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ENVIRONMENTAL PROBLEMS

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ADMINISTRATION OF THE SYSTEM OF MUNICIPAL SOLID WASTE MANAGEMENT LUBLIN EXPERIENCE IN THE PERIOD FROM 2007 UNTIL 2010

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Abstract. This article presents main concepts of building modern system of communal resources management in Lublin. The author indicates major tools used for realisation of the project, describing the results of introducing above mentioned system in the first four years of its functioning (2007–2010).

Key words: solid waste management, Lublin

Introduction

The dynamic social and economic development of Poland after 1989 caused that our society started to produce more and more material goods and services in order to satisfy their own needs. An increased demand for consumer goods was connected with a rapid increase in solid waste volume.

Technical and technological progress, migration and urbanisation processes of urban centres caused that solid waste has become one of the major challenges facing local governments of those cities. For more than twenty years, since early 1990s, the system of municipal solid waste management in Poland has been developed based on the subsidiarity principles and free competition in a municipality area – collecting companies – property managers. In the second half of the decade two key legislative acts regulating the matter of solid waste management were adopted.

In 1996 the Act on cleanliness and order in municipalities abbreviated as [a.c.o.m.] [1] and the Act on solid waste of 1997 abbreviated as [a.w.] [2] with subsequent amendments in 2001 were adopted.

Poland's accession to the European Union resulted in a significant change in Polish legislation on solid waste management in 2005.

It became necessary to create legal instruments which would allow for obtaining recovery rates of municipal solid waste set out by the European Union and reduce the amount of landfilled waste, especially biodegradable waste.

The Act of 29 July 2005 amending the Act on solid waste and some other acts [3] fundamentally changed the two most important legal acts regulating solid waste management, including municipal solid waste. This refers to the above-mentioned acts:

– on cleanliness and order in municipalities of 1996 [1] and

– on solid waste of 1997 with subsequent amendments [2]

Both a.c.o.m. and a.w. contained provisions regarding the obligations of municipalities in the field of municipal solid waste management, development and implementation of separate collection system and collection of municipal solid waste from property owners and their proper further management.

Municipalities were provided with legal tools allowing for the construction of modern municipal solid waste management systems, allowing for the fulfilment of the obligations imposed by the European Union.

Polish legislation defines municipal solid waste as waste produced by households but also as waste which does not contain hazardous waste and comes from other producers but because of its nature or composition is similar to waste from households.

This group also includes green waste composed of parts of plants from the maintenance of green areas, gardens, parks and cemeteries, as well as markets excluding waste from cleaning streets and squares [2].

The authorities of Lublin noticed the problem of the increasing production of municipal solid waste and drawing on the experience of Western European countries regarding the administration of solid waste management adopted the Resolution of the City Council No. 207 of 26 June 2003 [4] which introduced in the city the separate collection system of municipal solid waste with the division to dry fraction and wet fraction defining:

– **dry fraction** as municipal solid waste including:

1) uncontaminated paper, cardboard, including packaging

2) plastic, including packaging (e.g. foil, plastic bottles)

3) metals, including packaging, e.g. aluminium and metal tins, small scrap

4) glass packaging

5) wooden packaging and textiles

6) composite packaging (e.g. drink and dairy products cartons)

Defined as the type of solid waste with the code 20 01 99 according to the Regulation of the Minister of Environment of 27 September 2001 on solid waste catalogue [5] suitable for re-use for material or energy purposes.

– **wet fraction** as municipal solid waste (e.g. food waste, contaminated paper and plastic waste, damaged dishes, worn textiles and other waste) listed in the group 20 in the waste catalogue according to the Regulation of the Minister of Environment of 27 September 2001 on waste catalogue.

The, Solid waste management system', apart from the above-mentioned legal regulation, was defined in detail in the Solid Waste Management Plan for the city of Lublin [4]. The plan was approved by the City Council on 8th July 2004 and it complied with the higher tier plans, i.e. The National Solid Waste Management Plan and Waste Management Plan for the Lubelskie Voivodeship. [6]

At the end of 2003 the City Council commissioned the Organisation and Management Scientific Society in Lublin to carry out tests on the morphological composition of municipal solid waste taking into account the type of buildings. The analysis was to provide a 'base' (reference point) in relation to which an assessment of the implementation of the separate collection system and its optimisation are made. The study involved three different types of buildings in the city, i.e. high multi-family buildings (skyscrapers) medium multi-family buildings (four-storey blocks of flats) and single-family houses.

In each of the three types of buildings organic waste (so-called wet fraction) had the largest percentage by weight, its amount ranged from 52.8 % (single-family houses) to 57.8 % (multi-family buildings) (Table 1).

Table 1

Solid Waste make-up according to the type of buildings

No.	Waste component group	Type of buildings		
		high multi-family	**medium multi-family**	**Single-family**
1	2	3	4	5
1.	Organic waste	57.8	57.5	52.8
2.	'Green' waste	0	0	0
3.	Paper, cardboard	8.5	7.7	6.1
	including packaging	*2.2*	*2.4*	*1.65*
4.	Plastic	13.8	9.2	7.2
	including packaging	12.6	8.5	6.15
5.	Glass	8.3	12.4	9.9
	including packaging	8.3	11.9	8.7
6.	Composite waste	6.9	5.7	6.2
7.	Textiles	2.2	3.6	2.9
8.	Metals	2.0	2.1	2.7
	including: iron packaging	*1.6*	*1.8*	*2.1*
	other from iron	*0.2*	*0.16*	*0*
	colour	*0.2*	*0.16*	*0.6*
9.	Mineral waste	0	1.5	0.15
10.	Small fraction	0.2	0.2	14.6

Source: Own work on the basis of materials of the Environmental Protection Department of the City Hall [7]

A large part of the collected waste consisted of reusable materials from 27 % in single-family houses to 32–37 % in total in medium and high buildings.

Medium buildings and single-family houses produced the most of glass (including packaging), i.e.

12.4 % and 9.9 %, while in high buildings – plastic – 13.8 %. The amount of separated metal was similar in all types of buildings and ranged between 2–2.2 %.

The main differences in the comparison of the composition of waste were found in the amount of small fraction (ashes), which in single-family houses amounted to 14.6 %, while in multi-family buildings only to 0.2 %.

Hazardous substances were observed in solid waste in the course of the study. 13 batteries, one car battery without electrolyte and 3 litres of engine oil were found in the total mass of the tested waste.

In the second half of 2005 local government of Lublin decided to create an integrated system of municipal solid waste management and subject it to the principles of sustainable development.

It was assumed that the system has to fulfil four basic premises; it has to be:

1. **realistic** – have economic foundations of its operation;

2. **flexible** – its operation has to take into account the changing environment;

3. **effective** – ensure the achievement of the recovery rates and reduction of the amount of landfilled waste;

4. **verifiable** – there are objective tools to check its effectiveness.

The following two local laws adopted in 2006 were legal instruments of the new integrated system:

§ The Resolution of the City Council of Lublin No. 963/ XXXIX / of 23 March on the Regulations of cleanliness and order in the city of Lublin [4];

§ The Ordinance 496/2006 of the Mayor of Lublin of 16 November 2006 on the requirements for entrepreneurs applying for a permit for the collection of municipal solid waste from property owners and emptying holding tanks and transport of wastewater in the city of Lublin [4].

The new legislation maintained a basic separation of solid waste into wet fraction and dry fraction. Furthermore, in order to implement new statutory requirements inhabitants were required to separate collection of (Fig. 1):

§ green waste
§ solid waste from construction works
§ bulky municipal waste
§ hazardous municipal waste
§ waste electrical and equipment

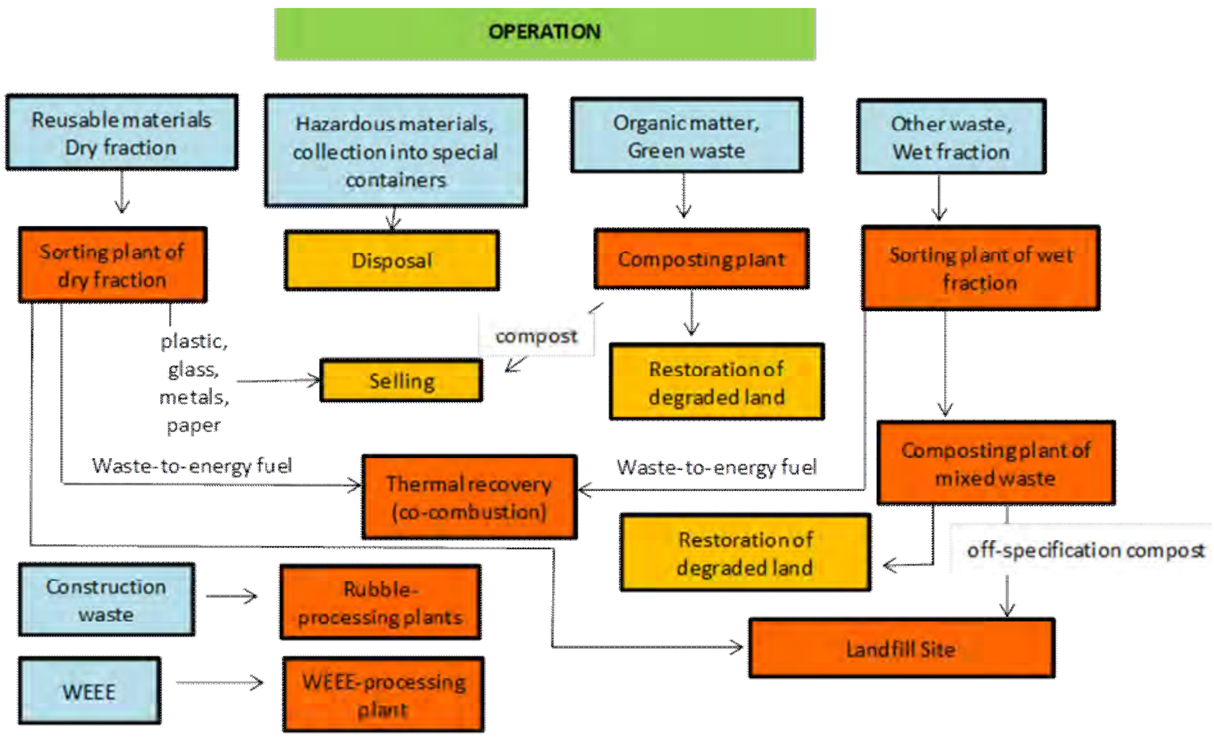

Fig. 1. Functional diagram of solid waste management in Lublin in 2007

Source: Own work on the basis of materials of the Environmental Protection Department of the City Hall

In order to implement these ambitious plans it became necessary to develop an effective model of cooperation with the following main cells:

– the inhabitants represented by district councils;

– entrepreneurs managing solid waste / WMP-Sita; WMP-Kom-Eko;

– local governments of municipalities.

It was assumed that there will be four functional areas of close cooperation:

– **education;**

– **organizational;**

– **economic;**

– **logistics.**

In the **education** area particular emphasis was put on informing each inhabitant of the city about the conditions of the new system:

§ 50 thousand information folders were prepared, printed and distributed among the residents;

§ an advertising spot promoting separate waste collection under the title ‘Our Town – Our Home’ was prepared and emitted;

§ a two-day training for city councillors, heads of housing estates administrations, managers of large stores, heads of departments of administration in Lublin hospitals, universities, important industrial plants was conducted;

§ educational workshops for teachers of Lublin schools in the Solid Waste Management Plant Kom-Eko Sp. z o. o. were organised;

§ 75 students (obtained a title of educators in the field of solid waste) were trained by the Lublin Environmental Protection Foundation (acting in cooperation) and they conducted lectures in Lublin schools in October and November;

§ an annual event ‘Eco-Picnic’ aiming to present the issues of separate waste collection was created.

§ The following was prepared in the organisational area:

§ circulation of documents confirming the origin of municipal solid waste;

§ annual schedules of the collection of dry fraction in the districts with low buildings;

§ agreement between the Mayor of Lublin and the Board of Cemex Polska Sp. z o. o. regarding Refuse Derived Fuel (RDF) supply from the Solid Waste Management Plant (WMP)-Sita and Solid Waste Management Plant (WMP)-Kom-Eko.

In the **economic** area actions were focused in two levels:

§ varied maximum rates for the collection of municipal solid waste – wet fraction and dry fraction – for the owner of the property (Table 2).

Table2

Price list of maximum rates

Wet fraction of municipal solid waste		**Dry fraction of municipal solid waste**	
Capacity	**Cost**	**Capacity**	**Cost**
bin SM-110l i 120l	**16.50 PLN**	bag 110 l	**6.45 PLN**
bin SM-240l	**24.20 PLN**	bin with the capacity of 1.1 m^3	**38.50 PLN**
bin SM-360l	**33.20 PLN**	bin with the capacity of 2.2 m^3, 2.5 m^3	**77.00 PLN**
bin 550l-750l	**38.50 PLN**	container 7 m^3	**185.00 PLN**
bin PA-1100l	**55.00 PLN**	**Green waste**	
container 7 m^3	**410.45 PLN**	**Capacity**	**Cost**
container 10 m^3	**513.10 PLN**	110 l	**5.15 PLN**
container 15 m^3	**806.25 PLN**	container 7 m^3	**205.40 PLN**

Source: the Resolution of the City Council [4]

▪ varied costs of landfilling municipal solid waste (for entrepreneurs using the Landfill Site in Rokitno) depending on the obtained recovery rates at the fixed level of 7 % calculated according to the formula:

$$S/(S+W)*100\,\%=7\,\%,$$

where: S – solid waste in Mg separated or subject to recovery; W – solid waste landfilled in Mg

The largest changes regarded the **logistics** area. Within the area the following were prepared and implemented:

§ dry fraction collection system;

§ bulky waste collection system;

§ green waste collection system;

§ collection system of solid waste from construction works;

§ bins for dry fraction (2.5 m^3) and 7 m^3 were designed and purchased – 1185 pieces;

§ bins for the collection of grass packaging – 115 pieces;

§ bins for the collection of hazardous waste were designed and purchased – 21 pieces;

§ bins for the collection of drugs that have passed their expiration date – 77 pieces;

§ collection subsystem of cemetery waste was organised;

§ subsystem of mobile collection points of hazardous waste was organised;

§ collection subsystem of WEEE (2 fixed points and 6 mobile points) was organised;

§ collection subsystem for drugs that have passed their expiration date was organised together with Lublin pharmacies;

§ collection subsystem of used tyres (seedlings for tyres) was organised.

The Environmental Protection Department was entrusted with the implementation and supervision over the system.

