UDC 531.758:53.088:551.510.4

DOI: 10.29202/nvngu/2018-5/14

A. O. Zaporozhets[1], Cand. Sc. (Tech.),
orcid.org/0000-0002-0704-4116,
O. O. Redko[2],
orcid.org/0000-0002-9054-5746,
V. P. Babak[1], Corr. Member of the NAS of Ukraine,
Dr. Sc. (Tech.), Prof.,
orcid.org/0000-0002-9066-4307,
V. S. Eremenko[3], Dr. Sc. (Tech.), Assoc. Prof.,
orcid.org/0000-0002-4330-7518,
V. M. Mokiychuk[2], Cand. Sc. (Tech.), Assoc. Prof.,
orcid.org/0000-0002-2309-9555

1 – Institute of Engineering Thermophysics of NAS of Ukraine, Kiev, Ukraine, e-mail: a.o.zaporozhets@nas.gov.ua
2 – National Aviation University, Kyiv, Ukraine
3 – National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", Kyiv, Ukraine

METHOD OF INDIRECT MEASUREMENT OF OXYGEN CONCENTRATION IN THE AIR

Purpose. Determination of a functional relationship between the oxygen concentration in the air and meteorological parameters (temperature, pressure, humidity) in open areas.

Methodology. The functional relationship between the oxygen concentration in the air and meteorological parameters is established on the basis of experimental gas laws. Approximating functions of the oxygen volume concentration changing in the air are obtained using mathematical statistics methods. The correction for the determination of the excess air ratio was determined on the basis of the theory of errors. Forecasting the oxygen volume concentration in the air was carried out on the basis of the inverse functional dependence established by means of the discrete Fourier transform.

Findings. Approaches to measuring and predicting the oxygen volume concentration in the air based on meteorological parameters are substantiated.

Originality. A method has been developed for determining the air gas concentration based on meteorological parameters of the environment. The method for determining the excess air ratio as an informative parameter for controlling the fuel combustion has been improved. A method for predicting the oxygen volume concentration in the air based on the discrete Fourier transform is proposed.

Practical value. Technical solutions are proposed and new methods and means of measuring the oxygen volume concentration in the air are developed, including those for improving the accuracy of determining the excess air ratio during the fuel burning in boilers. Also, the obtained results can be applied in different areas of medicine, ecology, agro-industrial sector, and others.

Keywords: *oxygen concentration, air composition, meteorological parameters, Fourier transform*

Introduction. The quantitative and qualitative composition of atmospheric air on large territories of Ukraine is characterized by a wide range of negative parameters. Significant emissions of harmful substances into the atmosphere from the main sources of pollution (energy facilities, transport, chemical and light industry, and metallurgy) continue to grow rapidly, which increases the risks of negative effects on public health and environmental quality.

The modern system of point quality control of atmospheric air does not allow solving problems of identification and control of severe pollution zones in large areas. Thus, large areas with a population of many thousands, containing large industrial complexes, do not pay attention to the air quality control system, which does not allow assessing the exposure danger of atmospheric air constituents for human health to the full extent [1].

Among the factors of the external environment, which provide the optimal physiological activity of the organism, an important role is played by the oxygen of the surface layer of the atmosphere. The processes of human respiration are directly related to its quantitative (volume, pressure) and qualitative (ionization, dissociation) characteristics, including the absorption of oxygen from atmospheric air, its delivery to tissues and oxidative processes at the tissue, cellular and molecular levels.

In connection with the lack of direct measurement of the oxygen concentration parameter by many air quality control systems, the development and study of indirect measurement of its quantity through a number of other measured parameters which commonly used atmospheric monitoring systems (in particular, meteorological stations) are an urgent issue.

Analysis of the recent research and publications. The displaying of observational data with significant spatial coverage over a long period of time remains one of the main problems in urban climate studies. Classical meteorological stations and networks are rarely designed to monitor atmospheric air conditions in various urban environments, although the heterogeneity of urban structures leads to a changing in various parameters on a citywide scale (in particular, thermal ones) [2]. One of the approaches to solve the above-mentioned problems of observation networks is the using of data from meteorological stations, widely used by citizens. In the territories of developed countries, in particular Europe and North America, local residents use meteorological stations from the "Netatmo" manufacturer (www.netatmo.com). Data stations in automatic mode can send data about measured meteorological parameters to the company's server via a Wi-Fi network, the user only needs to agree to general access to his information [3]. Parameters, which these meteorological stations measure, include temperature (outside and inside the room), pressure, humidity, noise, and concentration of CO_2. As can be seen from the general review, the development strategy for research on climatic parameters and atmospheric air parameters in the cities will soon be based on crowdsourcing, that is, the collection of atmospheric parameters from unconventional sources, such as civil weather stations which have a significant spatial network in cities and beyond [4].

One of the main problems with the use of such meteorological stations is the limited number of measured parameters. This is due to the fact that each parameter is measured by a direct method (using sensors), and their using is limited economically and technologically [5].

Investigation of the relationship between climatic parameters and the concentration of various substances in the air has been carried out for a long time [6].

Some of the new studies are related to the influence of weather conditions on the level of short-wave radiation of the Earth's surface [7].

In the USA, on the territory of 75 cities of different states in the period from 2001 to 2010, the influence of daily and short-term changes in climatic parameters on the $PM_{2.5}$ concentration in the surface layer was studied. It was shown that the concentration of this pollutant in tropical types of weather significantly increases compared with moderate climatic conditions [8].

The relationship between the changing in ozone concentration in the surface layer of the atmosphere and the synoptic weather conditions in the city of Chicago in the summer in the period 1990–2014 was also investigated. It was shown that the formation of dry tropical weather conditions leads to an increase in the ozone concentration with a high level of reliability [9].

