available in solution that describes the low selectivity of the conductometric method.

The accuracy will increase if the electrolytic cell would be placed in a thermostat, and make the measurements of the changes of resistance of the solution on each discrete portions of titrant after the setting the constant temperature.

Polarographic method is based on measuring the strength of the current, which is dependent on the voltage during electrolysis in case when one electrode (cathode) has a rather small surface area, and the other (anode) has a higher surface area.

The power of current at which the full discharge of all ions of analyzed that enters the space due to diffusion electrode is achieved, is called the limiting diffusion current. The magnitude of this current is proportional to the initial concentration of the studied substance (ions) in solution. The amperage on the inpatient solid electrode is determined by the equation:

$$I(t) = 706 \cdot n \cdot D^{1/2} \cdot m^{2/3} \cdot t^{1/6} \cdot C, \tag{3}$$

where *I(t)* — current strength; *n* — number of oxidation/restore electrons, which entered in reaction with the ion; *D* — diffusion factor of the ion; m — mass of mercury that flows from the capillary; *C* — concentration of oxidation/restore ions.

The main difference of the polarographic method is the use of the indicator electrode during electrolysis. Due to the small surface area of the current the density of the current on it is relatively large. As a result in part of the solution, which is located along with the electrode, the concentration of the ions in the process of electrolysis sharply decreases. It causes the rapid establishment of equilibrium process when all ions that reach the electrode by diffusion discharge and the current intensity sets constant (diffusion current).

Today the polarography on solid electrodes has spread widely because of the several advantages of this method:

• work in the field of positive potentials, where the use of mercury drop electrodes is limited due to the anodic dissolution of mercury;

• use of thickened/solid electrolyte and metal electrode selection according to the peculiarities of a particular type of gas;

• continuous analysis of the flow of controlled size.

Amperage on inpatient solid electrode is determined by the equation:

$$I = F \cdot D \cdot S \cdot n \cdot \frac{C_s - C_0}{\delta}, \tag{4}$$

where *F* — Faraday number; *D* — diffusion coefficient; *S* — surface area of the electrode; *n* — the number of electrons taking part in the reaction; C_s — molar concentration of the substance in solution; C_0 — molar concentration of the substance at the electrode surface; δ — thickness of diffusion layer.

Gas analyzers that are based on polarographic methods are used to determine gases, which have redox properties (SO_2, NO_2, H_2, Cl_2, O_2, O_3), while the accuracy of the classical polarography is ±2–3%. Also among the advantages of this method there is it`s selectivity and high sensitivity.

Potentiometric method is based on measuring the potential of the indicator electrode immersed in the sample solution, which changes as a result of chemical reactions and depends on the temperature and concentration of the solution.

The potential of the indicator electrode is measured with the help of comparative electrode. During measuring the potential difference the current passing through the cell must have sufficiently small values (ranging 10^{-6}-10^{-14} Å) to prevent the electrodes polarization.

The solubility of most gases such as SO_2, H_2, CO_2 and others is small and their concentration in the dilute electrolyte solutions is very close to the activities, therefore the direct potentiometric method is used to determine these gases.

In a potentiometric titration in the place of equivalence when the concentration of the studied gas is low, a sharp change in the potential of the indicator electrode means the need to end titration. Potentiometric titration method is more sensitive and excludes subjective error that occurs during the visual finding the moment of titration completion.

Coulometric method. This method of analysis is based on full electrooxidation or electroreduction of the electrically active substance. Also the total amount of current required for electrochemical conversion of the substance is fixed. The total amount of matter that had transformed is determined according to the received information, and it's concentration is calculated.

Faraday's law is base of the coulometry:

$$m = \frac{M \cdot I \cdot t}{F \cdot n}, \quad (5)$$

where m — mass of electrochemically converted substance; M — molar mass of the substance; I — current strength in electrolysis; t — time of electrolysis; F — Faraday number; n — the number of electrons involved in oxidation/restore of a single ion.

To make coulometric analysis output of the substance on the current must be 100%, that is all the current flowing through the cell must be spent on the electrochemical reaction involving the studied matter. The basic requirement of coulometry implementation is the need to except the adverse reactions (chemical and electrochemical) involving the controlled sample, otherwise the error will be introduced in the analysis.

Table 1 shows the comparative characteristics of these methods to determine the main components of the flue gas of the boiler plant and associated gases, mainly used in gas analyzers.