A unit devoted to the issues regarding solid waste, the solid waste management division, was created within the organisational structure of the Department.

Employees of the solid waste management division together with the municipal police officers formed 'environmental patrols' which aimed to directly control the implementation of the Lublin solid waste management system in companies and inhabitants producing municipal solid waste.

The effectiveness of the implementation of the Lublin solid waste management system is shown in Table 3.

Table 3

Weight of solid waste collected in the period from 2007 until 2010 in Mg

Type of waste	2007	2008	2009	2010
WEEE	421.3	512.0	282.65	392.39
Hazardous waste	9.518	19.135	21.420	13.445
Drugs that have passed their expiration date	1.963	4.782	5.420	5.865
Bulky waste	802.8	1008.2	1068.47	793.88
Clothing	589.4	600.2	607.58	537.35
Tyres	45.1	14.5	15.8	16.8
RDF	2570.2	5335.92	13555.12	27563.5
Packaging	4452.76	3787.54	3986.14	4273.26

Source: Own work on the basis of materials of the Environmental Protection Department of the City Hall [7]

Results and Discussion

In the period from 2007 until 2010 a total of 73,313.67 tons of solid waste was collected. The collected amount of solid waste which was not landfilled due to the implementation of the integrated municipal solid waste management system proved the validity of the assumptions and the selection of tools for their implementation. The thesis was confirmed in 2009 when the Municipality of Lublin was awarded the title of 'Leader of Polish Ecology' for the project entitled 'Lublin system of separate waste collection – a model for other municipalities', and in 2011 the title of 'Leader of Polish Ecology' was awarded to Kom-Eko for consistent implementation of Lublin solid waste management system.

The described period of preparation and implementation of the integrated municipal solid waste management system was highly praised by stakeholders: city authorities, entrepreneurs and, most importantly, the inhabitants.

Summary

The article presents main assumptions of the creation of a modern municipal solid waste management system for the City of Lublin. The author shows the tools which were used in the implementation of the project and describes the results of implementation of the system during the first four years of its operation, i.e. from 2007 until 2010.

Conclusion

In conclusion, the implementation of the law on cleanliness and order in municipalities was a great challenge facing Polish local governments. The studied example shows that many Polish local governments were able to implement new legal requirements. Two main factors determined the undoubted success of the authorities in Lublin.

The first one was the implementation of the model of separate waste collection in and its subsequent modifications.

The second key factor was the agreement with the company Cemex Polska Sp. z o. o., which allowed for maintaining the development dynamics of the separate waste collection despite the temporary collapse of the secondary raw materials market.

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ENVIRONMENTAL PROBLEMS

Vol. 1, No. 2, 2016

CHANGE OF BACTERIAL AMOUNT DURING SONICATION

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Abstracts. The dynamics of the change of microbial amounts in water medium in sonication time was determined. Gases bubbling of different nature into the reaction medium for water disinfection from bacteria under cavitation conditions is proposed in the article. The rate constants of destruction of *Bacillus cereus* bacteria type in the gas atmosphere are expected. It was determined that the processes microorganisms' destruction at bubbling of all investigated gases are described by the kinetic equations of the first order.

Key words: ultrasound, microorganisms, water disinfection.

Introduction

Water ultrasound (US) treatment is one of the most effective decontamination methods resulting in the microorganisms (MO) inactivation [1, 2]. Water disinfection under the US action is explained by the cavitation process during sonication, i.e. formation, growth and collapse of gas bubbles in a liquid [3]. US effective disinfection action on various types of microorganisms is confirmed by numerous positive results but the information about kinetic reaction order of the disinfection process of natural waters and sewage was not found in the literature. A high decontamination degree has been achieved in our previous studies under acoustic cavitation effect in the model microbial suspensions [4, 5]. US can inactivate a wide range of bacterial pathogens, including *E. coli* [6] and *Salmonella* in a variety of liquids, effective against *Microcystis aeruginosa*. Microbial inactivation by ultrasound action is caused by the physical disruption of cells, lysis, and damage to DNA and the formation of free radicals. However, the mechanism of cells destruction is not fully understood. But at the same time, the researchers have noticed, that the US is highly effective nonchemical ecological method of water purification from organic and microbial components. On the contrary, in [7–9] it has been noted that the complete destruction of pathogens is achieved when the ultrasound treatment is used only after long scoring or by increasing the power of ultrasound generators. It is clear that the need for a long disinfecting processing doubted the feasibility of using ultrasound for industrial conditions. Obviously, it is due to the result of an inadequate study of complex phenomena, which is accompanying with the cavitation effect, together with the ignorance of basic laws of the studied process that characterize the interaction of the components of water available to it specific organisms, the impact of additional gas supplied by the action of ultrasound, etc. This is because the effectiveness of bactericidal action as ultrasonic and hydrodynamic cavitation depends on several factors: the parameters of the physical factor (a capacity [10–12], an intensity [10], the oscillation frequency, an exposure [13]) and so on; some of the physical features of the environment that is exposed to cavitation (temperature, viscosity); the morphological features of the research facilities (sizes and shapes of bacterial cells, the presence of the capsule, the chemical composition of the membranes, an age, a culture [14–15] etc.); the nature of bubbling natural environment through the treated gas under the cavitation effect [4] and others.

The main aim of the work

The purpose of this study has been to investigate the destruction of *Bacillus* bacteria type in the deaerated distilled water using ultrasound in the presence of different dissolved gases: oxygen, carbon dioxide, argon and helium.

Materials and methods

Ultrasound oscillation frequency of 22 kHz low-frequency generator UZDN-2T (power of 90 W) transmitted via magnetostriction emitter immersed in water volume study of the initial value of the number of known microorganisms (MO). The experiments have been carried out under T=298 K, P=1·10^5 Pa. Investigated object was model medium with some amount of *Bacillus* is 8·10^2 cells/cm^3).

The thermostat for MO growth is shown in Fig. 1.

Gases were used as additional gases for the researches, which were bubbled into the microbial dispersion at the rate of ~ 1 cm^3/s. The duration of the process was 2 h. The volume of the investigated dispersion (75 cm^3) in the glass reactor was cooled by water during the whole process.

Fig. 1. The thermostat for microorganisms growth. Conditions: incubation in a thermostat at 37 °C during 48 h

Results and discussion

Water purification depends on the sonication time. For this reason, the effect of water sonicating was measured for the predefined periods of time. Water samples were sonicated during the periods of 30; 60; 90 and 120 min.

The effect of ultrasound on removal of *Bacillus* in argon (Ar), helium (He), oxygen (O_2) and carbon dioxide (CO_2) medium after 60 minutes exposure was 79.13; 65; 81.5 and 28.13 %, respectively, and after 120 minutes – 95.5; 93.38; 90.5 and 76.5 %. Study shows that increasing the exposure of sonication the number of bacteria in water samples significantly reduces; the power of bacterial cells destruction increases greatly (Fig. 2).

Moreover, the rate constants of microbial inactivation (k) have been determined. In argon saturated water k amounts to 4.346·10^{-4} s^{-1}, for the helium saturated one it is 3.566·10 $^{-4}$ s^{-1}, for the oxygen – 3.211·10^{-4} s^{-1} and for the carbon dioxide – 1.666·10^{-4} s^{-1} (table 1).

Table 1

Rate constants of cells disappearance.
Conditions: τ = 2 hours, T=298 K, P=1·10^5 Pa and US frequency = 22 kHz

Investigated gases	k·10^4, s^{-1}
carbon dioxide	1.666
oxygen	3.211
helium	3.566
argon	4.346

According to the results, the application of acoustic cavitation enhances the process of water purification in the presence of gases. Inactivation of *Bacillus* bacteria type is described by a reaction equation of the first-order. It has been found that the highest efficiency was obtained under conditions of the simultaneous action of ultrasound and argon (disinfection degree – 95.5 %, cells inactivation rate constant – 4.346·10^{-4} s^{-1}).

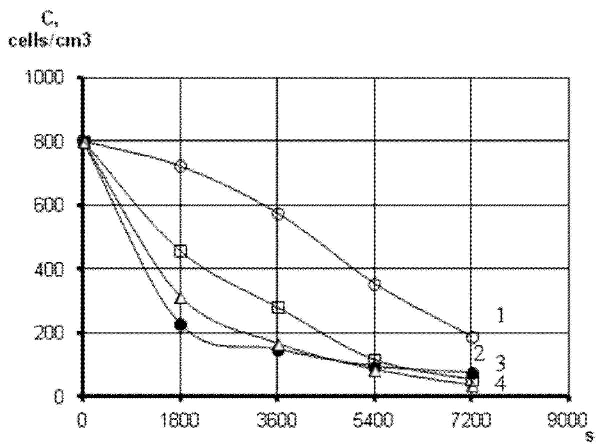

Fig. 2. Concentration of microorganisms as a function of sonication time in the presence of different gases: 1 – CO_2 , 2 – O_2, 3 – He, 4 – Ar

Conditions: C_0 = 8·10^2 cells/cm^3, T=298 K, P=1·10^5 Pa and US frequency = 22 kHz.

According to the results, the application of acoustic cavitation enhances the process of water purification in the presence of gases. Inactivation of *Bacillus* bacteria type is described by a equation of the first-order. It has been found that the highest efficiency was obtained under conditions of the simultaneous action of ultrasound and argon (disinfection degree – 95.5 %, cells inactivation rate constant – 4.346·10^{-4} s^{-1}).

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ENVIRONMENTAL PROBLEMS

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ADVANCED MODELING AND FORECASTING OF POLLUTANT CONCENTRATIONS TEMPORAL DYNAMICS IN THE ATMOSPHERE OF AN INDUSTRIAL CITY (GDANSK REGION)

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Abstract. In the paper we present the results of an advanced investigation of dynamics of variations of the atmospheric pollutants (sulphur dioxide) concentrations in the air basins of Polish industrial cities (Gdansk region) by using the improved non-linear prediction and chaos theory methods.

Chaotic behavior of the sulphurous anhydride concentration time series at two sites in the city of Gdansk has been computed. As usually, to reconstruct the corresponding chaotic attractor, it is necessary to determine time delay and embedding dimension. The former is determined by the methods of autocorrelation function and average mutual information, and the latter is calculated by means of the correlation dimension method and algorithm of false nearest neighbours. Further, the Lyapunov exponents' spectrum, the Kaplan-Yorke dimension and the Kolmogorov entropy and other invariants are calculated. An existence of a low-D chaos in the cited system is confirmed and using polynominal algorithm with neural networks block allows making an improved short-term forecast of the atmospheric pollutant fluctuations dynamics.

Key words: air pollution dynamics, studying and forecasting, chaos theory methods.

1. Introduction

Many studies in different fields of science have appeared where the methods of a chaos theory were used to a great number of various dynamical systems [1–35]. Especial interest atytracts its usinf under solving different problems in the Earth and environmental science as athe most of dynamical characteristics of environmental, hydrometeorological and ecological systems manifest typically non-linear chaotic behaviour. Nevertheless the studies concerning this behaviour in the time series of atmospheric constituent concentrations are sparse, and their outcomes are ambiguous [1–3]. The key problem of the Earth and environmental science is carrying out a forecasting model deals with the known problems. In this essense the methods of dynamical system and chaos theories could be especially useful. Let us remind that although a chaos theory puts fundamental limits for a long-rage forecasting [1–8], at the same time it can be used in order to obtain quite effective short-term prediction .

In ref. [5] the NO_2, CO, O_3 concentrations time series analysis was analysed and it was noted that O_3 concentrations in Cincinnati (Ohio) and Istanbul are evidently chaotic, so it is required essentially non-linear modeling the corresponding series [6]. In ref. [5] there is an analysis of the NO_2, CO, O_3 concentrations time series in Gdansk region and evidence of chaos has been definitely received. More over, a short-term forecast of atmospheric pollutants using a non-linear prediction method has been given. These studies have proved that non-linear methods of chaos theory and dynamical systems with satisfactory accuracy can be used for short-term forecasting the temporal dynamics of atmospheric pollutants concentrations, though a prediction model should be maken more exact. It is important to note that the time series are however not always chaotic, and thus chaotic elements should be found for each series.

In the paper we present the results of an advanced investigation of dynamics of variations of the atmospheric pollutants (sulphur dioxide) concentrations in the air basins of Polish industrial cities (Gdansk region) by using the improved non-linear prediction and chaos theory methods. It is presented an advanced analysis and forecasting of chaotic behaviour in the sulphurous anhydride concentration time series at two sites in the city of Gdansk. All calculations are performed with using "Geomath" and "Quantum Chaos" computational codes [3,5,9–39].

2. Testing of chaos in time series

2.1. Data

We have re-analysied the EU monitoring system data for time series concentrations of sulfur dioxide (SO_2) for the city of Gdansk (2003–2004). The multiyear hourly values of the corresponding concentrations (one-year total of 20×8760 data points) were studied. The examples of the time series of SO_2 concentration (in mg/m^3) are listed in Fig. 1.