Investigation of the relationship between meteorological parameters and air pollutant concentrations was conducted in China in 3 cities: Beijing, Shanghai and Guangzhou. For a long time, a systematic analysis of air pollutants was conducted, including $PM_{2.5}$, PM_{10}, CO, CO_2, NO_2, O_3, and meteorological parameters (temperature, wind speed, wind direction and relative humidity) from March 2013 to February 2014 [10].

Unsolved aspects of the problem. The above studies do not allow us to reveal the analytical relationships between the concentrations of substances in the air and meteorological parameters, which gives this work a high degree of relevance. The establishment of such dependencies for various substances will allow predicting the quality of atmospheric air for a sufficiently long period of time.

Measurement of oxygen concentration in the air (both mass and volume) depending on the meteorological parameters deserves special attention. The study of the dynamics of the oxygen concentration changing in the air will improve the accuracy and informativeness of the modeling and forecasting processes in the energy, ecology, medicine, meteorology and other fields.

Objectives of the article. The conducted studies aimed to determine the dependence of oxygen concentration in the air on meteorological parameters (temperature, humidity, absolute pressure) and to assess its seasonal/daily dynamics in a global scale.

To achieve the goal, the following tasks were set:

- to investigate the relationship between the oxygen concentration in the air (both mass and volume) and meteorological parameters of the environment;
- to analyze the seasonal and daily dynamics of the oxygen concentration changing in different continents with the help of the established dependence;
- to form the practical recommendations on the application of the dynamic nature in the oxygen concentration changing in the air in the energy sector.

Methodology. Air is a mixture of gases, of which the Earth's atmosphere is composed. Among them are: nitrogen (78 % vol.), oxygen (20.95 % vol.), noble gases (0.94 % vol.), carbon dioxide (0.03 % vol.), and other impurities. Oxygen in the air plays an important role as a chemical agent in various processes (burning of fuel, smelting metals from ores, industrial production of many chemicals).

Until now, it has been assumed that in a flat terrain the oxygen concentration in the air remains stable. In calculations, the oxygen concentration in the air is considered to be a stable parameter both in volume (20.95 %) and in mass (23.15 %). However, the conducted experimental studies [11] show that this value varies in a rather wide range during the year and during the day.

According to Dalton's law, the composition and the percentage of gases in the air are strictly constant both in volume and mass (Table 1). It is quite logical that the atmosphere, while remaining in a generally stable system, can locally vary the content of gases included in its composition. It is also quite obvious that the "price" of

Table 1

Composition and ratio of gases in dry air

Component	Concentration of gases, %	
	volume	mass
Nitrogen	78.08	75.50
Oxygen	20.95	23.15
Argon	0.93	1.29
Carbon dioxide	$31.40 \cdot 10^{-3}$	$4.60 \cdot 10^{-2}$

one percent of oxygen in a mixture of gases will be different for different climatic conditions of air (dense or rarefied, wet or dry, cold or warm). Thus, behind the stability of the percentage of gases, significant fluctuations in the absolute values of air gases, including oxygen are hidden.

A wide class of studies conducted in the twentieth century showed the illegitimacy of using as its quantitative oxygen parameter its partial pressure or the percentage ratio in atmospheric air. A partial oxygen density (D, g/m^3) can be used for various technological processes as a quantitative parameter of oxygen, the legitimacy of which can be brought to the basic gas laws (Boyle-Mariotte, Gay-Lusaka, Charles) and the Clapeyron equation.

The analytical relationships used to derive formulas for the determination of partial density and the oxygen volume concentration in the air, and to estimate the extended uncertainty of the measurement results, are given in [11]. In the same work it is shown that the oxygen concentration in the air depends on the meteorological parameters – temperature, absolute pressure and relative humidity, the change of which locally affects the quantitative composition of the air. In the calculations it was taken into account that the oxygen mass concentration in the air remains constant (23.15 %). The results given in this paper were obtained using the following equations:

- partial oxygen density

$$D = 0.2315 \cdot 10^6 \cdot \frac{(P-e)}{R \cdot T}; \quad (1)$$

- volume oxygen concentration

$$[\mathrm{O_2}]^V = \frac{8.314 \cdot D \cdot T}{P \cdot M_{\mathrm{O_2}}}, \quad (2)$$

where P is atmospheric pressure, hPa; e is water vapor pressure in the air, hPa; T is the air temperature, K; R is the universal gas constant; $M_{\mathrm{O_2}}$ is the oxygen molar mass.

Analysis of the oxygen concentration changing in the world. The study analyzed the changes in the main air meteorological parameters (temperature, absolute pressure, relative humidity) during 2014 in 12 cities in different continents: Berlin (Germany), Washington (USA), Canberra (Australia), London (United Kingdom), Madrid (Spain), New Delhi (India), Ottawa (Canada), Paris (France), Beijing (China), Rome (Italy), Seoul (South Korea), Tokyo (Japan). As a source of meteorological parameters data, the site wunderground.com was used. Geographical measurement points were local airports. Data of the exact location of the measurement sites are shown in Table 2.

Fig. 1 shows the approximating functions of the estimated oxygen volume concentration as a function of time in the main cities of the world and the coefficients of determination are given.

Practical recommendations. Taking into account the above theoretical calculations for the oxygen concentration in the air, an urgent task is to take into account the daily/seasonal meteorological parameters of air in various sectors, in particular in the energy sector when fuel burns.