As a result of comparing it's determined that the most informative methods in controlling the composition of flue gas boiler installation is conductometric and polarographic methods (8 of 10 analytical parameters). Their symbiosis is important as conductometric method can not measure the concentration of NO_x, and polarographic can not measure the concentration of CO_2. Consideration of these magnitudes is a necessary factor while regime-adjustment works and integrated ecological heating engineering testing of boilers.

3. Methodology

Air is a mixture of natural gases, which is 98–99% composed of nitrogen and oxygen, and carbon dioxide, water, hydrogen, rare gases and others (Table 2). In industry and home air oxygen is used in combustion processes, with its concentration is one of the most important parameters in the optimization of burners.

Traditionally, when calculating the EAC, level of the VCO in air is 21%. However, long-term climate-physical studies allowed not only to refute allegations about the stability of VCO on the plains, but also offer a new option of oxygen, which is part of the air — the partial density.

Table 1. – Comparative characteristics of electrochemical methods for the analysis of flue gas

Gas	Conductometric	Polarographic	Potentiometric	Coulometric
Hydrogen (H_2)	+	+	–	+
Carbon monoxide (CO)	+	+	–	–
Carbon dioxide (CO_2)	+	–	+	+
Hydrocarbons ($C_xH_yO_z$)	+	+	–	+
Nitrogen oxides (NO_x)	–	+	+	–
Oxygen (O_2)	+	+	–	–
Ozone (O_3)	–	+	–	+
Sulfur oxides (SO_x)	+	+	+	+
Chlorine (Cl_2)	+	+	–	+
Fluorine (F_2)	+	–	+	+

Table 2. – Air composition

Component	Formula	Mass concentration,%	Volume concentration,%
Nitrogen	N_2	75.50	78.08
Oxygen	O_2	23.15	20.95
Argon	Ar	1.29	0.93
Carbon dioxide	CO_2	4.68×10^{-2}	31.4×10^{-3}
Neon	Ne	1.4×10^{-3}	18.18×10^{-4}
Methane	CH_4	8.4×10^{-5}	2×10^{-4}
Helium	He	7.3×10^{-5}	5.24×10^{-4}
Krypton	Kr	3×10^{-3}	1.14×10^{-4}
Hydrogen	H_2	8×10^{-5}	5×10^{-5}
Xenon	Xe	4×10^{-5}	8.7×10^{-6}

As a result of these studies it was found a change in the partial density of oxygen in the air on the plains. It lies in the fact that the daily (seasonal) dynamics and fluctuations of the basic meteorological characteristics (temperature, absolute humidity, absolute barometric pressure) resulted by the dynamics of atmospheric processes, takes place the redistribution of the partial density of oxygen in the air and time, resulting in a daily (seasonal) frequency and weather anomalies.

The analytical value of the partial density of oxygen (E, g/m^3) is directly proportional to the atmospheric pressure (P, hPa) excluding partial pressure of water vapor (e, hPa) and inversely proportional to the air temperature (T, K):

$$E = 23.15 \cdot 10^3 \cdot \frac{P - e}{R \cdot T}, \tag{6}$$

where R is specific gas constant for dry air; 23.15% — mass concentration of oxygen in dry air. In this case, the partial pressure of water vapor:

$$e = \varphi \cdot p_{vap}, \tag{7}$$

where φ is the humidity of air,%; p_{vap} is the quantity, which can be determined according to recommendations of the Guide to Meteorological Instruments and Methods of Observation (Switzerland)[1]:

$$p_{vap}\left(P, T'\right) = f\left(P\right) \cdot r\left(T'\right), \tag{8}$$

$$f(P) = 1.0016 + 3.15 \cdot 10^{-6} \cdot P - 0.074 \cdot P^{-1}, \tag{9}$$

$$r\left(T'\right) = 6{,}112 \cdot e^{\frac{17{,}62 \cdot T'}{243{,}2 + T'}}, \tag{10}$$

where T' is the temperature of air in the Celsius degrees, °C

Transition to the VCO was held with the following equation:

$$[O_2] = \frac{6{,}236 \cdot E \cdot T}{P' \cdot M_{O_2}}, \tag{11}$$

where $[O_2]$ is the VCO in the air,%; P' is the atmospheric pressure, mm Hg; M_{O2} is the molar mass of oxygen, g/mol.