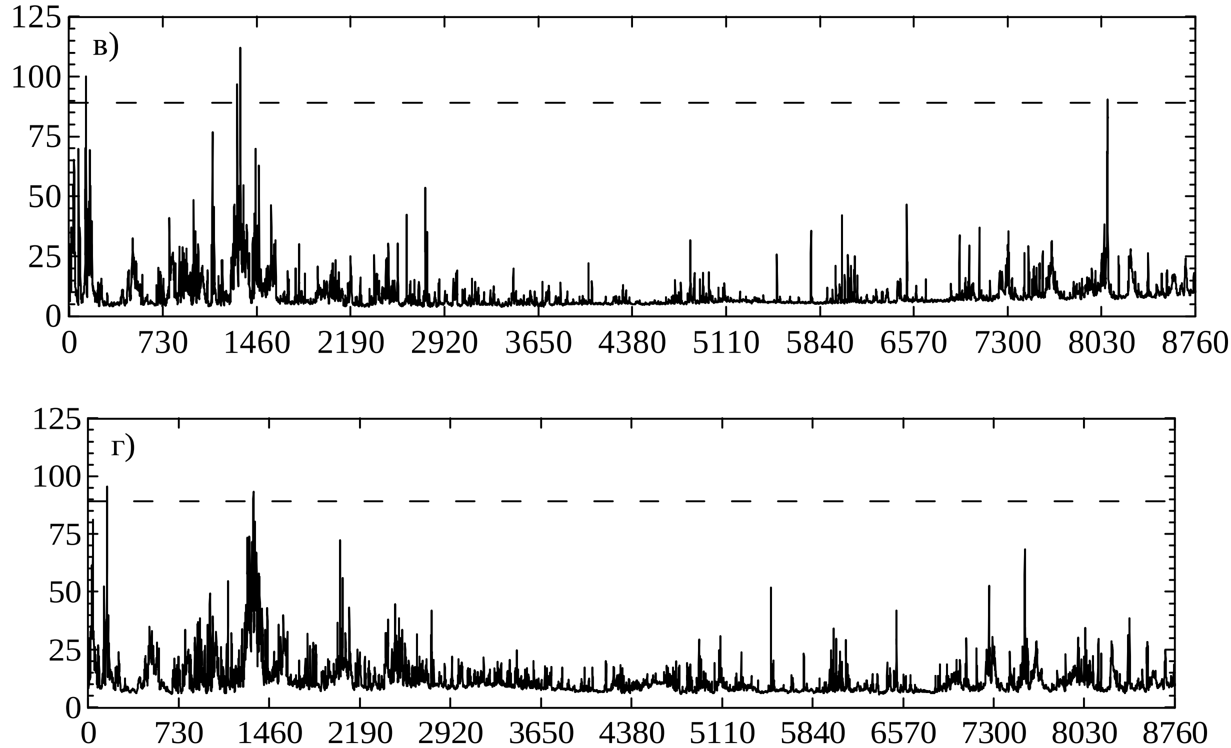

Fig. 1. Time series of SO_2 concentrations (in mg/m^3)

2.2. Testing of chaos in time series

Testing for chaos procedure in time series is described in details in [2, 14–18]. Here we are limited only by the key aspects. AS usually, we consider time series:

$$s(n)=s(t_0+ n\Delta t) = s(n),$$

where t_0 is a start time, Δt is a time step, and n is a number of the measurements. The valuable $s(n)$ in our case means an atmospheric pollutant concentration. The next step is in reconstruction of a phase space using the information contained in $s(n)$. Such reconstruction leads to a set of d-dimensional $\mathbf{y}(n)$-vectors for each scalar measurement of the atmospheric pollutant concentration. The main idea is the direct use of variable lags $s(n+\tau)$, where τ is some integer to be defined, which determines the coordinate system where a structure of orbits in phase space can be restored using a set of time lags to create a vector in d dimensions,

$$\mathbf{y}(n)=[s(n),s(n + \tau),s(n + 2\tau),..,s(n +(d-1)\tau)],$$

the required coordinates are provided. In a nonlinear system, $s(n + j\tau)$ there are some unknown nonlinear combinations of the actual physical variables. The space dimension d is the embedding dimension d_E.

2.3. Time lag

The choice of a proper time lag is important for subsequent reconstruction of phase space. If τ is too small, then the coordinates $s(n + j\tau)$, $s(n + (j + 1)\tau)$ are so close to each other in numerical value that they cannot be distinguished from each other. If τ is too large, then $s(n+j\tau)$, $s(n+(j+1)\tau)$ are completely independent of each other in a statistical sense. If τ is too small or too large, then the correlation dimension of attractor can be under-or overestimated. So, the optimal valus has some intermediate position between the above listed cases.

The first well knowjn approach to computing time lag is provided by a linear autocorrelation function $C_L(\delta)$ method. The main idea is to determine such time lag in which $C_L(\delta)$ is the fastest when passing through 0.

Another alternative approach is to use a nonlinear concept of independence, e.g. the average mutual information algorithm. The average mutual information I of two measurements a_i and b_k is symmetric and non-negative, and equals to 0 if only the systems are independent. The average mutual information between any values a_i from system A and b_k from B is averaged over all possible measurements of $I_{AB}(a_i, b_k)$. In ref. [4] it is suggested to choose such value of τ where the first minimum of $I(\tau)$ occurs.

2.4. Embedding dimension

The goal of the embedding dimension determination is to reconstruct Euclidean space R^d large enough sothat the set of points d_A can be unfolded without ambiguity. In other words, we can choose a fortiori large dimension d_E, e.g. 10 or 15, since the previous analysis provides us prospects that the dynamics of our system is probably chaotic. The correlation integral analysis is one of the widely used techniques to investigate chaos in time series. The analysis uses the correlation integral, $C(r)$, to distinguish between chaotic and stochastic systems. If the time series is characterized by an attractor, the correlation integral $C(r)$ is related to the radius r as

$$d = \lim_{\substack{r \to 0 \\ N \to \infty}} \frac{\log C(r)}{\log r},$$

where d is a correlation exponent. If the correlation exponent attains saturation with an increase in the embedding dimension, then the system is generally considered to have a chaotic dynamics. The saturation value of the correlation exponent is defined as the correlation dimension (d_2) of the attractor (see [3,7]).

In Fig. 2 we list the computed dependence of the correlation integral C (r) of radius r for different embedding dimensions d for SO_2 (b) at site 6 of Gdansk in 2003.

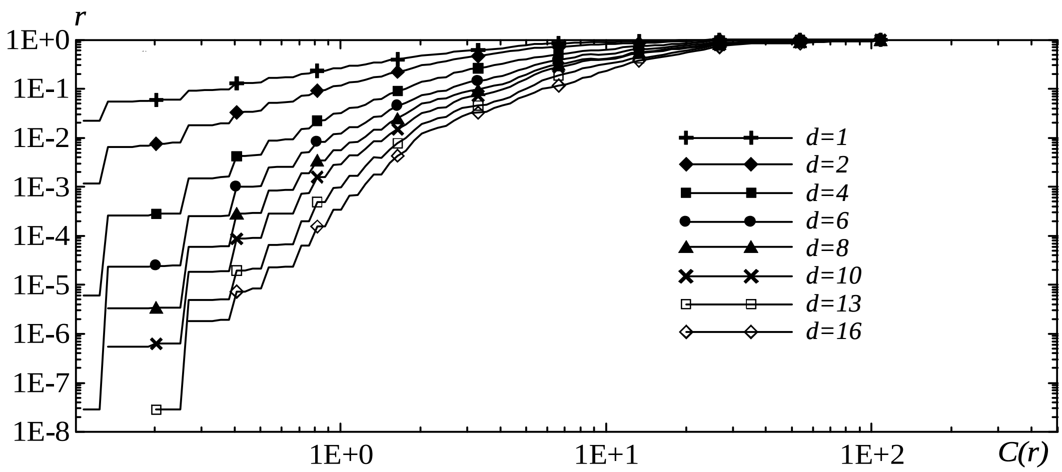

Fig. 2. The dependence of the correlation integral C (r) of radius r for different embedding dimensions d for SO2 (b) at site 6 of Gdansk in 2003–2004

3. Results for atmospheric pollutant time series

3.1. Results

Table 2 summarizes the results for the time lag calculated for first 10^3 values of time series.

The autocorrelation function for all time series remains positive. The values, where the autocorrelation function first crosses 0.1, can be chosen as τ, but in [1] it is shown that an attractor cannot be adequately reconstructed for very large values of τ. So, before making up a final decision we calculate the dimension of attractor for all values in Table 1. The outcomes explain not only inappropriate values of τ, but also shortcomings of the correlation dimension method [7]. If algorithm [1] is used, then a percentage of false nearest neighbours is comparatively large in the case of large τ. If time lag is determined by average mutual information, then algorithm of false nearest neighbours provides $d_E = 6$ for all air pollutants.

Table 1

Time lags (hours) subject to different values of C_L, and first minima of average mutual information, I_{min1}, for the time series of SO_2 at the sites of Gdansk

	$C_L = 0$	$C_L = 0,1$	$C_L = 0,5$	I_{min1}
	Site 6			
SO_2	–	233	13	19
	Site 9			
SO_2	–	148	27	18

3.2. Nonlinear prediction model

First of all, it's important to define how predictable a chaotic system is. The predictability can be estimated by the Kolmogorov entropy, which is proportional to a sum of positive Lyapunov exponents.

The spectrum of the Lyapunov exponents is one of dynamical invariants of non-linear system with chaotic behaviour. The limited predictability of the chaos is quantified by local and global Lyapunov exponents, which can be determined from measurements. The Lyapunov exponents are related to the eigenvalues of the linearized dynamics across the attractor. Negative values show stable behaviour while positive values show local unstable behaviour.

For chaotic systems, that are both stable and unstable, the Lyapunov exponents indicate the complexity of the dynamics. Large positive values determine some average prediction limit. Since the Lyapunov exponents are defined as asymptotic average rates, they are independent of the initial conditions, and hence the choice of trajectory, and they do comprise an invariant measure of the attractor. The estimate of this measure is the sum of positive Lyapunov exponents. The estimate of the attractor dimension is provided by the conjecture d_L and the Lyapunov exponents are taken in descending order. The dimension d_L gives values close to the dimension estimates discussed earlier and is preferable when estimating high dimensions. To compute the Lyapunov exponents, we use a method of linear fitted maps [3], although the maps with higher order polynomials can be used too.

3.3. Nonlinear model

Nonlinear model of chaotic processes is based on the concept of a compact geometric attractor on which observations evolve plus (so-called chaos geometric approach). Since an orbit is continually folded back on itself by dissipative forces and the non-linear part of dynamics, some orbit points $y^r(k)$, $r = 1, 2, ..,N_B$ can be found in the neighbourhood of any orbit point $y(k)$, and points $y^r(k)$ arrive in the neighbourhood of $y(k)$ at quite different times k.

One can then choose some interpolation function, which accounts for whole neighbourhood of phase space and how they evolve from near $y(k)$ for the whole set of points near $y(k+1)$. The implementation of this concept is to build parameterized non-linear function $F(x, a)$ which transforms $y(k)$ into

$$y(k+1) = F(y(k), a)$$

and uses various criteria to determine parameters of a. Since one has the notion of local neighbourhoods, one can build up one's model by processing neighbourhood by neighbourhood and, after piecing these local models together, produce a global non-linear model that captures much of the structure in an attractor itself.

3.4. Short-term forecast of atmospheric pollutant time series

Table 2 shows the calculated parameters: correlation dimension (d_2), embedding dimension (d_E), Kaplan-Yorke dimension (d_L), two first Lyapunov exponents, $E(\lambda_1,\lambda_2)$, and the average limit of predictability (Pr_{max}, hours) for time series of the SO_2 at the sites of Gdansk (in 2003-2004).

Firstly, it should be noted that presence of two (from the six) positive λ_i suggests that the system broadens in the line of two axes and converges along the rest four axes in the six-dimensional space. The time series of SO_2 at site 10 have the highest predictability (more than 2 days), and other time series have the predictabilities slightly less than 2 days.

Table 2

The correlation dimension (d_2), embedding dimension (d_E), first two Lyapunov exponents, E(l$_1$,l$_2$), the Kaplan-Yorke dimension (d_L), and the average limit of predictability (Pr_{max}, hours) for time series of SO_2 at the sites of Gdansk (in 2003)

	τ	d_2	d_E	λ_1	λ_2	d_L	Pr_{max}	K
	Site 1							
SO_2	19	1,58	6	0,0164	0,0066	5,01	43	0,71
	Site 2							
SO_2	17	3,40	6	0,0150	0,0052	4,60	49	0,73

The concrete example is presented in Figure 3, where the empirical (solid bold line) and theoretical forecasting (solid thin line by the polynomial-type prediction algorithm with neural networks block and dotted line by the standard polynomial-type algorithm [5, 17–19]) concentration lines SO_2 (for the one hundred points) are presented. As one can see, despite the fact that almost all the peaks on the actual curve repeat, as forecasted, the difference between the forecasted and actual data in the case of high concentrations of the ingredients can be quite large. In a whole, the results of this forecast can be considered as very satisfactory.

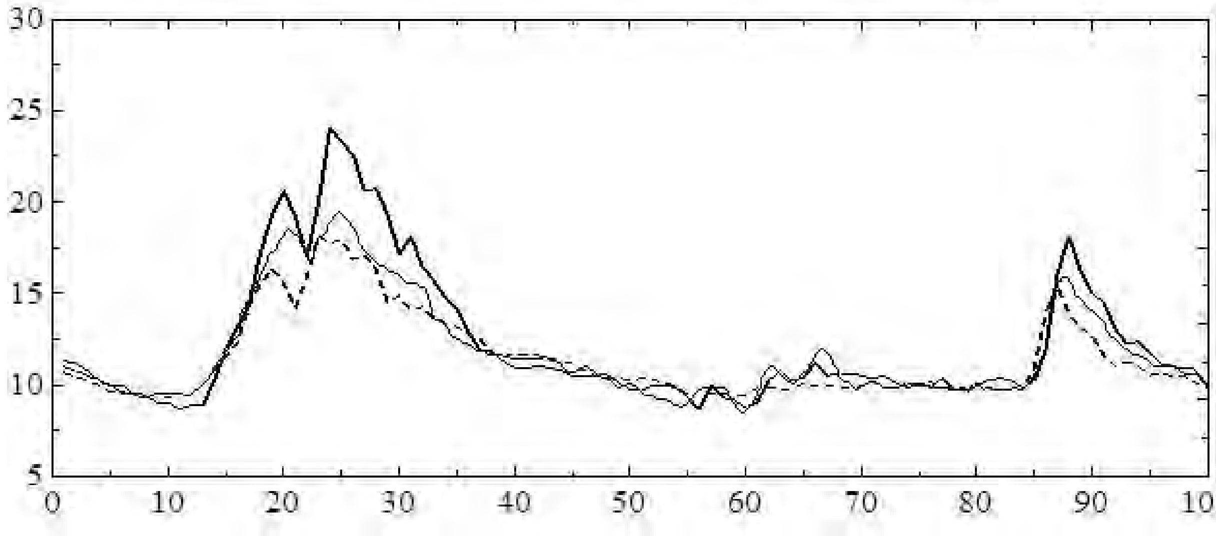

Fig. 3. The empirical (solid bold line) and forecasted (solid thin line and dotted line) curves of SO_2 concentration for the last six hundred members of time series shown in Fig. 1. Axis X – a serial number of the term (see text)

4. Conclusions

In this work, we have studied the dynamics of variations of the atmospheric pollutants (sulphur dioxide) concentrations in the air basins of Polish industrial cities (Gdansk) by using non-linear prediction and chaos theory methods. Chaotic behaviour in the sulphurous anhydride concentration time series at a few sites of Gdansk is numerically investigated. Usually, to reconstruct the corresponding attractor, the time delay and embedding dimension are needed. The former is determined by the methods of autocorrelation function and average mutual information, and the latter is calculated by means of the correlation dimension method and the algorithm of false nearest neighbours. Further, the Lyapunov exponents' spectrum, the Kaplan-Yorke dimension and the Kolmogorov entropy are calculated. The improved results on the short-term forecast of the SO_2 atmospheric pollutant time fluctuations dynamics in Gdansk region are given.