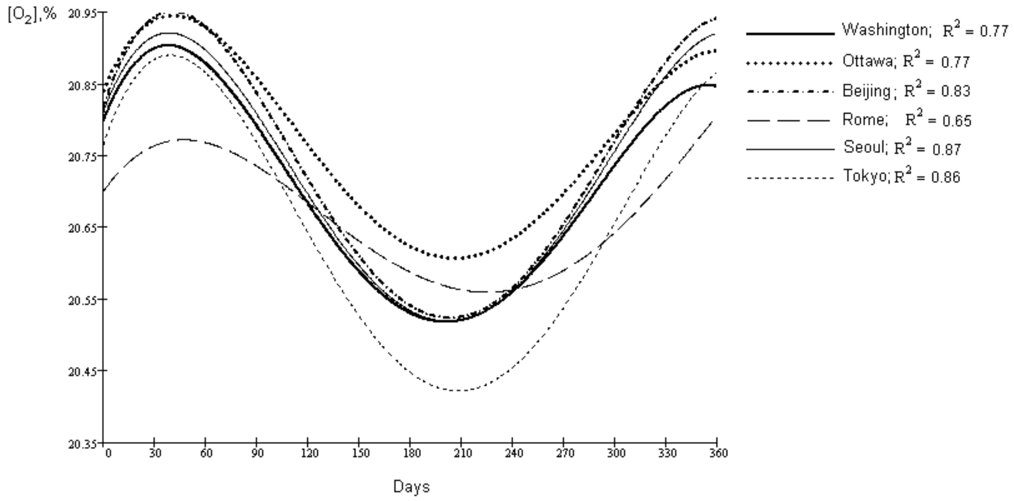
The combustion process can be controlled in 2 ways:

1) visually, according to such characteristics of the torch as its length, color, brightness and the like. For the

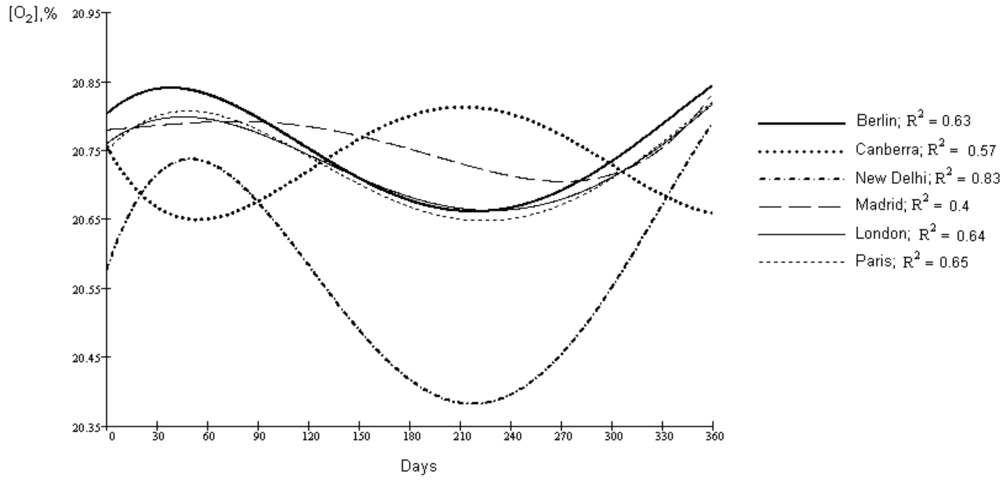
Table 2

Locations of meteorological parameters' measurement points

Country	City	Airport classifier (ICAO)	Geographical coordinates
Germany	Berlin	EDDB	N52°21.73' / E13°30.04'
USA	Washington	KDCA	N38°51.09' / W77°2.26'
Australia	Canberra	YSCB	S35°18.42' / E149°11.70'
United Kingdom	London	EGLL	N51°28.65' / W0°27.68'
Spain	Madrid	LEMD	N40°28.33' / W3°33.65'
India	New Delhi	VIDP	N28°34.12' / E77°6.73'
Canada	Ottawa	CYDH	N45°7.83' / W75°56.90'
France	Paris	LFPG	N49°0.59' / E2°32.87'
China	Beijing	ZBAA	N40°4.40' / E116°35.90'
Italy	Rome	LIRU	N41°57.12' / E12°30.05'
South Korea	Seoul	RKSM	N37°26.75' / E127°6.85'
Japan	Tokyo	RJTY	N35°44.92' / E139°20.92'



a



b

Fig. 1. Graphs of behavior of the calculated value of the oxygen volume concentration during 2014 in the main cities of the world:

a – Washington, Ottawa, Beijing, Rome, Seoul, Tokyo; b – Berlin, Canberra, New Delhi, Madrid, London, Paris

application of this subjective method of assessment, it is necessary to have extensive experience with boiler units;

2) with the composition of the combustion products (the data are obtained using a gas analyzer).

Using the data of the composition of the fuel combustion products, it is possible to determine an important parameter characterizing the combustion process - the excess air ratio (EAR).

The EAR value is usually determined by the composition of the combustion products, in particular by the concentration of $[O_2]$ in the flue gases

$$\alpha = 1 + \frac{21}{21 - [O_2]_{out}}, \quad (3)$$

where $[O_2]_{out}$ is oxygen volume concentration in flue gases.

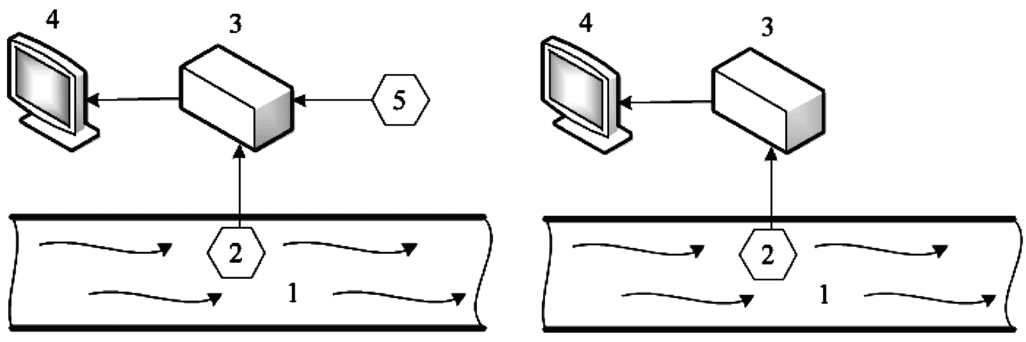
To effectively control the quality of the combustion process, various types of gas analyzers can be used, the measurement principle of which is based on formula (3). At the same time, the level of the oxygen volume concentration in the air is established at the level of 21 %.