The final analytical representation of functional dependence of the VCO in the air on meteorological parameters takes the form[2]:

$$[O_2](P, T', \varphi) = 20.957 \cdot \left(1 - \frac{e(P, T', \varphi)}{P}\right). \tag{12}$$

During the research it was analyzed the change of the main meteorological parameters (temperature, pressure, humidity) during 2014–2016 in 3 cities: Vienna (Austria) (Fig. 3), Kiev (Ukraine), Moscow (Russia) and obtained seasonal changes of VCO in the air in these areas (Fig. 4).

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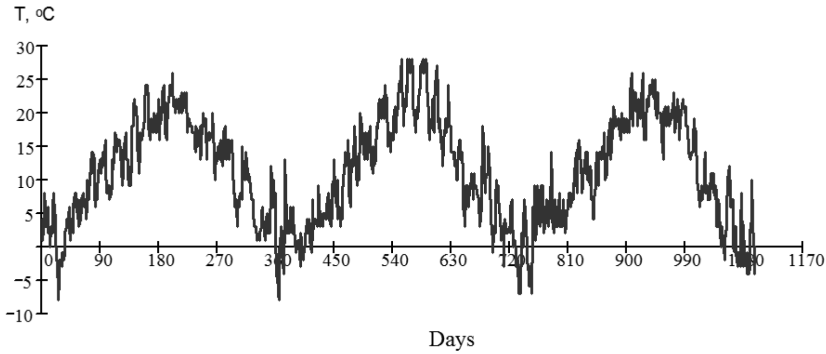
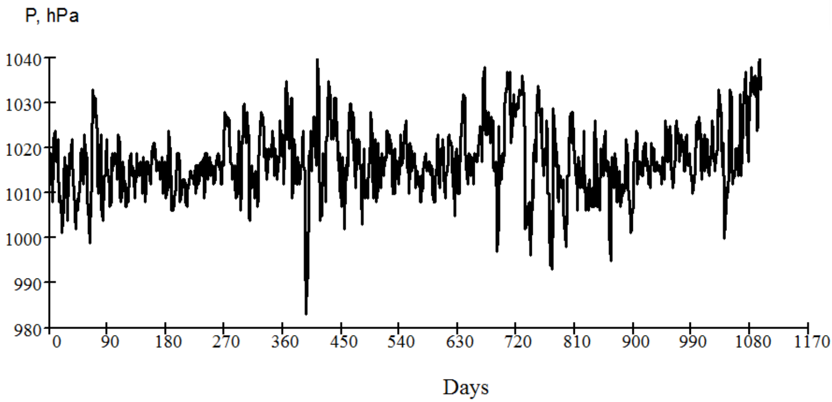
[1] Guide to Meteorological Instruments and Methods of Observation/World Meteorological Organization, – 2008. – № 8.– 119 p

[2] Бабак В. П. Влияние метеорологических параметров на оптимизацию процесса горения/В. П. Бабак, А. А. Запорожец, А. А. Редько//Научные известия НТСМ. – 2015. – № 2. – Т. 165. – С. 361–364; Редько О. О. Дослідження альтернативного методу вимірювання концентрації кисню в повітрі/О. О. Редько, В. М. Мокійчук, А. О. Запорожець//Інтегровані інтелектуальні робото технічні комплекси: матеріали IX міжнародної науково-практичної конференції (17–18 травня, – 2016 р., м. Київ; Національний авіаційний університет. – Київ. – 2016. – С. 136–138.



a)



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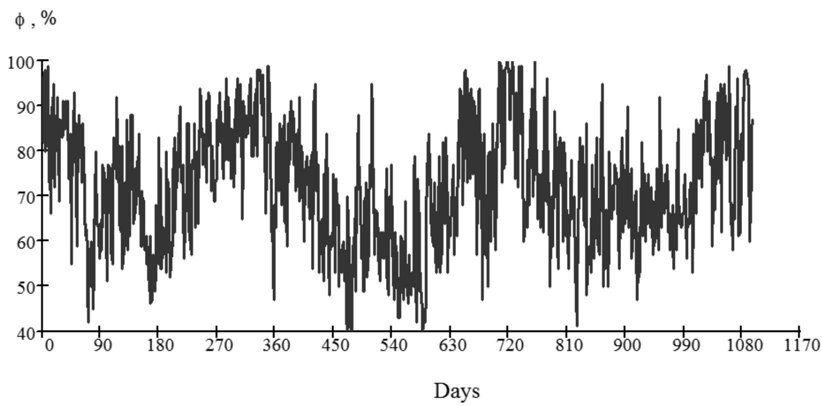

c)