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STUDYING AND FORECASTING OF THE PHOSPHATES POLLUTION DYNAMICS IN WATERSHEDS AND ANTROPOGENIC WATER MANAGEMENT LANDSCAPE DYNAMICS: APPLICATION TO THE SMALL CARPATHIANS RIVERS' WATERSHEDS

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Abstract. The paper concerns the results of the quantitative study of dynamics for phosphates concentrations in the Small Carpathians rivers watersheds in Earthen Slovakia by using methods of nonlinear analysis and forecasting, chaos theory and dynamical systems. The conclusions can be viewed from the perspective of carrying out new algorithms for analysis and forecasting of the dynamics and evolution of anthropogenic water management landscape. Chaotic behaviour of the phosphates concentration time series in the watersheds of the Small Carpathians is studied. It is shown that low-D chaos exists in the time series under investigation.

Key words: dynamics, studying, forecasting, phosphates concentrations, the Small Carpathians rivers watersheds, chaos theory methods.

Introduction

In modern theory of the hydro-ecological systems, water resources and environmental protection, the problem of quantitative treating of pollution dynamics is also one of the most important and fundamental problems, in particular, in applied ecology and urban ecology [1–18]. Let us remind [1–9] that most of the models are currently used to assess (as well as forecast) the state of the environment pollution by the deterministic models or their simplification, based on simple statistical regressions. The success of these models, however, is limited by their inability to describe the nonlinear characteristics of the pollutant concentration behaviour and lack of understanding of the involved physical and chemical processes. Especially serious problem occurred during the study of dynamics of the hydro-ecological systems. Although the use of chaos theory methods establishes certain fundamental limitation on the long-term predictions, however, as it has been shown in a series of our papers (see [1–22]), these methods can be successfully applied to a short-or medium-term forecasting.

These studies show that chaos theory methodology can be applied and a short-range forecast by the non-linear prediction method can be satisfactory. It opens very attractive perspectives for the use of the same methods in studying dynamics of the pollution of other hydro-and ecological systems. Earlier the pollutions variations dynamics of nitrates concentration in the river water reservoir in Earthen Slovakia was studied by using a chaos theory [9]. Here a non-linear behaviour of the phosphates concentration in time series in the watersheds of the Small Carpathians is studied. All calculations are performed with using "Geomath" & "Quantum Chaos" PC codes [9, 16, 17, 23–42].

Method of testing of chaos in time series

As the initial data we use the results of empirical observations made on six watersheds (Fig. 1.) in the region of the Small Carpathians, carried out by co-workers of the Institute of Hydrology of the Slovak Academy of Sciences [2]. Fig. 2 shows temporal changes in the concentrations of phosphates in the catchment areas. In Fig. 3 we list the Fourier spectrum of the concentration of phosphates in the water catchment of Vydrica (C-Most) for the period of 1991–1993. The X-axis - frequency, the axis Y – energy.

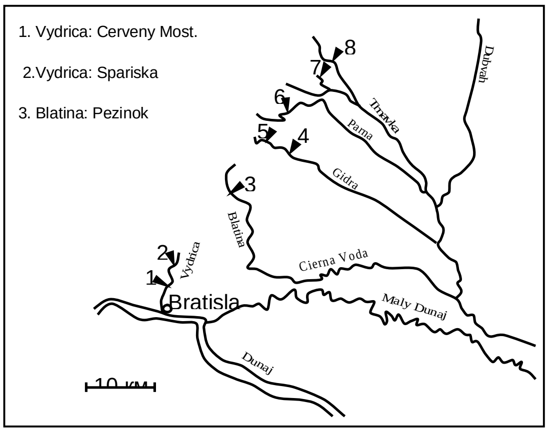

Fig. 1. Observation sites in the Small Carpathians [2]

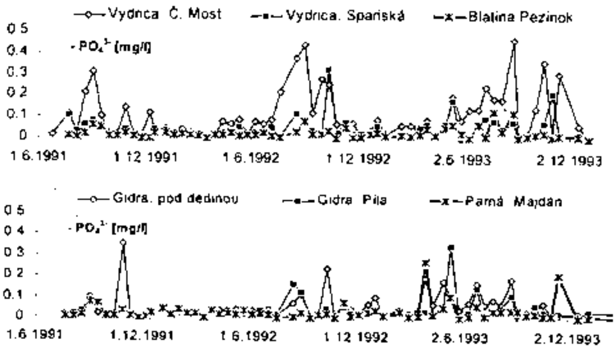

Fig. 2. Temporal changes in the concentrations of phosphates in some water catchments of the Small Carpathians (Slovakia) [2]

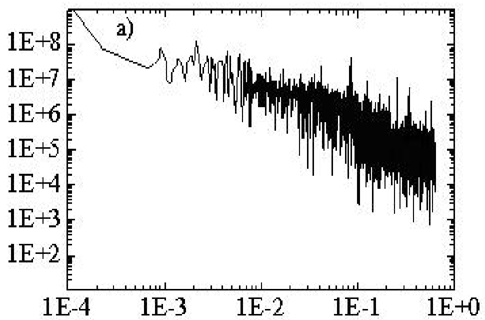

Fig. 3. The Fourier spectrum of the concentration of phosphates in the water catchment area of Ondava (Stropkov) for the period of 1.6.1991–2.12.1993

The Fourier spectrum looks the same as in the case of a random process, so there is the possibility of using methods of chaos theory.

Let us consider scalar measurements: $s(n)=s(t_0+ n\Delta t) = s(n)$, where t_0 is start time, Δt – a time step, and n – a number of measurements. The key task is to reconstruct phase space using the information contained in $s(n)$. Such reconstruction results in a set of d-dimensional $\mathbf{y}(n)$-vectors for each scalar measurement. The main idea is the direct use of variable lags $s(n+\tau)$, where τ is some integer to be defined, which determines the coordinate system where a structure of orbits in phase space is restored. Using a set of time lags to get a vector in d dimensions,$y(n)=[s(n),s(n + \tau),s(n + 2\tau),..,s(n +(d–1)\tau)]$, the required coordinates are provided. In a nonlinear system, $s(n + j\tau)$ are some unknown nonlinear combination of the actual physical variables. The dimension d is the embedding dimension, d_E.

The choice of a proper time lag is important for subsequent reconstruction of phase space. If τ is too small, then the coordinates $s(n + j\tau)$, $s(n +(j +1)\tau)$ are so close to each other in numerical value that they cannot be distinguished from each other. If τ is too large, then $s(n+j\tau)$, $s(n+(j+1)\tau)$ are completely independent of each other in a statistical sense. If τ is too small or too large, then the correlation dimension of attractor can be under-or overestimated. One needs to choose some intermediate position between the above listed cases. The first approach is to compute the linear autocorrelation function $C_L(\delta)$ and determine such time lag in which $C_L(\delta)$ is the fastest when passing through 0. This gives a good hint of choice for τ at which $s(n+j\tau)$ and $s(n+(j +1)\tau)$ are linearly independent. It's better to use the approach of nonlinear concept of independence, e.g. of average mutual information. The average mutual information I of two measurements a_i and b_k is symmetric and non-negative, and equals to 0 if only the systems are independent. The average mutual information between any values a_i from system A and b_k from B is the average over all possible measurements of $I_{AB}(a_i, b_k)$. In ref. [3] it is suggested to choose such value of τ where the first minimum of $I(\tau)$ occurs.

The goal of the embedding dimension determination is to reconstruct Euclidean space R^d large enough so that the set of points d_A can be unfolded without ambiguity. The embedding dimension, d_E, must be greater, or at least equal to the dimension of attractor, d_A, i.e. $d_E > d_A$. In other words, we can choose a fortiori large dimension d_E, e.g. 10 or 15. The correlation integral analysis is one of the widely used techniques to investigate chaos in time series. The analysis uses the correlation integral, $C(r)$, to distinguish between chaotic and stochastic systems. According to [4], integral $C(r)$ is calculated based on the algorithm. If the time series is characterized by an attractor, the correlation integral $C(r)$ is related to the radius r as

$$d = \lim_{\substack{r\to 0\\ N\to\infty}} \frac{\log C(r)}{\log r},$$

where d is a correlation exponent. If the correlation exponent attains saturation with an increase in the embedding dimension, then the system is generally considered to exhibit chaotic dynamics (see refs. [4, 16, 17]).

Fig. 4 lists the dependence of the correlation dimension (axis Y) on the embedding dimension (axis X) for the concentration of phosphates in the watershed of Ondava (Stropkov) for the period of 1991–1993. There is a corresponding curve, the analysis of which shows that saturation value for d_2 concentrations in the watershed of Vydrica (C.Mist) for the studied period of 1991–1993 amounts to 6.3 and was achieved by embedding dimension *ds*, at 18. The same result is obtained on the basis of false nearest neighboring points (Fig. 4). The dimension of the attractor in this case was defined as the embedding dimension, in which the number of false nearest neighboring points was less than 3 %.

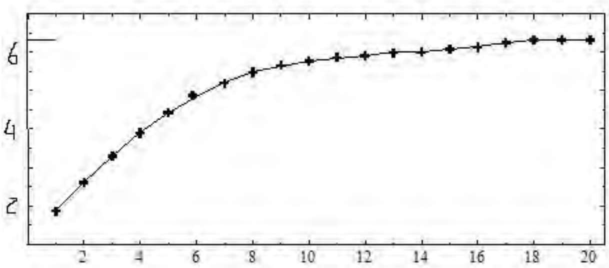

Fig. 4. The dependence of the correlation dimension (axis Y) on the embedding dimension (axis X) for he concentration of phosphates in the watershed of Vydrica (C.Miost) for the studied period of 1991–1993

It is known that the limited predictability of chaos is quantified by local and global Lyapunov exponents. The Lyapunov exponents are related to the eigenvalues of the linearized dynamics across the attractor. Large positive values determine some average prediction limit. Since the Lyapunov exponents are defined as asymptotic average rates, they are independent of the initial conditions, and hence the choice of trajectory, and they do comprise an invariant measure of the attractor. An estimate of this measure is a sum of positive Lyapunov exponents. The estimate of the attractor dimension is provided by the conjecture d_L and the Lyapunov exponents are taken in descending order. To compute them, method of linear fitted maps [1, 2] is used. The sum of positive Lyapunov exponents determines the Kolmogorov entropy, which is inversely proportional to the limit of predictability ($Pr_{\max}$).

Results and conclussions

In Table 1 we list the values of the time delay (τ), depending on the different values of the autocorrelation function (C_L) and the first minimum of mutual information ($I_{\min 1}$) for the concentration of phosphates in the watersheds of the Small Carpathians.

Table 1

The values of time delay (t), depending on different values of autocorrelation function (C_L) and the first min of mutual information ($I_{\min 1}$) for phosphates concentration in the studied watersheds

River (Site)	C_L = 0	C_L = 0,1	C_L =0,5	$I_{\min 1}$
Vydrica (C.Most)	–	288	57	24
Vydrica (Spariska)	–	289	55	22
Blatina (Pezinok)	–	316	66	21
Gidra (Main)	–	274	53	19
Gidra (Pila)	–	267	52	22
Pama (Majdan)	–	314	63	20

Table 2 summarizes the results of the numerical reconstruction of the attractors, as well as average limit of predictability ($Pr_{\max}$) and Gottwald-Melbourne parameter K [5] for the phosphates concentrations in the watersheds of studied region.

Table 2

Time lag (t), correlation dimension (d_2), embedding dimension (d_E), the Kaplan-Yorke dimension (d_L), average limit of predictability ($Pr_{\max}$) and parameter K for the phosphates concentrations in the watersheds of the Small Carpathians

River (Site)	τ	d_2	d_E	d_L	$Pr_{\max}$	K
Vydrica (C.Most)	21	6,3	7	5,1	11	0,7
Vydrica (Spariska)	20	6,7	7	5,8	12	0,6
Blatina (Pezinok)	20	5,9	6	6,1	13	0,6
Gidra (Main)	17	6,1	7	6,8	14	0,7
Gidra (Pila)	18	6,8	7	6,4	11	0,7
Pama Majdan)	19	5,2	6	5,8	11	0,6

As it was indicated, the sum of positive Lyapunov exponents λ_i determines the Kolmogorov entropy, which is inversely proportional to the limit of predictability ($Pr_{\max}$). Let us remind that since the conversion rate of the sphere into an ellipsoid along different axes is determined by the λ_i, it is clear that the smaller the amount of positive dimensions, the more stable is a dynamic system. Consequently, it increases its predictability.

On the other hand, the conclusions can be viewed from the perspective of new algorithms for the analysis and forecasting of the dynamics and evolution of anthropogenic water management landscape. Therefore in this paper we present the results of studying the dynamics of variations of phosphates concentrations in the rivers water reservoirs in Earthen Slovakia) systems in the definite region by using non-linear prediction approaches and chaos theory methods. Chaotic behaviour in the phosphates concentration time series in a number of the the watersheds of the Small Carpathians (Slovakia). We have shown that low—middle-dimensional chaos elements exist in the time series under investigation and quite sufficient predictability can be obtained in the forecasting of the pollution concentrations dynamics.

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ANALYSIS AND FORECAST OF THE ENVIRONMENTAL RADIOACTIVITY DYNAMICS BASED ON THE METHODS OF CHAOS THEORY: GENERAL CONCEPTIONS

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Abstract. For the first time, we present a completely new technique of analysis, processing and forecasting of any time series of the environmental radioactivity dynamics, which schematically is as follows: a) general qualitative analysis of a dynamical problem, typical environmental radioactivity dynamics (including a qualitative analysis from the viewpoint of ordinary differential equations, the "Arnold-analysis"); b) checking for the presence of chaotic (stochastic) features and regimes (the Gottwald-Melbourne's test; the correlation dimension method); c) reducing the phase space (the choice of time delay, the definition of the embedding space by the correlation dimension methods and false nearest neighbours algorithms); d) determination of the dynamic invariants of a chaotic system (computation of the global Lyapunov dimension λ_α; determination of the Kaplan-Yorke dimension d_L and average limits of predictability Pr_{max} on the basis of the advanced algorithms; e) a nonlinear prediction (forecasting) of any dynamical system evolution. The last block really includes new (in the theory of environmental radioactivity dynamics and environmental protection) methods and algorithms of nonlinear prediction such as methods of predicted trajectories, stochastic propagators and neural networks modeling, renorm-analysis with blocks of polynomial approximations, wavelet-expansions etc.

Key words: environmental radioactivity dynamics, the ecological state, time series of concentrations, pollutants, analysis and prediction methods of the theory of chaos.