The basis of the proposed invention is the task of improving the standard method for determining EAR by measuring the current oxygen concentration in the environment, which eliminates methodological errors and increases accuracy. The problem is solved by the determination of the EAR according to the formula

$$\alpha = 1 + \frac{[O_2]^V}{[O_2]^V - [O_2]_{out}}. \quad (4)$$

The proposed method for determining the EAR, based on the measurement of the current oxygen volume concentration in the air, is realized according to the scheme shown in Fig. 2.

Method A. The internal oxygen sensor *2* is installed in the opening of the smoke path *1* and measures the residual oxygen concentration in the flue gases. An external oxygen sensor *5* is located outside the smoke path, and measures the oxygen concentration in the environ-



a *b*

Fig. 2. Technical realization of methods for increasing the accuracy of determining EAR:

a – using 2 oxygen sensors; b – using 1 oxygen sensor; 1 – flue gases; 2 – internal oxygen sensor; 3 – analytical block; 4 – monitor; 5 – external oxygen sensor

ment. Signals from both sensors go to the analytical block, which determines the EAR according to the (4). The EAR value is displayed on the monitor *4* and can be used for other settings during the combustion process control.

Method B. Using a gas analyzer, a preliminary measurement of the oxygen concentration in the environment is carried out. The value of this parameter is stored in the memory of the gas analyzer as $[O_2]^V$. Further, the sensor *1* of the gas analyzer is located inside the smoke path, and the EAR measurements are carried out according to the (4), while the parameter $[O_2]^V$ is assumed to be constant.

Method A is more accurate for the determination of EAR, since it takes into account the constant variations of the oxygen concentration in the air, but *method B* does not require an additional number of sensors, it is advantageous for the development of gas analyzers.

Table 3 shows the values of some methodological corrections that can occur in determining the EAR in the flue gases with different concentrations of residual oxygen.

As can be seen from the above material, the use of the proposed methods for determining the EAR reduces the methodical measurement error (up to 4 absolute values), improves the energy efficiency of various types of fuel burning and reduces operating costs [12].

Forecasting of volume oxygen concentration. Based on the daily changing meteorological parameters in Kiev city for 4 years (from January 1, 2014 to December 31, 2017), it can be concluded that the temperature and the calculated oxygen volume concentration are periodically changed (Fig. 3). The determination of the results with an excessive error in the aggregate of measurement data of meteorological parameters is impossible, since there are only single measurements of non-stable physical quantities.

To solve the problem of predicting the oxygen volume concentration, it is necessary to determine the form and coefficients of the approximation equation. The predicted value is found by substituting the ordinal number of the year's day, as an argument in the found equation. To find the best model of the approximation equation, we used:

a) the relationship that visually closely describes the nature of the change in the data over the entire range of values (Fig. 4, *a*);

b) the dependence defined by the built-in functions of the software package MathCAD (Fig. 4, *b*);

c) the dependence determined with the use of the Fourier series (Fig. 4, *c*).

The coefficient of determination of the functional dependence shown in Fig. 4, *a* is 0.450, and its analytical representation looks like

$$\left[O_2\right]_{for}(t) = 20.728 + 0.182 \cdot \sin\left(\frac{t}{59.279} - 4.85\right).$$

Table 3

The value of corrections in determining the EAR with the current oxygen concentration in the air

$[O_2]^V$ \ $[O_2]_{out}$	8	9	10	11	12	13	14	15	16	17	18	19
20.4	0.025	0.039	0.052	0.070	0.095	0.132	0.188	0.278	0.436	0.750	1.500	4.071
20.5	0.022	0.033	0.043	0.058	0.078	0.108	0.154	0.227	0.356	0.607	1.200	3.167
20.6	0.020	0.026	0.034	0.046	0.062	0.086	0.121	0.179	0.278	0.472	0.923	2.375
20.7	0.015	0.019	0.025	0.034	0.046	0.063	0.090	0.132	0.204	0.345	0.667	1.676
20.8	0.010	0.013	0.017	0.022	0.030	0.042	0.059	0.086	0.133	0.224	0.429	1.056
20.9	0.005	0.006	0.008	0.011	0.015	0.021	0.029	0.042	0.065	0.109	0.207	0.500