Figure 3. Changes of temperature (a), pressure (b), humidity (c) in the air in Vienna in 2014–2016

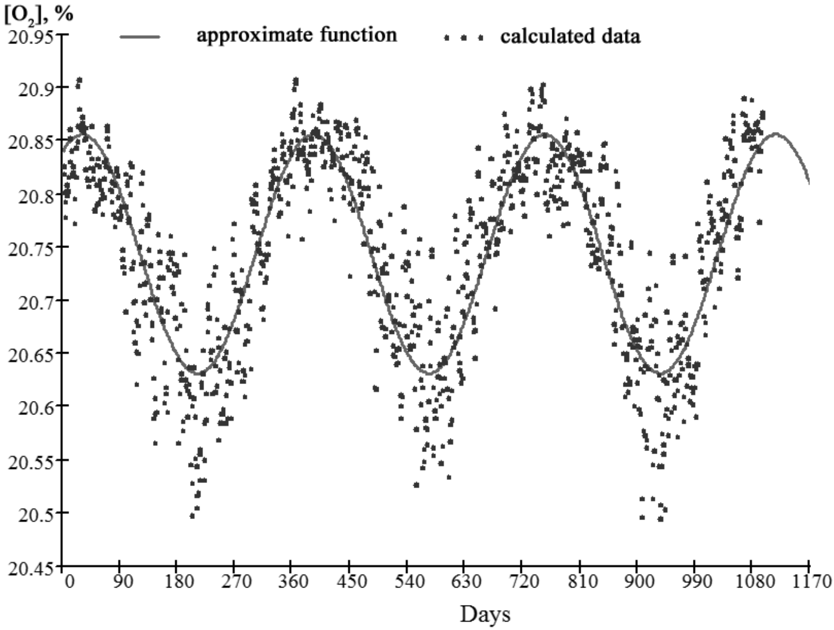

Figure 3′. Calculated VCO in the air in Vienna in 2014–2016

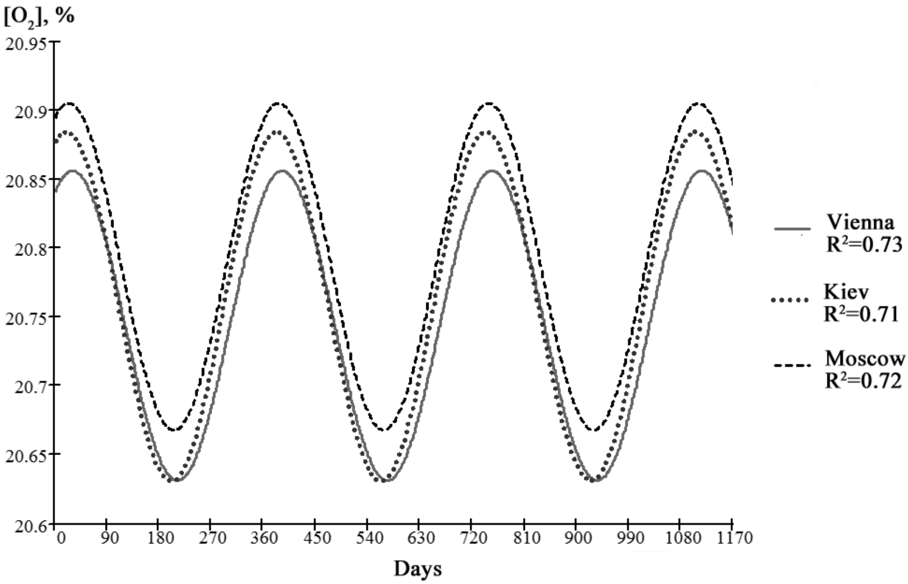

Figure 4. Approximate functions of VCO changes in the air in Vienna, Kiev and Moscow in 2014–2016

Taking into account the above data about the VCO in the air it`s an urgent task to incorporate the daily/seasonal changes in climatic environmental parameters and operating conditions during the combustion process control.

Therefore, recommended to consider an amendment to the current value of the VCO in the air that is possible in 2 technical methods described in the next section.