Introduction

One of the most actual and important problems of applied ecology and environment protection is associated with correct quantitative description of environmental radioactivity dynamics [1, 2]. In general, one should note the following actual problems:

- a long-term investigation of radionuclides behaviour in the environment;
- elucidation of the mechanism of radionuclides transfer in the environment by animals, through the food chain;
- elucidation of the mechanism of transformation and transportation of radioactive substances due to meteorological phenomena and other factors;
- provision of a think-tank functioning for the recovery of the environment;
- conservation of research materials and samples and archiving of research methodologies and research objects.

Key objectives of the atmospheric radionuclide dynamics include the research of radionuclides transportation in the atmospheric environment, the dynamics of terrestrial radionuclides – research of radionuclides transfer and migration in the terrestrial environment, marine radionuclides dynamics – research of radionuclides transfer in the marine environment and radiation hydrology – research of radionuclides transfer from land by fresh water environments due to hydrological phenomena. Key radio-ecological transfers and effects include research cycles of radionuclides in forest ecosystems, the research of radionuclide transfer to biota in inland waters, the research of radionuclides transfer in soil-plant system, the research of biological effects of irradiation in microbes, algae, and plants, and biological effects of animals' radiation exposure, with an emphasis on free-range animals.

The main purposes of modeling, measurements and forecasting approach are: to evaluate and predict the transfer of radionuclides and radiation in the environment using computer simulations and other methods, to design improved technologies for monitoring and measuring radiation, to develop mechatronical systems and remote control technologies that will enable sampling and other operations in the areas out of humans reach. It is important to make analysis, to archive the research outputs and samples, obtained from IER and other institutes around the world and provide these materials to researchers around the world upon their request.

The problem of studying the dynamics of chaotic dynamical systems arises in many areas of science and technology. We are talking about classes of problems of identifying and estimating the parameters of interaction between the sources of complex (chaotic) oscillations of the time series of experimentally observed values. Such problems arise in environmental sciences, such as geophysics, chemistry, biology, medicine, neuroscience, engineering, etc. [1–10]. The problem of analysis and forecasting of the impact of anthropogenic pressure on the state of atmosphere in an industrial city and development of consistent, adequate schemes for modeling the properties of concentration fields of air pollutions has been considered in details, for example, in Ref. [3].

In modern theory of the hydro-ecological systems, water resources and environmental protection, the problem of quantitative treating of pollution dynamics is also one of the most important and fundamental problems, in particular, for applied ecology and urban ecology [1–18]. Let us remind [1–3] that most of the models are currently used to assess (as well as forecast) the state of the environment pollution by the deterministic models or their simplification, based on simple statistical regressions. The success of these models, however, is limited by their inability to describe the nonlinear characteristics of the pollutant concentration behaviour and lack of understanding of the involved physical and chemical processes. Especially serious problem occurred during the study of dynamics of the hydro-ecological systems. Though the use of chaos theory methods establishes certain fundamental limitation on the long-term predictions, however, as it has been shown in a series of our papers [2–11]), these methods can be successfully applied to a short-or medium-term forecasting. In Ref. [2–4] we presented successful examples of quantitatively correct description of temporary changes in the concentration of nitrogen dioxide (NO2) and sulfur dioxide (SO2) in several industrial cities (Odessa, Trieste, Aleppo and the cities of Gdansk region) with a discovery of low-dimensional chaos. Moreover, some elements of this technique have been successfully applied to several prediction tasks for the other environmental management system. Here we mean the prediction of the evolution ecological state (temporal or even spatial) [6–11]. As example, let us remind the research results of variations dynamics of hydro-ecological systems (nitrates and sulphates concentrations in the Small Carpathians rivers watersheds in Eastern Slovakia) in the definite region by using non-linear prediction approaches and the recurrence plots method. At first, we discovered chaotic behaviour of nitrates and sulphates in the concentration of time series in the watersheds of the Small Carpathians. Naturally, except different physical and chemical features, from the formal mathematical point of view, difference between atmospheric and hydrological environmental systems is not essential, because in both problems, we deal with time series of fundamental pollution characteristics and therefore we should develop the technique for studying pollution dynamics of the hydro-ecological system, which will only have some differences in the details.

The main purpose of this paper is formally to represent theoretical basis of new general formalism for the analysis and forecasting of the environmental radioactivity dynamics and develop a new compact general scheme for modeling of temporal fluctuations of the pollution of temporal fluctuations field concentrations, based on the methods of chaos theory. Earlier it had been successfully realized in case of the atmosphere (air basin) of large industrial cities and some hydro-ecological systems (regions). Therefore, further we will consider the corresponding atmospheric formalism [2–4] and give the necessary comments in the case of important features of the environmental radioactivity dynamics.

New general formalism for analysis and forecasting of the dynamics of hydroecological systems pollutants

As usual, we start with the first key task on testing chaos in the time series of environmental radioactivity dynamics. Following to [2–4], one should consider scalar measurements of the system dynamical parameters, for instance:

$$(n)=s(t_0+ n\Delta t) =s(n), \quad (1)$$

where t_0 is a start time, Δt – s time step, and n – a number of measurements. In a general case, $s(n)$ is any time series (e.g. pollutants concentration in the atmosphere). As processes resulting in chaotic behaviour are fundamentally multivariate, one needs to reconstruct phase space using the information contained in $s(n)$.

Such reconstruction results in a set of d-dimensional vectors $\mathbf{y}(n)$ for each scalar measurement. The main idea is the direct use of variable lags $s(n+\tau)$, where τ is some integer to be defined, which determines the coordinate system where a structure of orbits in phase space can be restored by using a set of time lags to create a vector in d dimension,

$$y(n)=[s(n),s(n + \tau),s(n + 2\tau),..,s(n +(d-1)\tau)], \quad (2)$$

the required coordinates are provided. In a nonlinear system, $s(n + j\tau)$ there are some unknown nonlinear combinations of the actual physical variables. The space dimension d is the embedding dimension d_E.

The choice of a proper time lag is important for the subsequent reconstruction of phase space. If τ is too small, then the coordinates $s(n + j\tau)$, $s(n +(j +1)\tau)$ are so close to each other in numerical value that they cannot be distinguished from each other. If τ is too large, then $s(n+j\tau)$, $s(n+(j+1)\tau)$ are completely independent of each other in a statistical sense. If τ is too small or too large, then the correlation dimension of attractor can be under-or overestimated. Further, it is an important task to choose some intermediate position between the above cases. The first approach is to compute the linear autocorrelation function $C_L(\delta)$ and look for the time lag where $C_L(\delta)$is the fastest when passing through 0. This gives a good hint of choice for τ at which $s(n+j\tau)$ and $s(n+(j +1)\tau)$ are linearly independent. It is better to use the approach of nonlinear concept of independence, e.g. of average mutual information [1–3]. The average mutual information I of two measurements a_i and b_k is symmetric and non-negative, and equals to 0 if only the systems are independent. The average mutual information between any values a_i from system A and b_k from B is averaged over all possible measurements of $I_{AB}(a_i, b_k)$. In Refs. [2–4] it is suggested to choose such value of τ where the first minimum of $I(\tau)$ occurs.

The goal of the embedding dimension determination is to reconstruct Euclidean space R^d large enough so that the set of points d_A can be unfolded without ambiguity. The embedding dimension, d_E, must be greater, or at least equal to the dimension of attractor, d_A, i.e. $d_E > d_A$. In other words, we can choose a fortiori large dimension d_E, e.g. 10 or 15, since the previous analysis provides us prospects that the dynamics of our system is probably chaotic. The correlation integral analysis is one of the widely used techniques to investigate chaos in time series. The analysis uses the correlation integral, $C(r)$, to distinguish between chaotic and stochastic systems. According to [2–4], one should calculate the correlation integral $C(r)$. If the time series is characterized by an attractor, the correlation integral $C(r)$ is related to the radius r as

$$d = \lim_{\substack{r\to 0\\ N\to\infty}} \frac{\log C(r)}{\log r}, \quad (3)$$

where d is a correlation exponent. If the correlation exponent attains saturation with an increase in the embedding dimension, then the system is generally considered to exhibit chaotic dynamics. The saturation value of the correlation exponent is defined as the correlation dimension (d_2) of the attractor (see details in Refs. [3, 4].

Another method for determining d_E comes from asking the basic question addressed in the embedding theorem: when has one eliminated false crossing of the orbit with itself, which arose by virtue of having projected the attractor into a too low dimensional space? [2–4]. In other words, when points in dimension d are neighbours of one another? In examining this question first in dimension one, then in dimension two, etc. by far there are no incorrect or false neighbours remaining, so one should be able to establish a value for the necessary embedding dimension from geometrical consideration alone. Such approach was described by Kennel et al. [16, 17]. In dimension d each vector $\mathbf{y}(k)$ has the nearest neighbour $\mathbf{y}^{NN}(k)$ with nearness in the sense of some distance function. The Euclidean distance in dimension d between $\mathbf{y}(k)$ and $\mathbf{y}^{NN}(k)$ is called $R_d(k)$ [3]

$$R_d^2(k) = [s(k) - s^{NN}(k)]^2 + [s(k+t) - s^{NN}(k+t)]^2 + \ldots + [s(k+t(d-1)) - s^{NN}(k+t(d-1))]^2. \quad (4)$$

$R_d(k)$ is presumably small when one has a lot of data, and for the dataset with N measurements, this distance is of order $1/N^{1/d}$. In dimension $d+1$ this nearest-neighbour distance is changed due to the $(d+1)$st coordinates $s(k + d\tau)$ and $s^{NN}(k + d\tau)$ to

$$R_{d+1}^2(k) = R_d^2(k) + [s(k+dt) - s^{NN}(k+dt)]^2. \quad (5)$$

We can define some threshold size R_T to decide when neighbours are false. Then if [3]

$$\frac{|s(k+dt) - s^{NN}(k+dt)|}{R_d(k)} > R_T, \quad (6)$$

(the nearest neighbours at time point k are declared false). Kennel et al. [17] showed that for values in the range $10 \le R_T \le 50$ the number of false neighbours identified by this criterion is constant. In practice, the percentage of false nearest neighbours is determined for each dimension d. The value at which the percentage is almost equal to zero can be considered as the embedding dimension.

The predictability can also be estimated by the Kolmogorov entropy, which is proportional to the sum of positive Lyapunov exponents. The spectrum of the Lyapunov exponents is one of dynamical invariants for non-linear system with chaotic behaviour. Local and global Lyapunov exponents quantify the limited predictability of chaos, which can be determined from measurements. The Lyapunov exponents are related to the eigenvalues of the linearized dynamics across the attractor. Negative values show stable behaviour while positive values show local unstable behaviour.

For chaotic systems that are both stable and unstable, the Lyapunov exponents indicate the complexity of the dynamics. Large positive values determine some average prediction limit. Since the Lyapunov exponents are defined as asymptotic average rates, they do not depend on the initial conditions, i.e. the choice of trajectory, and they do comprise an invariant measure of the attractor. An estimate of this measure is a sum of positive Lyapunov exponents. The estimate of the attractor dimension is provided by the conjecture d_L and the Lyapunov exponents are taken in descending order. The dimension d_L gives values close to the dimension estimates discussed earlier and is preferable when estimating high dimensions. If one computes the whole spectrum of the Lyapunov exponents, other invariants of the system, such as the Kolmogorov entropy and the attractor dimension can be found. The Kolmogorov entropy measures the average rate at which information about the state is lost with time. An estimate of this measure is the sum of the positive Lyapunov exponents. The estimate of the attractor dimension is provided by the Kaplan and Yorke conjecture (see details in Refs. [2–4, 16, 18]):

$$d_L = j + \frac{\sum_{a=1}^{j} l_a}{|l_{j+1}|}, \quad (7)$$

where j is such that $\sum_{a=1}^{j} l_a > 0$ and $\sum_{a=1}^{j+1} l_a < 0$, and the Lyapunov exponents are taken in descending order. The dimension d_L gives values close to the dimension estimates discussed earlier and is preferable when estimating high dimensions. To compute Lyapunov exponents, one should use linear fitted map method although maps with higher order polynomials can be used [18–23]. Another new approach was developed by Glushkov-Prepelitsa et al using the neural networks technique [25]. All calculations are performed with using “Geomath” and “Quantum Chaos” computational codes [3–11, 25–47].

Conclusions

Summing up the above said and the results of the work done [1–3], it is useful to summarize the key points into the system sequence for investigating chaos availability and wording the forecast (evolution) model for the environmental radioactivity dynamics. It should be noted that the overall difference between the modeling of environmental radioactivity dynamics and the radioactivity dynamics of usual chemical pollution of atmospheric and hydrological systems is not essential and is connected only with treating the dynamics of these systems from the viewpoint of the evolutionary theory of differential equations. The above methods are just a part of a large set of approaches (see our versions in [1–11]), which is used in the identification and analysis of chaotic regimes of the time series in the environmental radioactivity dynamics. Shortly speaking, the whole technique of analysis, processing and forecasting of any time series of the radioactive pollutants in different geospheres will look as follows (see figure 1 below):

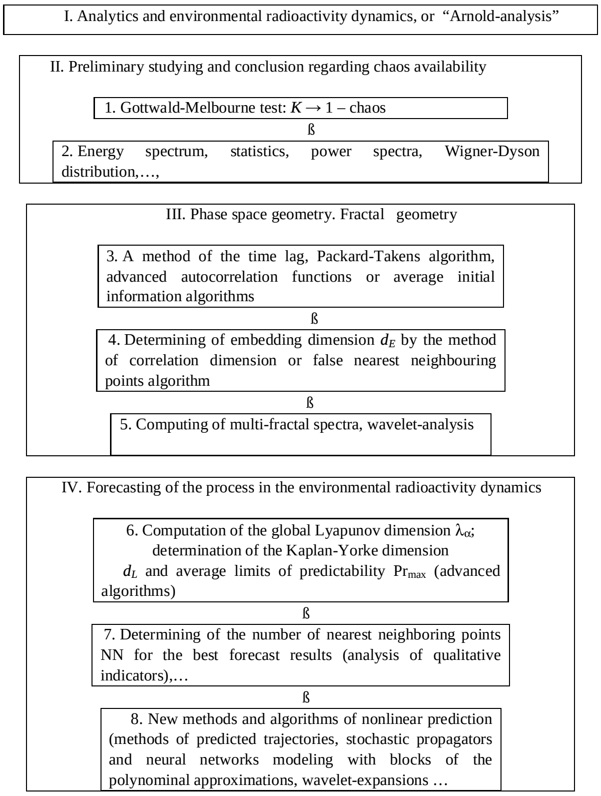

Fig. 1. General compact scheme for computation of the characteristics of the environment, radioactivity dynamics of time series and a non-linear analysis, modeling and prediction

A) General qualitative analysis of dynamical problem of typical hydro-ecological systems (including qualitative analysis from the viewpoint of ordinary differential equations, the "Arnold-analysis");

B) Checking for the presence of chaotic (stochastic) features and regimes (the Gottwald-Melbourne test; the method of correlation dimension);

C) Reducing of the phase space (choice of time delay, the definition of the embedding space by the methods of correlation dimension and false nearest neighbors algorithms);

D) Determination of the dynamic invariants of a chaotic system (computation of the Lyapunov exponent λ_α; determination of the Kaplan-Yorke dimension d_L and average limits of predictability Pr_{max} on the basis of advanced algorithms;

E) A non-linear prediction (forecasting) of dynamical evolution of the system.