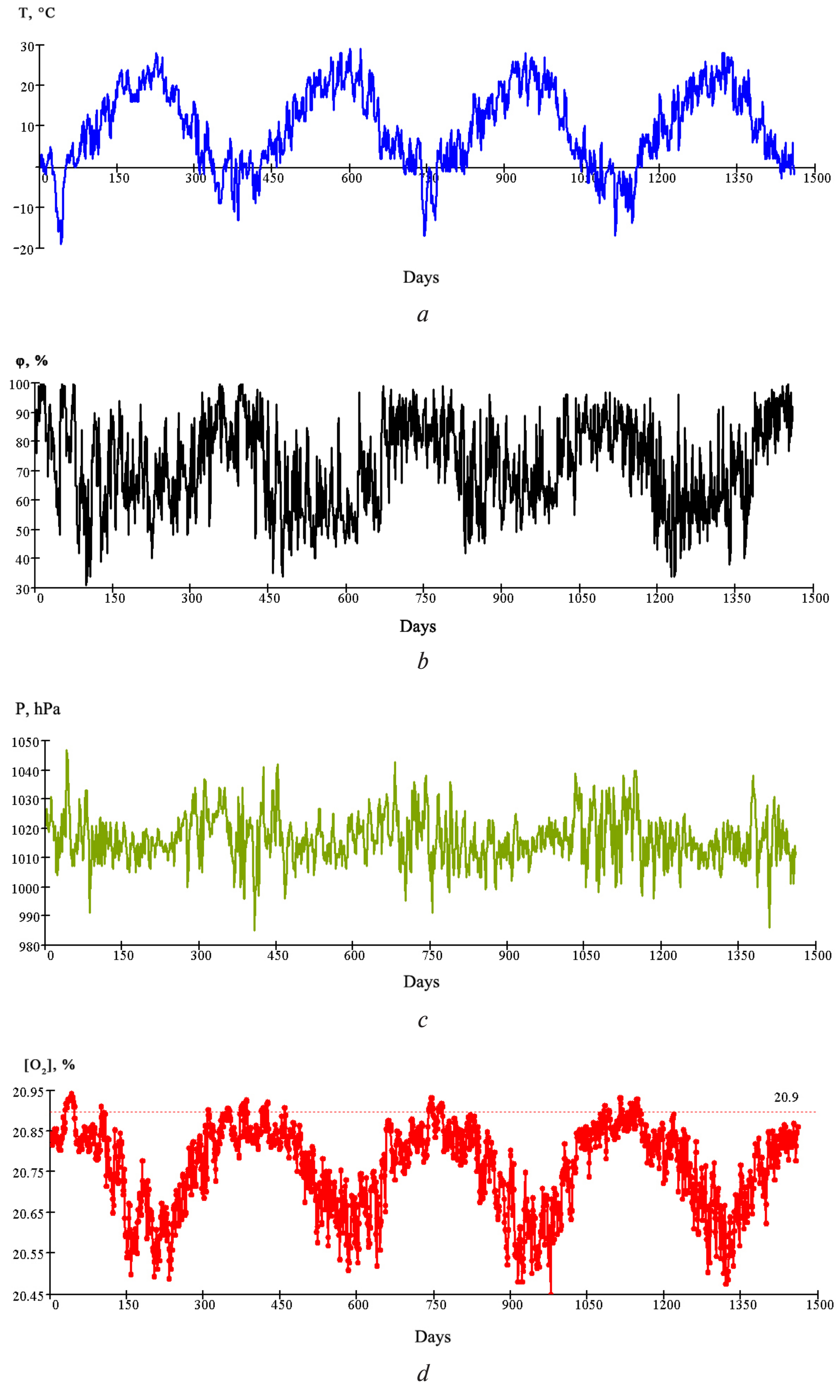


Fig. 3. Measured values of the meteorological parameters:

a – temperature; b – humidity; c – pressure and d – oxygen volume concentration in the air calculated from January 1, 2014 to December 31, 2017

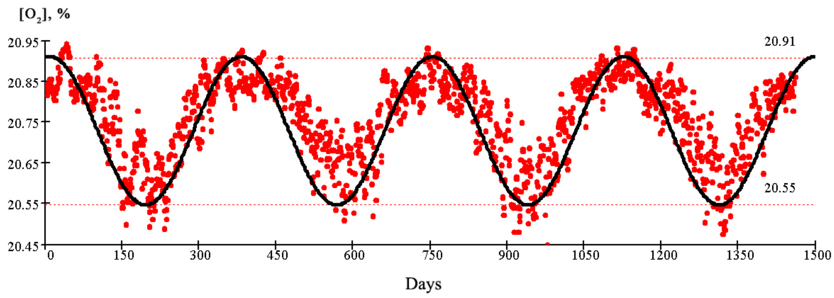
The coefficient of determination of the functional dependence shown in Fig. 4, *b* is 0.709, and its analytical representation has the form

$$\left[O_2\right]_{for}(t) = 20.761 + 0.126 \cdot \sin\left(\frac{t}{58.885} - 5.015\right).$$

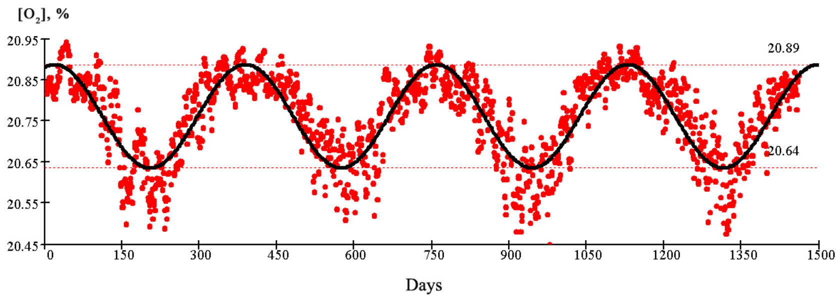
The choice of the discrete Fourier transform to approximate the data is due to their periodic nature and the possibility of finding the functional dependence with the coefficient of determination close to 1. The approximation model has the form of an expression of the inverse Fourier transform

$$\left[O_2\right]_{for}(t) = C_0 + 2 \cdot \sum_{j=1}^{m} C_{kj} \cos\left(\omega_0 \cdot k_j \cdot t - \theta_{kj}\right), \quad (5)$$