Fig. 5 shows the twoparametric dependence of the amendment (correction for error of method of EAC measurement) from its arguments, which is calculated as follows[1]:

$$\nabla\alpha([O_2],[O_2]_{out}) = \frac{[O_2]_{out}\cdot(21-[O_2])}{([O_2]-[O_2]_{out})\cdot(21-[O_2]_{out})}. \quad (13)$$

For obtaining the true result in the table 3 shows the values of some corrections that must be subtracted from the measured value of the EAC.

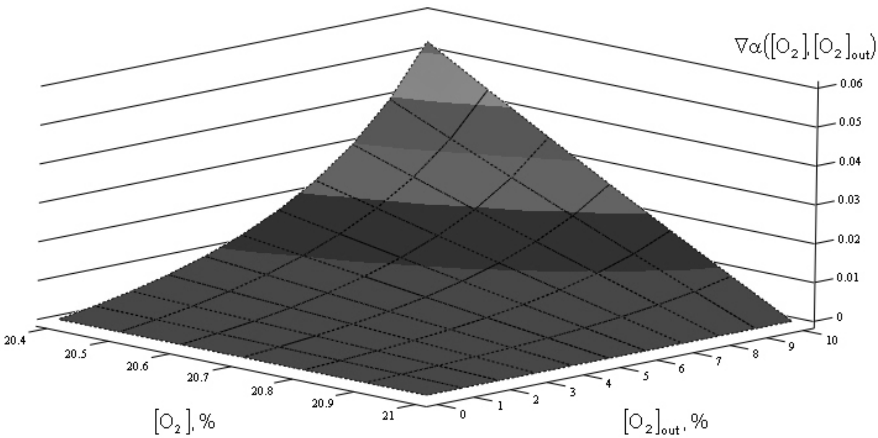

Figure 5. Twoparametric dependence of the amendment (correction for error of method of EAC measurement) from VCO in the air $[O_2]$ and the VCO in the output gas $[O_2]_{out}$

Table 3. – Correction for error of method of EAC measurement

$[O_2]_{out}$ / $[O_2]$	11	12	13	14	15	16	17	18	19
20.4	0.070	0.095	0.132	0.188	0.278	0.436	0.750	1.500	4.071
20.5	0.058	0.078	0.108	0.154	0.227	0.356	0.607	1.200	3.167
20.6	0.046	0.062	0.086	0.121	0.179	0.278	0.472	0.923	2.375
20.7	0.034	0.046	0.063	0.090	0.132	0.204	0.345	0.667	1.676
20.8	0.022	0.030	0.042	0.059	0.086	0.133	0.224	0.429	1.056
20.9	0.011	0.015	0.021	0.029	0.042	0.065	0.109	0.207	0.500

[1] Запорожець А. О. Підвищення точності вимірювання коефіцієнта надлишку повітря в котлоагрегатах із застосуванням газоаналізаторів електрохімічного типу/В. П. Бабак, А. О. Запорожець, О. О. Редько//Промышленная теплотехника. – 2015. – № 1. – С. 82–96.

The figure 4 shows the approximated sinusoidal functions for the values of O_2 calculated by the formula (11) from the meteorological. For each received approximated function it was calculated the coefficient of determination R^2, whose values for most of the surveyed cities are more than 0.71. These interpolants shows the unevenness of the VCO change in different cities around the world during 2014–2016.

4. Technical realization

It`s possible to control the process of fuel combustion in the following ways:

• visually by such characteristics of the torch as it`s length, color, luminosity, etc. For possession of this subjective evaluation method it`s necessary to have a large professional experience;

• by the composition of combustion products produced by a gas analyzer.

During the analysis of the composition of combustion products firstly it`s necessary to pay attention to the content of carbon monoxide CO. The absence of CO in the analysis data indicates the complete fuel combustion of fuel and absence of the heat loss from the chemical combustion incompleteness.

If CO is present in the combustion products it`s necessary to increase the air supply in order to minimize or eliminate it`s content in the combustion products according to the production instruction or regime map.

The absence of CO from the combustion gases number in the combustion products doesn`t indicate the quality fuel combustion. It`s also necessary to control the content of oxygen and triatomic gases RO_2 in the dry combustion products. Using data about the contents of these components it`s possible to set an important quantity characterizing the quality of combustion — EAC.