The last block includes new methods and algorithms of nonlinear prediction, such as methods of predicted trajectories, stochastic propagators and neural networks modeling, renorm-analysis with blocks of polynomial approximations, wavelet-expansions [10, 11, 25]. Indeed, one should use a few algorithms at any step of studying. Naturally, if aggregate and dynamic topological invariants [1–11] are identical for two chosen systems, then evolutions of these systems are also subject to the same laws, including the same or analogous systems of differential equations. This fact is very useful especially while using such new methods and algorithms of nonlinear prediction as methods of predicted trajectories, stochastic propagators and neural modeling networks with blocks of the polynomial approximations, wavelet-expansions [1, 10, 11, 25].

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WATER RESOURCES OF UKRAINE: USAGE, QUALITIVE AND QUANTITATIVE ASSESMENT (WITH DETAILE DESCRIPTION OF ODESSA REGION)

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Abstract. The level of pollutant in river and reservoirs water in Ukraine is rather high. The assessment of the modern state of water resources in the different regions had been done. In generally it was determined that water infrastructure in Ukraine needs reconstruction. New State Program of Water Management Conception and new Law about water management up to 2020 had been approved. Nine basins committees were organized. Committees are composed of representatives of science, practical specialists and the public. The main directions of this Program were supported by World Summit on Sustainable Development.

Key worlds: Ukraine water resource, water quality, assessment, remediation

1. Introduction

The level of pollutant in river and reservoirs water in Ukraine is rather high. So, it is one the most important ecological problem. In Ukraine surface water objects embrace of 24,1 thousands km^2 (about 4 per cent from country area). The volume of potential fresh water recourses is 209,8 km^3 year^{-1}, 75 per cent from this volume is transit water coming from Russia, Byelorussia and Romania. It is necessary to organize optimal regime of water using, assessment and remediation.

2. Relevance and methodology

The problem of the drinking water quality is very important in Ukraine at present time. For the understanding of the modern situation and water resources status available data set was used, retrospective analyses was done according the laws of Ukraine and main directions of with New State Program of Water Management Conception.

3. Discussion

The water resources of Ukraine consist on surface and underground water. The surface water is 24,1 thousands km^2, it is 4 % from common area of Ukraine. There are rivers, lakes, water pools, reservoirs and canals. The most important objects are rivers. There are more then 63 thousands rivers in Ukraine. The big ones (the catchments area is more 50 thousands km^2) – 9, the middle (catchment area is from 2 to 50 thousands km^2) – 87. For population and economic needs 1103 artificial reservoirs (common volume is more 55 billions m^3), near 48 thousands reservoirs and 7 big canals 1021 km long have been done. Average volume of renewable water resources consists on 95,2 km^3 per year (2,01 thousands m3 per capita per year) They are include local runoff – 54 billions m3 per year and inflow – 40,5 billions m^{3}per year. The local formation river runoff for 1 km^2 is important index. In the most provided by water resources regions this index consists on 618–225 thousands km^3 per year (Zakarpatska, Ivano-Frankivska and Lvivska oblast). In the poor provided regions this index consists on 5–23 thousands km^3 per year (Mikolaevska, Zaporizhska, Odeska, Khersonska oblast). Water availability of 13 regions that cover 60 % of the country area is less than average level 86,8 thousands km^3 per year [1]. Forecast resources of underground water consist of thousands 71,7 m^3 per day including water with mineralization up to 1,5 g/dm^3 (drinking water) is 57,5 m^3 per day. There is 1,27 m^3 per day per capita from Forecast resources of underground water and 0,27 m^3 per day per capita as an operational stocks of underground water. [2].

Without Danube the total rivers run off is 87,7 km^3 year^{-1} (average data) in shallow water – 55,9 km year^{-1} (Fig. 1).

The Fig. 1 shows zoning Ukraine's area with main river basins [3]. There are 63119 rivers (including 9 big rivers, 81 – middle and 63029 – small), 1137 artificial reservoirs (with total volume about 55 billion m^3), 40000 artificial pools and 7 canals 1021 km long had been done [4].

In average per capita withdrawals consist on 1,9 thousands m^3, (without transit run off), in shallow wateryear – 1,22 thousands m^3. Per day in average it consist on 5,2 m^3.

There is water deficit in the south-eastern part (from 120 – 400 m^2 per person year^{-1}, ground water includes). It is to 15 – 20 times less than in the western part. The most clean water also in the western part of the country (Fig. 2).

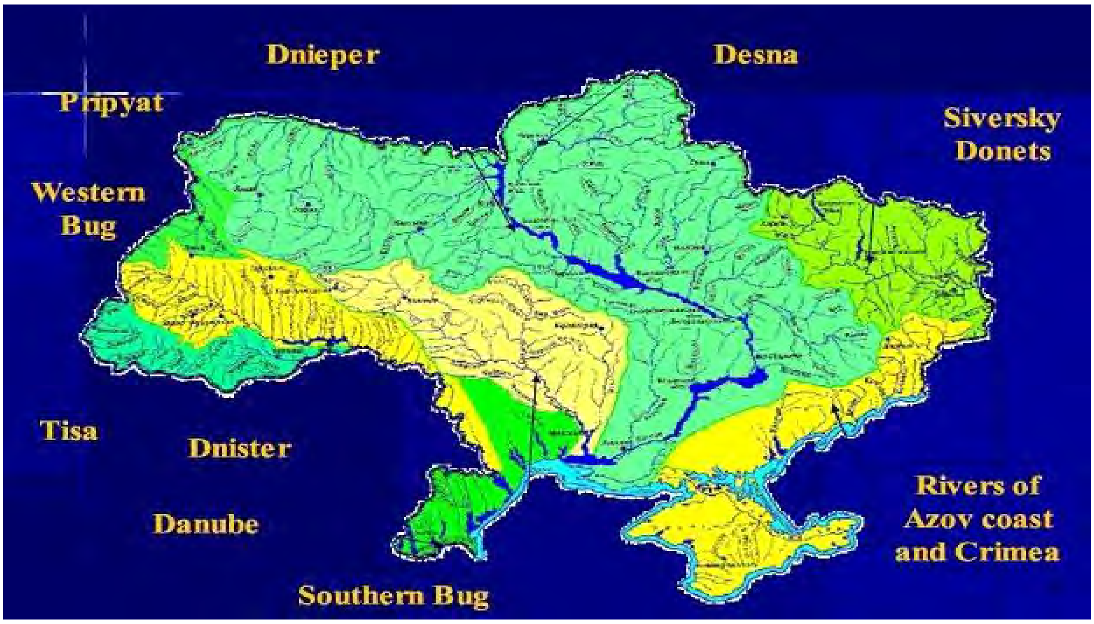


Fig. 1. Main river basins of Ukraine [3]

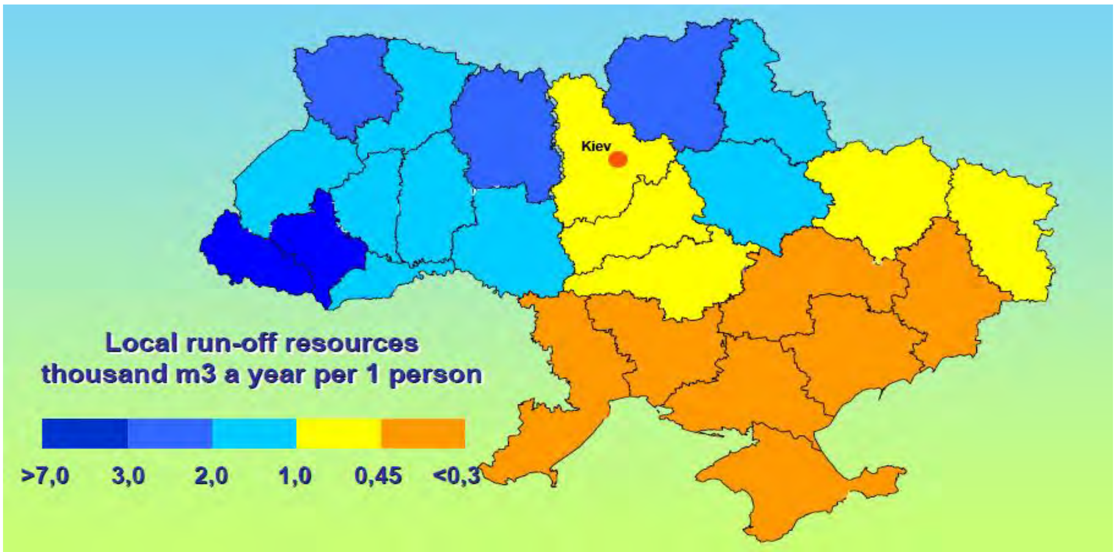


Fig. 2. Regionalized water supply, using data from [5]

Ukraine is one of the low-flow regions in Europe. In Ukraine in the Black sea lowland area there is water deficit problem for drinking, domestic and irrigated water using. Besides, the quality of surface and underground water sometimes is not good enough for drinking, domestic and irrigated water. It is linked with small hydrographic net, degradation of the small rivers (2000 small rivers disappeared), landscape and climatic features of steppe area, small part of fresh underground water and huge anthropogenic press to the water resources.

Per capita withdrawals Ukraine occupies the last place among the former Soviet republics, 70 per cent of population using surface water from the rivers, lakes and artificial reservoirs, 30 per cent – using ground water. The main source of the drinking water is the Dnieper River, but 70 per cent quality of the water does not meet health standards.

The agriculture area in Ukraine is 41576 southern hectares (68 per cent from the total country area). Irrigated area is 2175 southern hectares (5 per cent from the total country area). After Soviet period irrigated area is sharply decreasing (from 2175 to 600 southern hectares in 2010) [6]. It is necessary to increase the irrigated area in southern part of the country up to 1,5 million hectares avoiding dependence on climate condition. It is planning to use the rivers water. Mostly classification of water quality corresponds to the IV–V classes (by chemical and bacterial condition) [7]. The dirtiest regions (drinking water characteristics) are Dnieper river basin, Siversky Donets, Azov rivers basin, Dniester tributaries and Western Bug. The Fig. 3 shows fresh water consumption dynamics, it indicates strong decreasing tendency of water consumption for industrial sector and soft ones for agricultural and housing infrastructures since 1990 (Fig. 3) [5]. More detailed data for 2005–2010 is given in Table 1.

Table 1

Dynamics of water consumption in Ukraine in a period 2005–2010

Characteristics	Year						
	2005	2006	2007	2008	2009	2010	Average
The total amount of water used, km^3:	8,7218 *100 %*	8,5976 *100 %*	9,2201 *100 %*	8,580 *100 %*	8,7195 *100 %*	9,0942 *100 %*	8,8222 *100 %*
– Drinking water	2,409 *27,62 %*	2,298 *26,72 %*	2,192 *23,77 %*	2,103 *24,52 %*	1,956 *22,44 %*	1,917 *21,08 %*	2,145 *24,19 %*
– Industry	4,878 *55,93 %*	4,872 *56,68 %*	5,167 *56,04 %*	5,045 *58,80 %*	5,149 *59,05 %*	5,511 *60,62 %*	5,104 *56,35 %*
– Agriculture for irrigation	1,186 *14,00 %*	1,181 *13,74 %*	1,625 *17,63 %*	1,224 *14,26 %*	1,411 *16,18 %*	1,477 *16,23 %*	1,351 *15,34 %*
– Agriculture for water upply	0,2488 *2,85 %*	0,2466 *2,86 %*	0,2361 *2,56 %*	0,208 *2,42 %*	0,2035 *2,33 %*	0,1892 *2,07 %*	0,222 *2,52 %*

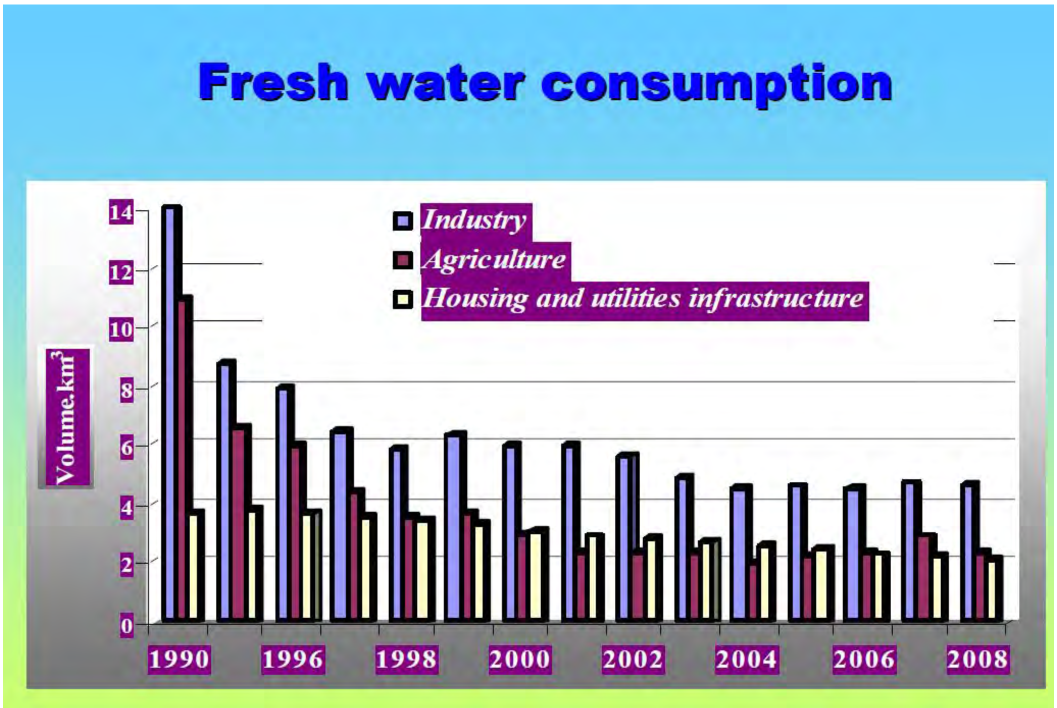


Fig. 3. Fresh water consumption, using data from [5]

According to the National Report of Ukraine 2013, water resources for economic needs are 15 – 16 billions m^3 annually. The main consumers of water are industry – 36 %, agriculture – 41 %, utilities – 23 %.