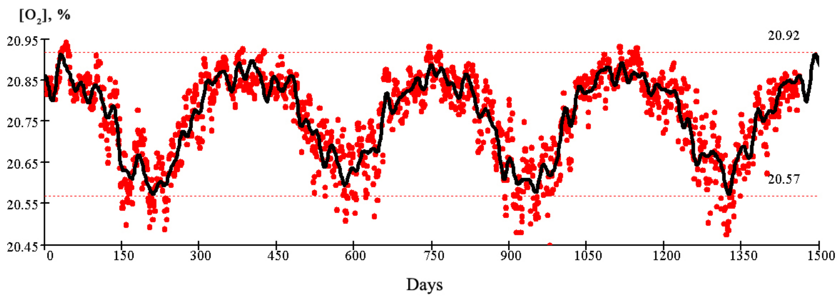
where m is the number of harmonics of the Fourier series; k is the index of the harmonic; $C_k = \sqrt{a_k^2 + b_k^2}$ is the real Fourier coefficient of the k^{th} harmonic, $k = \overline{0, m}$;



a



b



c

Fig. 4. The functional dependences of the calculated value of the oxygen volume concentration on time (the points reflect the calculated values of the oxygen volume concentration in the air, the solid line is the approximation function, the dashed line is the minimum and maximum value of the approximation function):

a – the approximation function that visually approximates the nature of the data change on the whole range of values; b – the approximation function defined by the built-in functions of the MathCAD software package; c – the approximation function, determined with the use of Fourier series in accordance with formula (5)

$\theta_k = \mathrm{arctg}\dfrac{b_k}{a_k}$ is the initial phase of the k^{th} harmonic;

$\omega_0 = \dfrac{2\pi}{T}$ is the circular frequency of the zero harmonic;

T is the period of a discrete sequence which is equal to the number of observations N (the number of days); $a_k =$ $= \mathrm{Re}[X_k]$; $b_k = \mathrm{Im}[X_k]$; $X_k = \sum_{n=0}^{N-1} x_n \cdot e^{-i \cdot k \cdot n}$ are N complex amplitudes of the cosine components of the Fourier series (direct Fourier transform), $e^{-i \cdot k \cdot t} = \cos kt + i \sin kt$; x_n is discrete values of n a posteriori data.

The members of the Fourier series were harmonics with the largest value of the complex coefficient C_k. The coefficient of determination R^2 of the functional dependence of the predicted value of the oxygen volume concentration on the time obtained for 15 harmonics (Fig. 4, *c*) is 0.803. The values of ordinal numbers, amplitudes and initial phases of the harmonic are given in Table. 4. At $m = 50$ $R^2 = 0.870$, $R^2 = 0.917$ at $m = 100$, $R^2 = 0.944$ at $m = 150$, $R^2 = 0.9641$ at $m = 200$.

As can be seen from Fig. 4 the range of values of the functions found for the predicted oxygen volume concentration is narrower than the a posteriori range. As a predicted value of the oxygen volume concentration, it is proposed to use:

- the value of the function of the Fourier series by the (6). The values of the function parameters are the same as for the function (5). The argument of the function is the sum of the ordinal number of the day in a year and the period of the Fourier series. The adjustment for a leap year is not taken into account.

$$\left[O_2\right]_{for.1}(t) = C_0 + 2 \cdot \sum_{j=1}^{m} C_{kj} \cos\left(\omega_0 \cdot k_j \cdot (t + q \cdot T) - \theta_{kj}\right), \quad (6)$$

where q = 0, 1, 2, ...;

- average predicted values of the oxygen volume concentration in the air calculated according to the (6) for the corresponding argument with a period of 365 days.

$$\left[O_2\right]_{for.2}(t)=C_0+$$
$$+\frac{2\cdot\sum_{l=0}^{y-1}\sum_{j=1}^{m}C_{kj}\cos\left(\omega_0\cdot k_j\cdot(t+l\cdot 365)-\theta_{kj}\right)}{y}, \quad (7)$$

where y is the integer value of the number of years, which corresponds to the experimental data on which the approximation function was determined by (5).

Estimation of forecasting reliability was chosen relative error

$$\delta=\frac{\left|\left[O_2\right]^V-\left[O_2\right]_{for}\right|}{\left[O_2\right]^V}\cdot 100\,\%.$$

In order to assess the reliability of the use of the approximation function model for the prediction problem, the predicted and a posteriori values are compared for one day 2014–2018, with $q=0$ for $[O_2]_{for.1}(t)$ and for $[O_2]_{for.2}(t)$ – $y=[0, 1, 2, 3]$ in accordance with the year. For all studied functions $R^2\approx 0.8$. The results of the corresponding calculations are given in Table 5.

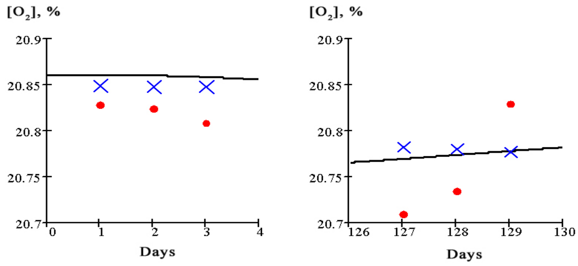
Table 6 shows the predicted values of the oxygen volume concentration in the air, obtained from formulas (6) and (7), with relative errors and calculated values obtained from formula (2). These values were obtained for several days in January and May 2018 (Fig. 5).

Taking into account the value of the calculated relative errors given in Tables 3, 4 and the graphical representation of the calculated predicted values of the oxygen volume concentration in the air in Fig. 5, the authors prefer calculating the predicted value according to the (7).

Conclusions. Thus, the conducted studies have shown that the oxygen concentration in the ambient air is not a constant value. As it was reflected, its value in the open area can be established with the help of humidity, temperature and air pressure, but this requires additional measuring devices.

As a practical aspect in this paper, it was proposed to apply the developed method in the energy sector.

Currently, the problem of saving fuel resources is relevant for the whole world, therefore monitoring of the



a *b*

Fig. 5. Graphical representation of the predicted and calculated values of the oxygen volume concentration in the air in January and May 2018 (the points reflect the calculated values $[O_2]^V$, the solid line – the approximation function $[O_2]_{for.1}(t)$, the crosses – the predicted values $[O_2]_{for.2}$):

a – three days in January; b – three days in May 2018

fuel combustion process should be as accurate as possible.