One of the options to define this value is the calculation by "nitric formula", which has the following form for complete combustion:

$$\alpha = \frac{[N_2]}{[N_2] - 3.76 \cdot [O_2]}, \tag{14}$$

where $[N_2]$, $[O_2]$ — volume concentration of N_2 and O_2 in dry combustion products; 3.76 — the ratio of nitrogen to oxygen in the air.

Thus to determine the stoichiometric coefficients of air-fuel mixture using the following dependence[1]:

$$K = \frac{M_{air} \cdot \alpha \cdot (k + l/4 - m/2)}{(k \cdot a + l \cdot b + m \cdot c) \cdot [O_2]}, \tag{15}$$

where M_{air} — molar mass of air; *k, l, m* — number of atoms of carbon, hydrogen and oxygen (hydrocarbon fuel — $C_kH_lO_m$); *a, b, c* — atomic weight of carbon, hydrogen and oxygen, K — mass stoichiometric coefficient.

[1] Запорожець А. О. Дослідження стехіометричної суміші «повітря-паливо» органічних сполук. Частина 2. Алкени, алкіни/А. О. Запорожець//Наукоємні технології. – 2014. –№ 4. – С. 393–399; Запорожець А. О. Дослідження стехіометричної суміші «повітря-паливо» органічних сполук. Частина 1. Алкани//Наукоємні технології. – 2014. – № 2. – С. 163–167.

In practice, the standard formula for determining the EAC is used (1).

The basis of the invention is the task of improving the standard method for determining the EAC, by measuring the VCO in the environment, which provides an exception of the methodological errors and improve the accuracy of this method.

The problem is solved in that way that determination the EAC, is realized by the formula[1]:

$$\alpha = \frac{[O_2]}{[O_2]-[O_2]_{out}} = 1 + \frac{[O_2]_{out}}{20.957 \cdot \left(1 - \frac{e(P,T',\varphi)}{P}\right) - [O_2]_{out}}. \quad (16)$$

Measuring the VCO in the environment allows to exclude correction of existing method; to increase the accuracy and stability of EAC, determination, to reduce the operating costs in the combustion process.

The method of determining the EAC, that is based on the measurement of VCO in the environment, is implemented using the circuit shown in Fig. 6.

The proposed methods are implemented as follows[2].

Method (a). In the hole of the flue path an inside oxygen sensor that measures the residual oxygen concentration in the flue gases is set. External oxygen sensor is placed in the environment (outside flue tract) and measures the VCO in the air. The signals from both sensors come to the analytical unit, which determines the EAC by the formula (16).

Method (b). With the help of gas analyzer a preliminary measurement of VCO in the environment is made. The value of this parameter is stored in the analyzer`s memory as $[O_2]$. Then the sensor of the gas analyzer is placed inside the smoke tract and the EAC measurement is made by the formula (16) assuming parameter $[O_2]$ constant.

Method (a) has greater accuracy of the EAC as it takes into account daily/seasonal fluctuations in the VCO in the air, but the method (b) does not require additional number of sensors that are financially advantageous in developing the gas analyzers.

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[1] Бабак В. П. Влияние метеорологических параметров на оптимизацию процесса горения/В. П. Бабак, А. А. Запорожец, А. А. Редько//Научные известия НТСМ. – 2015. – № 2. – Т. 165. – С. 361–364.

[2] Запорожець А. О. Система якості горіння повітряно-паливної суміші в котлоагрегатах малої та середньої потужності/В. П. Бабак, А. О. Запорожець//Методи та прилади контролю якості. – 2014. – № 2 (33). – С. 106–114; Пат. № 110761, Україна, МПК F23N5/18, G01N27/419. Спосіб визначення коефіцієнта надлишку повітря/Бабак В. П., Запорожець А. О., Редько О. О.; заявник та патентовласник Інститут технічної теплофізики НАН України; заявл. 19.02.2015; опубл. 10.02.2016, Бюл. № 3; Пат. № 111568, Україна, МПК G01N35/00, G01N33/00, G01N1/22. Спосіб градуювання газоаналізатора/Бабак В. П., Запорожець А. О.: заявник та патентовласник Інститут технічної теплофізики НАН України; заявл. 22.07.2015; опубл. 10.05.2016, Бюл. № 9.

Based on theoretical calculations it was shown that the use of the proposed ways to determine the EAC reduces correction (to 0.4 values of the EAC) improves energy efficiency by burning various types of fuel and reduce operating costs.