According to the National Report (Kiev. Ministry of Housing of Ukraine. Drinking Water Quality and State of Water Supply in Ukraine. 2009. National report. 2010. – 710 p. [7] "The consequences of climate change. Ukraine" the air temperature in Ukraine rise by 5–8 ^oC the problem with deficit water will be take place. Increasing of precipitation in winter and droughts – in warm period will take place also as a result of climate change. Decreasing of underground water provokes deterioration of water quality. In the southern regions extremely hot summers provokes intensity euthrophication processes that limits the normal function of wastewater treatment plants. The degree of pollution of surface waters is shown on Fig. 4 [8].

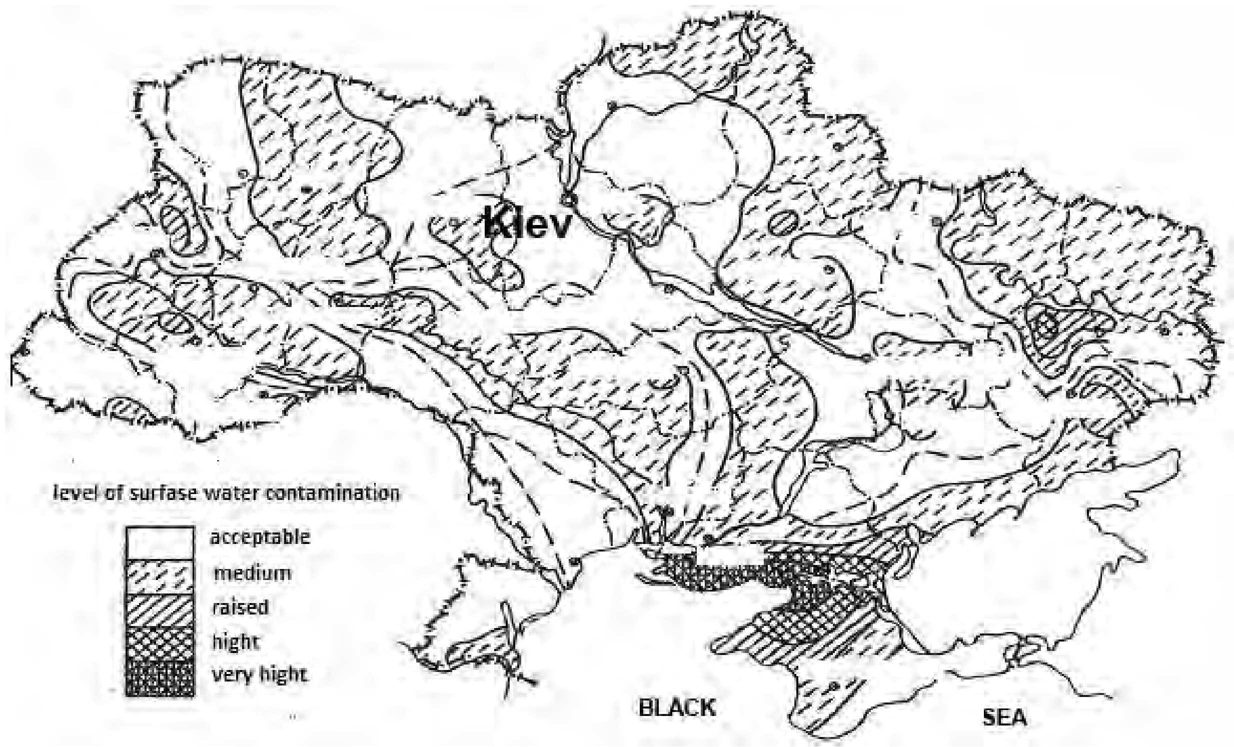
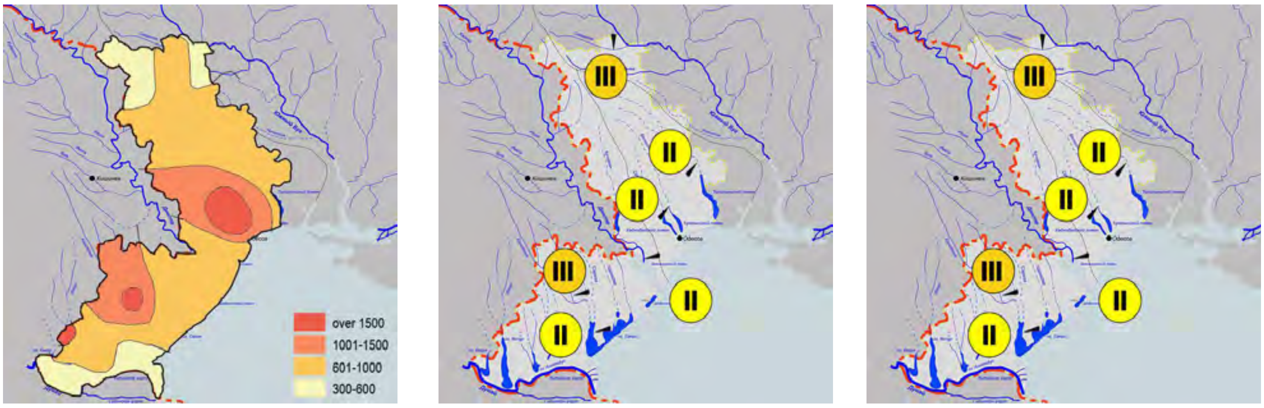


Fig. 4. The degree of pollution of surface waters [8]

The system of water conditioning does not meet modern requirements. For instance, the main method of water disinfection is water chlorination. It is linked with the formation of organochlorine compounds that is very dangerous for the human health. In all the cities of Ukraine deterioration (age progress) of water supply systems achieved 60–70 per cent. As a result of constant interruptions to the supply of water are the secondary contamination of drinking water and the cause of proliferation of harmful microorganisms, blue-green algae, development of corrosion.

Since the southern part of Ukraine has the worst water supplies it is necessary to implement local water quality and quantity assessment for a region within this area. The Odessa region is located in the Southern part of Ukraine. Mild climate and Black Sea make prosperous environment for development of different economic sectors. However from on the other hand these circumstances lead to increasing of anthropogenic influence on the environment. It is significant that water bodies are among different environment components are affected with anthropogenic influence as well.

In general Odessa region's hydrographic network covers basins of several rivers: Danube (24 per cent), Dniester (16 per cent), Uzhny Bug (8 per cent). At the same time water supplies distribution is very irregular, moreover the water supply of 50 % region population lives in Dniester region. It is possible to describe water quality by two sides it should include conditions of surface water and ground water. Water quality can describe with some indexes that indicate mineralization, tropho-saprobiological and toxic pollution. The highest mineralization level was measured in Kuialnitskiy, Hadzhibeevskiy firths (liman – local names) and in the of Sasik Lake. Toxic tropho-saprobiological indexes of water correspond to the second and the third quality classes (the first class is the best quality, the fifth - is the worst) that means the water quality in the Odessa region is satisfactorily (Fig. 5).



a) b) c)

Fig. 5. Water quality indexes: a – mineralization levels; b – tropho-saprobiological indexes of water quality; c – toxic pollution indexes of water quality

The water supply quality in Odessa city depends on water level at Dniester River and has annual periodicity. For example in 2009 high water levels were registered in April – May and low water levels were registered in August – October (Fig. 6) [10]. As for majority indexes Dniester water quality corresponded to the second quality class it means that the fresh water supply needs prior purification.

Regarding provision of the population with expected drinking groundwater resources, the Odessa and Mykolayiv provinces (Oblasts) have the lowest values, and the Kherson Oblast – the highest values (second only to the Chernihiv Oblast): the Odessa province – 0.28 m^3 daily per capita, the Mykolayiv Oblast – 0,33 m^3 daily per capita, the Kherson Oblast – 4.01 m^3 daily per capita (the average for Ukraine is 1.27 m^3 daily per capita). As regards provision of the population with commercial drinking groundwater resources, the Odessa and Mykolayiv Oblasts are also characterized by the lowest rates, and the Kherson Oblast – by the highest rates in Ukraine: the Odessa Oblast – 0.18 m^3 daily per capita, the Mykolaiv Oblast – 0,06 m^3 daily per capita, the Kherson Oblast – 0,74 m^3 daily per capita (the average for Ukraine is 0,33 m^3 daily per capita) [9].

The hygienic aspect of drinking groundwater safety and quality can be defined by the indices of epidemic safety, sanitary, chemical and radiation indices, as well as the optimal content of mineral substances, i.e. a mineral composition adequate to the physiological need of a human organism: total hardness, total alkalinity, the content of iodine, potassium, calcium, magnesium, sodium, solid residual and fluorine. Deviation from optimal value range is typical for almost all the identifiable parameters of balanced mineral composition of groundwater in the industrial-and-urban agglomerations of the Northwestern Black Sea Regions (Odeska, Mikolaevska, Khersonska oblast), yet after the groundwater treatment calcium, magnesium and sodium concentrations are significantly decreased, which further provokes development of the diseases associated with deficiency of these elements. Additional treatment of groundwater only partially solves the problem of balancing the mineral components of drinking water, and in some cases may even aggravate the problem. Fluoride concentration in drinking water from surface and ground sources of water-supply does not reach the minimum standards that require substantiation of appropriateness to perform the water fluorination, use fluorinated toothpastes and other means of prevention of caries and other diseases among public at large. Long-term consumption of drinking groundwater with an imbalance of the mineral composition can be one of the negative impact factors for the public health, so there is a need for further special studies [11].

The ground water is more protected from the different anthropogenic impacts in comparing with surface water bodies. It is gives some advantages for usage ground water as fresh water supply. The assessment of ground water is more difficult in comparison to surface water. So it is necessary to distinguish ground water into two categories: potential supplies and exploited supplies. The surface and ground water supply in the Odessa region are distributed irregularly as well as. The reason is the Odessa region has various geological structures. The assessment of potential water supplies of Ukraine is about 0.19 m^3 day^{-1} per capita. Zoning of the Odessa region by potential and exploited ground water supply was implemented with cluster analysis and revealed that

Southern part of the region including Odessa city had better exploited but worst potential ground water supply (Fig. 7, 8). In general (for 2005) exploited supplies were 405010 m^3 day^{-1} and potential supply was 805500 m^3 day^{-1}. It is also very significant that ground water supply has also irregular vertical distribution.

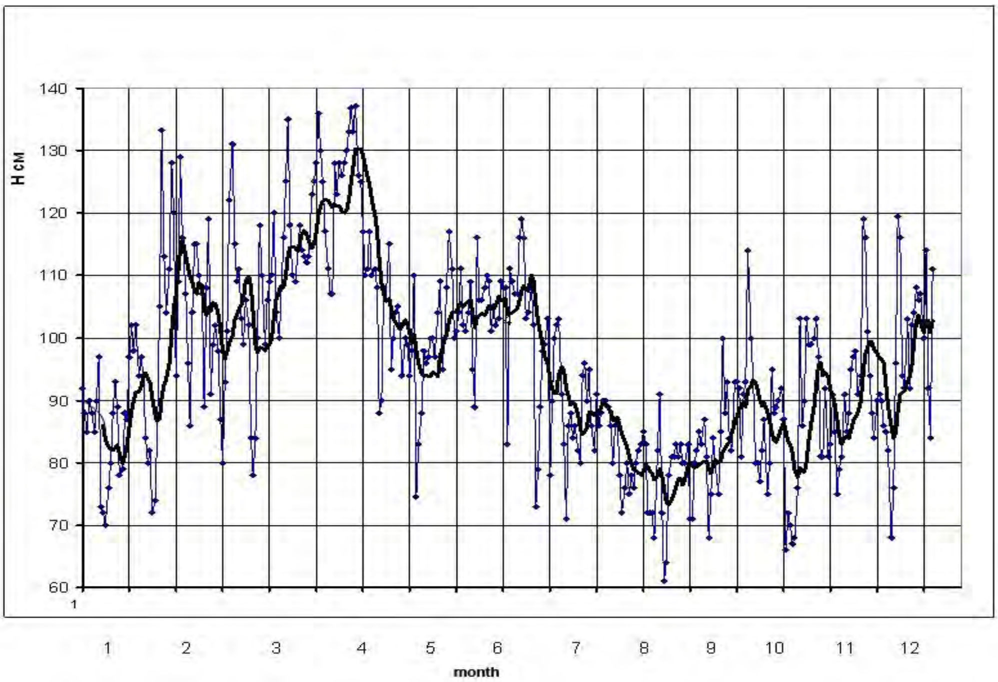
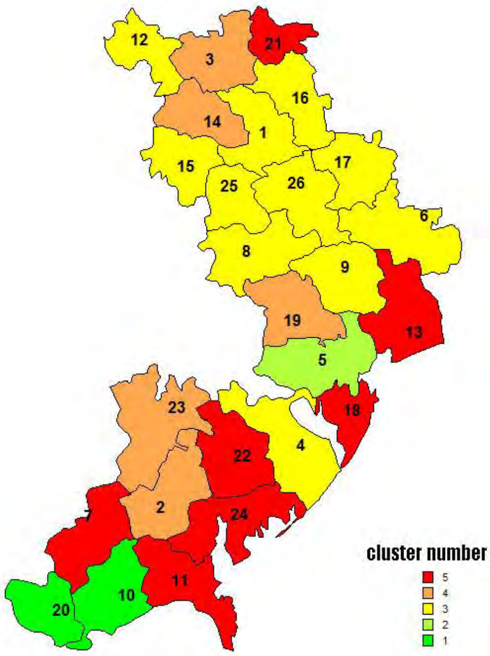


Fig. 6. Daily average water levels of Dniester river in 2009 (Measurement point in Mayaki village) [10]



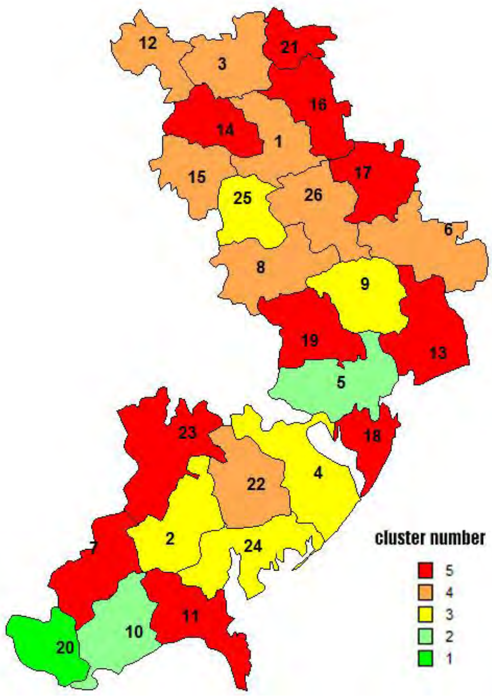


Fig. 7. Zoning of Odessa oblast's potential ground water supply by cluster analysis

Fig. 8. Zoning of Odessa oblast's exploited ground water supply by cluster analysis

Numbers correspond administrative districts: 1 – Ananivskiy, 2 – Arcizckiy, 3 – Baltskiy, 4 – B-Dnistrovskiy, 5 – Biliaevskiy, 6 – Berezivskiy, 7 – Bolgradskiy, 8 – Velikomichailovskiy, 9 – Ivanivskiy, 10 – Izmailskiy, 11 – Kiliyskiy, 12 – Kodimskiy, 13 – Kominternivskiy, 14 – Kotovskiy, 15 – Krasnooknianskiy, 16 – Lubashivskiy, 17 – Mikolaevskiy, 18 – Ovidiopolskiy, 19 – Rozdilnianskiy, 20 – Reniyskiy, 21 – Savranskiy, 22 – Saratskiy, 23 – Tarutinskiy, 24 – Tatarbunarskiy, 25 – Frunzovskiy, 26 – Shiriaevskiy

The water supply infrastructure in the Odessa region is based on surface water bodies and ground water as well. For example in 2009 water consumption was distributed between fresh water consumption – 37,8 per cent; irrigation – 22,1 per cent; industry needs – 18,9 per cent, fishery needs – 16,9 per cent, agricultur**e** – 3,8 per cent, other – 0,5 per cent.