The proposed methods for increasing the accuracy of determining EAR in boilers with the use of gas analyzers have a great prospect, since they exclude the error that contain the electronic systems of these devices. In order to determine the EAR in the boiler, it is necessary to determine the current oxygen concentrations in the flue gases and the environment, and compare them with each other. Thus, the application of the proposed methods can improve the accuracy of determining the EAR to 10 %.

However, the practical aspects of applying the method of indirect measurement of the oxygen concentration in the air are not limited. In general, the technique of indirect measurement of oxygen concentration in the air can be used in medicine – to create microclimatic zones with a specified gas composition of the environment; in the agricultural sector – to control the growth of agricultural crops; in the environment – during creating climate maps, as well as other areas.

An approach is also proposed for the prediction of the oxygen volume concentration, which is based on the use of a certain functional dependence. This dependence is an approximation function, whose parameters are calculated from the calculated values of the oxygen volume concentration in the air. In turn, the initial data for calculating the oxygen volume concentration in the air is the meteorological parameters measured for previ-

Table 4

The values of the parameters of the Fourier series shown in Fig. 4, *c*

j	k	C_k	Θ_k	j	k	C_k	Θ_k	j	k	C_k	Θ_k
0	0	20.760	0	5	21	0.006	2.104	10	67	0.005	-1.420
1	4	0.063	–0.479	6	39	0.006	0.936	11	20	0.005	2.600
2	8	0.013	2.050	7	30	0.005	2.107	12	42	0.005	0.773
3	2	0.008	2.221	8	16	0.005	–1.432	13	28	0.004	2.114
4	6	0.006	–1.432	9	47	0.005	–1.028	14	55	0.004	0.258
								15	34	0.004	–1.171

Table 5

The predicted and calculated values of the oxygen volume concentration in the air (year)

03.01 ($t = 3$)	2014	2015	2016	2017
$[O_2]^V$, %	**20.83**	**20.79**	**20.785**	**20.849**
$[O_2]_{for.1}(t)$, %	20.858	20.847	20.826	20.858
δ_1, %	0.13	0.28	0.20	0.04
$[O_2]_{for.2}(t)$, %	20.836	20.835	20.854	20.847
δ_2, %	0.03	0.22	*0.33*	0.01

Table 6

The predicted and calculated values of the oxygen volume concentration in the air (days)

Date	01.01.18	02.01.18	03.01.18
t, day	1	2	3
$[O_2]^V$, %	**20.827**	**20.823**	**20.808**
$[O_2]_{for.1}(t)$, %	20.860	20.860	20.858
δ_1, %	0.16	0.18	0.24
$[O_2]_{for.2}(t)$, %	20.848	20.848	20.847
δ_2, %	0.10	0.12	0.19
Date	08.05.18	09.05.18	10.05.18
t, day	127	128	129
$[O_2]^V$, %	**20.709**	**20.734**	**20.829**
$[O_2]_{for.1}(t)$, %	20.769	20.774	20.778
δ_1, %	0.29	0.19	0.25
$[O_2]_{for.2}(t)$, %	20.782	20.779	20.777
δ_2, %	0.35	0.22	0.25

ous years. Increasing the reliability of forecasting is achieved by increasing the period of the discrete sequence and the number of harmonics of the Fourier series in determining the functional dependence of the oxygen volume concentration on time.

References.

1. Xu, W., Song, W., Zhang, Y., Liu, X., Zhang, L., Zhao, Y., Liu, D., Tang, A., Yang, D., Wang, D., Wen, Z., Pan, Y., Fowler, D., Collet Jr., J. L., Erisman, J. W., Goulding, K., Li, Y. and Zhang, F., 2017. Air quality improvement in a megacity: implications from 2015 Beijing Parade Blue pollution control actions. *Atmospheric Chemistry and Physics*, 17(1), pp. 31–46. DOI: 10.5194/acp-17-31-2017.

2. Chapman, L., Bell, C. and Bell, S., 2017. Can the crowdsourcing data paradigm take atmospheric science to a new level? A case study of the urban heat island of London quantified using Netatmo weather stations. *International Journal of Climatology*, 37(9), pp. 3597–3605. DOI: 10.1002/joc.4940.

3. De Vos, L., Leijnse, H., Overeem, A. and Uijlenhoet, R., 2017. The potential of urban rainfall monitoring with crowdsourced automatic weather stations in Amsterdam. *Hydrology and Earth System Sciences*, 21(2), pp. 765–777. DOI: 10.5194/hess-21-765-2017.

4. Meier, F., Fenner, D., Grassmann, T., Otto, M. and Scherer, D., 2017. Crowdsourcing air temperature from citizen weather stations for urban climate research. *Urban Climate*, 19, pp. 170–191. DOI: 10.1016/j.uclim.2017.01.006.

5. Valipour, M., 2017. Analysis of potential evapotranspiration using limited weather data. *Applied Water Science*, 7(1), pp. 187–197. DOI: 10.1007/s1320.

6. Pope, F., Chapman, L., Fisher, P., Mahmood, M., Sangkharat, K., Thomas, N. and Thornes, J., 2017. Resilience of urban ambulance services under future climate, meteorology and air pollution scenarios. In: *EGU General Assembly Conference Abstracts* [online], 19, p. 17757. Available at: <http://adsabs.harvard.edu/abs/2017EGUGA.1917757P> [Accessed 21 September 2017].

7. Parding, K. M., Liepert, B. G., Hinkelman, L. M., Ackerman, T. P., Dagestad, K. F. and Olseth, J. A., 2016. Influence of synoptic weather patterns on solar irradiance variability in northern Europe. *Journal of Climate*, 29(11), pp. 4229–4250. DOI: 10.1175/JCLI-D-15-0476.1.