In articles[1] showed that a comparison of numerical results of uncertainties of the VCO values measured by the direct (0.104%, with gas analyzers) and indirect (≤0.03%, based on meteorological parameters) methods reveals that the former can be applied in practice for the calculation of VCO with a better accuracy.

The proposed methods and technical solutions used in the monitoring and diagnosis of power objects systems[2].

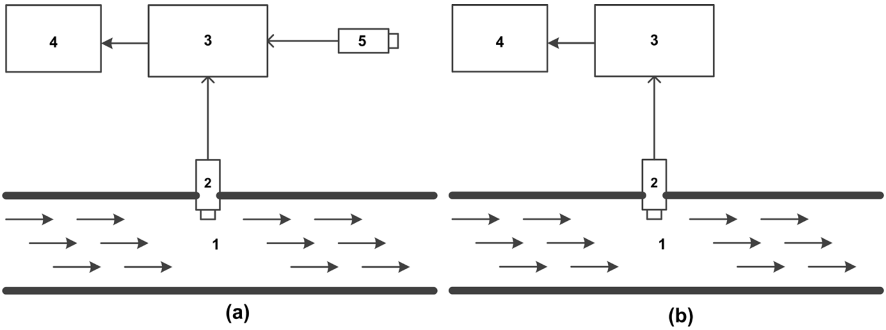

Figure 6. Methods of increasing the measurement accuracy of the EAC: (a) – with using two oxygen sensors; (b) – with using a single oxygen sensor. *1* – flue gases; *2* – internal oxygen sensor, *3* – analytical unit, *4* – display, *5* – external oxygen sensor

5. Conclusions

Today the problem of fuel resources saving is very actual for the whole world, so monitoring combustion processes in boilers should as accurate as possible.

The proposed methods to improve the accuracy of EAC measurement in boilers using gas analyzers (including electrochemical type) has extraordinary promise as it takes into account correction, which is built into the electronic system of calculation of the devices. To determine the EAC of the gas analyzer it`s necessary to determine the current VCO in the flue gases and compare it with the value of the VCO in the air, which is considered to equal 21% (1).

[1] Babak, V. P. Improving the efficiency of fuel combustion with regard to the uncertainty of measuring oxygen concentration/V. P. Babak, V. M. Mokiychuk, A. A. Zaporozhets, A. A. Redko// Eastern-European Journal of Enterprise Technologies. – 2016. – Vol. 6. – № 8 (84). – P. 54–59.

[2] Бабак В. П. Технологія Smart Grid в системах моніторингу об'єктів теплоенергетики /В. П. Бабак, А. О. Запорожець, А. Д. Свердлова//Промышленная теплотехника. – 2016. – № 6. – Т. 38. – С. 71–81; Свердлова А. Д. Разработка многоуровневой системы диагностики теплотехнического оборудования/А. Д. Свердлова, А. А. Запорожец, А. А. Редько//Мультидисциплинарный научный журнал «Архивариус». – 2016. – № 13. – Т. 1. – С. 9–13

However, this option is not constant and depends not only on the height of the object of control, but also on such parameters as humidity, temperature and pressure.

The final formula for determining the EAC considering the current VCO in the air is:

$$\alpha = 1 + \frac{[O_2]}{[O_2] - [O_2]_{out}}.$$

Thus, the application of the proposed methods of improving the accuracy of EAC measurement in gas analyzers will improve the EAC measurement accuracy to 10%.

Of course, the results obtained by the proposed article (formula 12) to calculate the VCO are approximate and require further investigation.

The determined level of oxygen in a specific point on the earth may also depend on the distance of measuring devices from the control zone, accuracy of the devices, and especially polluting gases that are present in the air. With the last factor it`s connected the "23.15" coefficient of the formula (6), because the mass concentration of the oxygen in dry air is not a constant value.

References:

1. Babak V. P. Improving the efficiency of fuel combustion with regard to the uncertainty of measuring oxygen concentration/V. P. Babak, V. M. Mokiychuk, A. A. Zaporozhets, A. A. Redko//Eastern-European Journal of Enterprise Technologies. – 2016. – Vol. 6. – № 8 (84). – P. 54–59.
2. Guide to Meteorological Instruments and Methods of Observation/World Meteorological Organization, – 2008. – № 8.– 119 p.
3. Kouprianov V. I. Applications of a cost-based method of excess air optimization for the improvement of thermal efficiency and environmental performance of steam boilers/V. I. Kuprianov//Renewable and Sustainable Energy Reviews. – 2005. – Vol. 9, Issue 5. – P. 474–498.
4. Kouprianov V. I. Optimization of excess air for the improvement of environmental performance of a 150 MW boiler fired with Thai lignite/V. I. Kouprianov, V. Tanetsakunvatana//Applied Energy. – 2003. – Vol. 74, Issue 3–4. – P. 445–453.
5. Апаратно-програмне забезпечення моніторингу об'єктів генерування, транспортування та споживання теплової енергії: Монографія/В. П. Бабак, С. В. Бабак, В. С. Берегун та ін.; за ред. чл.-кор. НАН України В. П. Бабака/ – К., Ін-т технічної теплофізики НАН України, – 2016. – 352 с.
6. Бабак В. П. Влияние метеорологических параметров на оптимизацию процесса горения/В. П. Бабак, А. А. Запорожец, А. А. Редько//Научные известия НТСМ. – 2015. – № 2. – Т. 165. – С. 361–364.
7. Бабак В. П. Технологія Smart Grid в системах моніторингу об'єктів теплоенергетики/В. П. Бабак, А. О. Запорожець, А. Д. Свердлова //Промышленная теплотехника. – 2016. – № 6. – Т. 38. – С. 71–81.

8. Бабак В. П. Экспериментальные исследования изменения объемной концентрации кислорода в воздухе и его влияние на процесс горения/В. П. Бабак, А. А. Запорожец, А. А. Редько//Научные известия НТСМ. – 2016. – № 1. – Т. 187. – С. 81–84.
9. Запорожець А. О. Дослідження стехіометричної суміші «повітря-паливо» органічних сполук. Частина 2. Алкени, алкіни/А. О. Запорожець//Наукоємні технології. – 2014. –№ 4. – С. 393–399.
10. Запорожець А. О. Дослідження стехіометричної суміші «повітря-паливо» органічних сполук. Частина 1. Алкани//Наукоємні технології. – 2014. – № 2. – С. 163–167.
11. Запорожець А. О. Підвищення точності вимірювання коефіцієнта надлишку повітря в котлоагрегатах із застосуванням газоаналізаторів електрохімічного типу/В. П. Бабак, А. О. Запорожець, О. О. Редько//Промышленная теплотехника. – 2015. – № 1. – С. 82–96.
12. Запорожець А. О. Система якості горіння повітряно-паливної суміші в котлоагрегатах малої та середньої потужності/В. П. Бабак, А. О. Запорожець//Методи та прилади контролю якості. – 2014. – № 2 (33). – С. 106–114.
13. Методика расчета количества кислорода в атмосферном воздухе на основе метеорологических параметров с целью прогнозирования метеопатических эффектов атмосферы: [метод. рекомендации]/Гл. упр. лечеб.-профилакт. помощи; сост. В. Ф. Овчарова. – М.: МЗ СССР. – 1983. – 13 с.
14. Пат. № 110761, Україна, МПК F23N5/18, G01N27/419. Спосіб визначення коефіцієнта надлишку повітря/Бабак В. П., Запорожець А. О., Редько О. О.; заявник та патентовласник Інститут технічної теплофізики НАН України; заявл. 19.02.2015; опубл. 10.02.2016, Бюл. № 3.
15. Пат. № 111568, Україна, МПК G01N35/00, G01N33/00, G01N1/22. Спосіб градуювання газоаналізатора/Бабак В. П., Запорожець А. О.: заявник та патентовласник Інститут технічної теплофізики НАН України; заявл. 22.07.2015; опубл. 10.05.2016, Бюл. № 9.
16. Редько О. О. Дослідження альтернативного методу вимірювання концентрації кисню в повітрі/О. О. Редько, В. М. Мокійчук, А. О. Запорожець//Інтегровані інтелектуальні робото технічні комплекси: матеріали IX міжнародної науково-практичної конференції (17–18 травня, 2016 р., м. Київ; Національний авіаційний університет. – Київ. – 2016. – С. 136–138.
17. Свердлова А. Д. Разработка многоуровневой системы диагностики теплотехнического оборудования/А. Д. Свердлова, А. А. Запорожец, А. А. Редько//Мультидисциплинарный научный журнал «Архивариус». – 2016. – № 13. – Т. 1. – С. 9–13.

Contents