8. Liu, Y., Zhao, N., Vanos, J.K. and Cao, G., 2017. Effects of synoptic weather on ground-level PM 2.5 concentrations in the United States. *Atmospheric Environment*, 148, pp. 297–305. DOI: 10.1016/j.atmosenv.2016.10.052.

9. Jing, P., O'Brien, T., Streets, D.G. and Patel, M., 2016. Relationship of ground-level ozone with synoptic weather conditions in Chicago. *Urban Climate*, 17, pp. 161–175. DOI: 10.1016/j.uclim.2016.08.002.

10. Zhang, H., Wang, Y., Hu, J., Ying, Q. and Hu, X. M., 2015. Relationships between meteorological parameters and criteria air pollutants in three megacities in China. *Environmental research*, 140, pp. 242–254. DOI: 10.1016/j.envres.2015.04.004.

11. Babak, V., Mokiychuk, V., Zaporozhets, A. and Redko, O., 2016. Improving the efficiency of fuel combustion with regard to the uncertainty of measuring oxygen concentration. *Eastern-European Journal of Enterprise Technologies*, 8(84), pp. 54–59. DOI: 10.15587/1729-4061.2016.85408.

12. Babak, V. P., Babak, S. V., Myslovych, M. V., Zaporozhets, A. O. and Zvaritch, V. M., 2018. *Provision of Diagnostic Systems for Energy Facilities*. Kyiv: Akademperiodyka. DOI: 10.15407/akademperiodyka.353.134.

Метод непрямого вимірювання концентрації кисню в повітрі

А. О. Запорожець[1], *А. А. Редько*[2], *В. П. Бабак*[1], *В. С. Єременко*[3], *В. М. Мокійчук*[2]

1 – Інститут технічної теплофізики НАН України, м. Київ, Україна, e-mail: a.o.zaporozhets@nas.gov.ua

2 – Національний авіаційний університет, м. Київ, Україна

3 – Національний технічний університет України „Київський політехнічний інститут імені Ігоря Сікорського“, м. Київ, Україна

Мета. Встановлення функціональної залежності між концентрацією кисню в повітрі та метеорологічними параметрами (температурою, тиском, вологістю) на відкритих місцевостях.

Методика. Функціональна залежність між концентрацією кисню в повітрі та метеорологічними параметрами встановлена на базі експериментальних газових законів. Апроксимуючі функції зміни об'ємної концентрації кисню в повітрі отримані за допомогою методів математичної статистики. Поправка для визначення коефіцієнта надлишку повітря визначалася на основі теорії похибок. Прогнозування об'ємної концентрації кисню в повітрі проведено із застосуванням оберненої функціональної залежності, встановленої за допомогою дискретного перетворення Фур'є.

Результати. Обґрунтовані підходи до вимірювання й прогнозування об'ємної концентрації кисню в повітрі на базі метеорологічних параметрів.

Наукова новизна. Розроблено метод визначення концентрації газів повітря на основі врахування метеорологічних параметрів навколишнього середовища. Удосконалено метод визначення коефіцієнта надлишку повітря як інформативного параметра контролю процесу спалювання палива. Запропоновано метод прогнозування об'ємної концентрації кисню в повітрі на базі дискретного перетворення Фур'є.

Практична значимість. Запропоновані технічні рішення та розроблені нові методи й засоби вимірювання об'ємної концентрації кисню в повітрі, зокрема для підвищення точності визначення коефіцієнта надлишку повітря при спалюванні палива в котлах. Також отримані результати можуть бути застосовані в різних напрямах екології, медицини, в агропромисловому секторі тощо.

Ключові слова: *концентрація кисню, склад повітря, метеорологічні параметри, перетворення Фур'є*

Метод непрямого измерения концентрации кислорода в воздухе

А. А. Запорожец[1], *А. А. Редько*[2], *В. П. Бабак*[1], *В. С. Еременко*[3], *В. М. Мокийчук*[2]

1 – Институт технической теплофизики НАН Украины, г. Киев, Украина, e-mail: a.o.zaporozhets@nas.gov.ua

2 – Национальный авиационный университет, г. Киев, Украина

3 – Национальный технический университет Украины „Киевский политехнический институт имени Игоря Сикорского“, г. Киев, Украина

Цель. Установление функциональной зависимости между концентрацией кислорода в воздухе и метеорологическими параметрами (температурой, давлением, влажностью) на открытых местностях.

Методика. Функциональная зависимость между концентрацией кислорода в воздухе и метеорологическими параметрами установлена на базе экспериментальных газовых законов. Аппроксимирующие функции изменения объемной концентрации кислорода в воздухе полученные с помощью методов математической статистики. Поправка для определения коэффициента избытка воздуха определялась на основе теории погрешностей. Прогнозирование объемной концентрации кислорода в воздухе проведено с использованием обратной функциональной зависимости, установленной с помощью дискретного преобразования Фурье.

Результаты. Обоснованы подходы к измерению и прогнозированию объемной концентрации кислорода в воздухе на базе метеорологических параметров.

Научная новизна. Разработан метод определения концентрации газов воздуха на основе учета метеорологических параметров окружающей среды. Усовершенствован метод определения коэффициента избытка воздуха как информативного параметра контроля процесса сжигания топлива. Предложен метод прогнозирования объемной концентрации кислорода в воздухе на базе дискретного преобразования Фурье.

Практическая значимость. Предложены технические решения и разработаны новые методы и средства измерения объемной концентрации кислорода в воздухе, в том числе для повышения точности определения коэффициента избытка воздуха при сжигании топлива в котлах. Также полученные результаты могут быть применены в различных направлениях медицины, экологии, агропромышленном секторе, и тому подобное.

Ключевые слова: *концентрация кислорода, состав воздуха, метеорологические параметры, преобразование Фурье*

Рекомендовано до публікації докт. техн. наук А. В. Яцишиним. Дата надходження рукопису 18.04.17.