The wastewater amount (2009) was about 303,4 million m^3. The pollution comes to water bodies mainly from municipal sector that was about 53,2 per cent of total wastewater amount. Contamination of surface and ground water reflects on the Black Sea. About 82,7 million m^3 of the Odessa city sewage comes to Black Sea without proper purification. Unfortunately centralized wastewater management system functioned in a proper way only in 45,1 per cent of towns in the Odessa region according to 2010 statistical survey.

4. Conclusion

The main conclusions can be defined with three points:

At present time Water Infrastructure in Ukraine needs reconstruction. The fist task is water quality. It is necessary to coordinate efforts for the problem decision with international institutions, UN and EU to organize monitoring and water management.

The government of Ukraine approved New State Program of Water Management Conception and new Law about water management up to 2020. This document is the practical tool of realization the sate politic for water protection (surface, ground- and sea water), water ecosystems and management of water resources.

Nine basins committees were organized. Committees are composed of representatives of science, practical specialists and the public. The main directions of this Program were supported by World Summit on Sustainable Development.

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Vol. 1, No. 2, 2016

PROSPECTS OF USING METHODS EFFECTIVE USE OF ALTERNATIVE ENERGY

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Abstracts: The article presents the possibility of the development of science-based concept of integrated processes complex enterprises energy mix (alternative energy and polymer wastes). A review of the literature and the necessary articles written on the subject: as technologies and economies develop and become more complex, energy needs increase greatly; types and methods of alternative energy, as well as the possibility of calculating the basic set of main economic indicators are classified; identified possible areas of work in obtaining the necessary information and results. The results of studies of complex innovative projects conducted as inter-university cooperation.

Key words: environmental safety, alternative energy, complex projects, polymer wastes, estimation criteria, scientifically grounded processes

Introduction

In this, we discusses phase of work in NTU "KhPI" – studies the possibility of increasing the economic efficiency of alternative energy sources. A review of the literature and the necessary articles written on the subject:

1. As technologies and economies develop and become more complex, energy needs increase greatly.
2. Types and methods of alternative energy, as well as the possibility of calculating the basic set of main economic indicators are classified.
3. Identified possible areas of work in obtaining the necessary information and results.

Energy is a fundamental input for economic systems. Current economic activity depends overwhelmingly on fossil fuels including oil, coal, and natural gas. Solar or wind energy stored in firewood or other biomass energy meets other basic needs for home heating and cooking.

A review of the literature alternative energy

Each stage of economic development has been accompanied by a characteristic energy transition from one major fuel source to another. Today, fossil fuels – coal, oil and natural gas –are by far the dominant energy source in industrial economies, and the main source of energy production growth in developing economies (see Fig. 1) [1]. But the twenty-first century is already seeing the start of the next great transition in energy sources – away from fossil fuels towards renewable energy sources. This transition is motivated by many factors, including concerns about environmental impacts (particularly climate change), limits on fossil fuel supplies, prices, and technological change. Solar energy comes in three basic forms [2]: low temperature solar thermal; solar electric or photovoltaic (PV); high-temperature solar thermal energy.

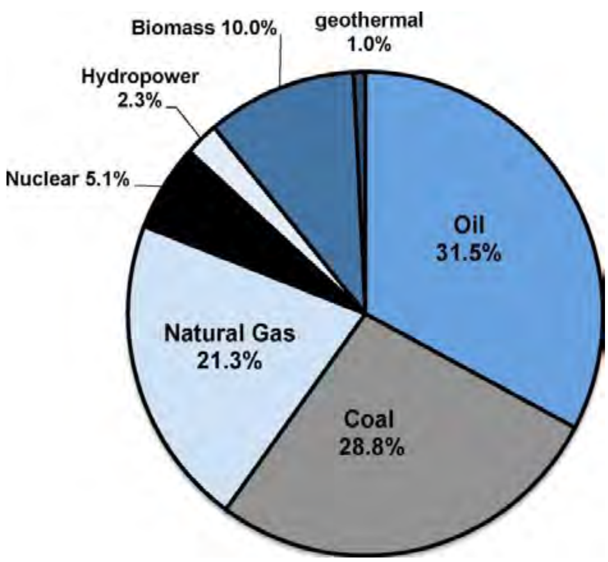

Fig. 1. Global Energy Consumption by Source, 2011 Source: International Energy Agency (IEA 2013)

Like biomass and hydropower, wind power has been used since ancient times. On the best sites, modern electricity production from wind is very close to cost parity with sources like coal and nuclear power. But there is a big difference between wind power cost on the best sites and on less suitable sites. Wind power is generated by the energy in moving air, and available energy varies with the cube of wind velocity [1–5].

The authors then estimate the infrastructure that would be necessary to supply all energy worldwide from WWS in 2030. Table 1 presents their results, based on the assumption that 90 % of global energy is supplied by wind and solar, and 10 % by other renewables. The efficiency of a solar collector depends on the ability to absorb heat and the reluctance to lose heat once absorbed. Fig. 2 presents principle of energy flows in a solar collector [3].

Table 1

Infrastructure Requirements for Supplying All Global Energy in 2030 from Renewable Sources

Energy Source	Percent of 2030 Global Power Supply	Number of Plants/Devices Needed Worldwide
Wind turbines	50	3,800,000
Wave power plants	1	720,000
Geothermal plants	4	5,350
Hydroelectric plants	4	900
Tidal turbines	1	490,000
Rooftop solar PV systems	6	1.7 billion
Solar PV power plants	14	40,000
Concentrated solar power plants	20	49,000
TOTAL	100	

Source: Jacobson and Delucchi (2011) [2].

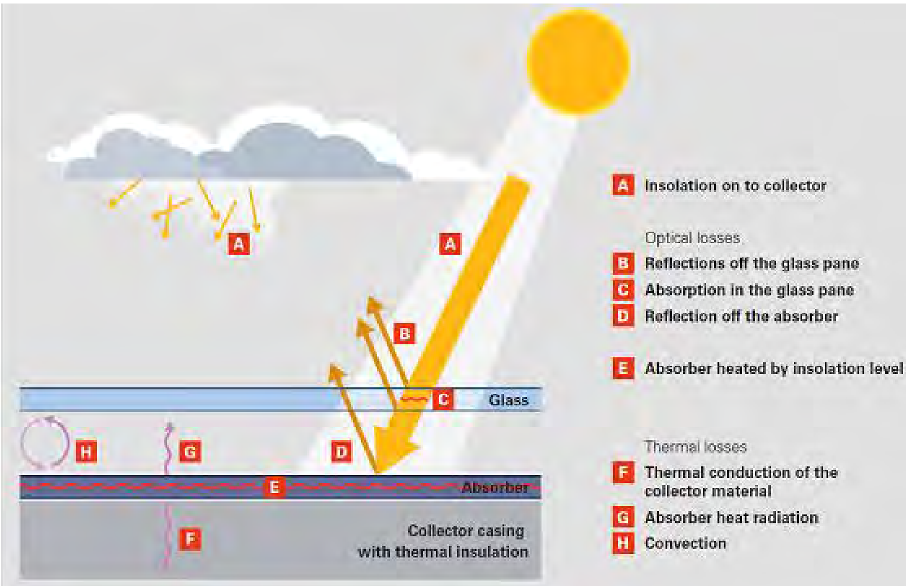

Fig. 2. Principle of energy flows in a solar collector [3]

A simple way to calculate the efficiency is to use equation 1 [4]:

$$h_c = h_0 - a_1 \frac{(T_m - T_a)}{G} - a_2 \frac{(T_m - T_a)^2}{G} \qquad (1)$$

where h_c – collector efficiency; G – total (global) irradience on the collector serface [W/m^2]; T_m – mean collector fluid temperature [°C]; T_a – temperature of the ambient air [°C].

A review of the experimental research alternative energy together with the students

Most renewables are less available and/or have higher costs than fossil fuels used in the recent past. The costs of renewable energy resources are attributable in part to inherent characteristics, particularly their low net energy ratios, intermittent availability, and capital intensity.

Development of new technology will reduce cost but may not make renewable energy cost competitive with market prices of fossil fuels in the near future unless fossil-fuel externalities are considered. The speed of the transition to renewable energy will be highly influenced by policy choices; potential policies include increasing energy research and development expenditures, feed-in tariffs, and renewable energy targets (Table 2).

These questions was designed together with the students, as complex and innovative projects in the student scientific society – is the third stage of the work in NTU “KhPI”. Attraction to address environmental problems in Ukraine public student organizations in the process of learning in higher education will allow them to prepare in the future society of Ukraine to the organized collection of various types of waste. Our work is focus on evidence-based choice of integrated energy of different origin – alternative energy (AE) (Fig. 3, 4) and energy waste. This will reduce, primarily, the total amount of waste to be disposed of in landfills or polluting harmful emissions. This approach allows using the resource potential of these types of waste, and creating conditions for compliance with legal, health and environmental, economic and organizational aspects of the problem of waste management in general.

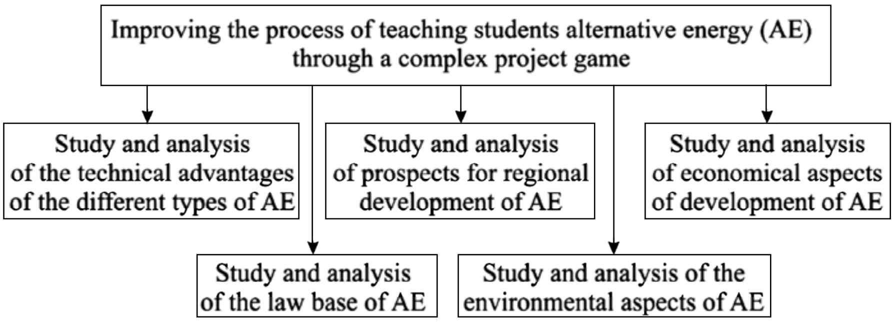

Fig. 3. Improving the process of teaching students

Table 2

Transparent materials in different areas of the solar spectrum-comparative characteristics of materials panels for solar collector

Materials for the pane	Wavelength, microns			
	0,295–0,400	0,400–0,750	0,750–2,000	5–15
Polyethylene film with stabilization	26	80	80	80
PVC film	22	88	88	10
Polyamide film	73	87	88	30
Fiberglass	4	80	85	2
Glass	46	83	83	0

While working to develop the principle of evaluating the effectiveness of the use of funds expended primarily for the construction of a particular object of alternative energy. For example, the methodology to calculate the allocation of public funds for the expansion of the subsequent reinvestigation innovation construction by depreciation and profits, which are formed in the process of the wind power plant (Fig. 3).

The total number of articles, papers in international and other conferences, study guide, tutorials, and guidelines for students – more than 30 are prepared and published.

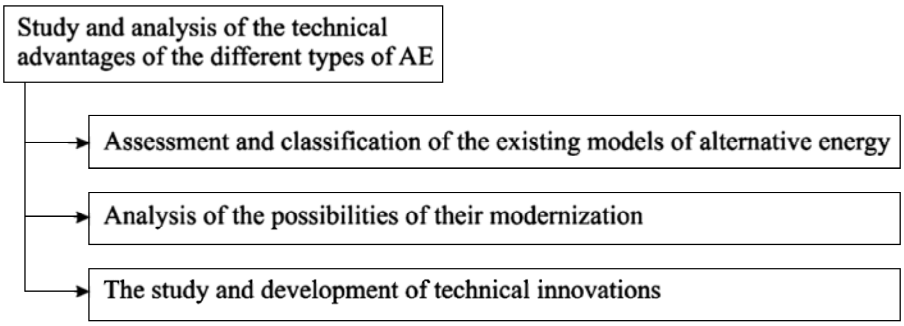

Fig. 4. Study and analysis the process of teaching students

The global system of education is in a state of crisis, which is cause by both internal and external to its factors. For Ukraine, this transition to a market economy, a high level of unemployment among university graduates, especially in the economic crisis, sharply exacerbated the problems and opportunities for young people to find their niche in the job market, highlighted lack of preparation of graduates for the real organizational and technical activities.

Description of the problem to be solved.

The problem of learning the practical skills of the students in higher education, even in the most modern of techniques, it is very difficult to solve. Creating the conditions for training students for the acquisition of the necessary competencies for life will contribute to the competitiveness of graduates in the labor market; the key competence can facilitate their participation in the development of the democratic principles of society.

Ways and means to the development of solar and wind energy and the environment are widely used in the EU. This is linked to the development effectiveness environmental management and legislation. Such experience is required at the stage of Ukraine training students in high school. University graduates, getting on the company as experts will have a modern legal framework, national programs of the EU.

In order to integrate Ukraine into the EU and for the realization of our project to the following questions:

1) classification of wind power plants in terms of investment;

2) classification of wind power plants in terms of economic efficiency;

3) the classification of solar energy in terms of investment;

4) classification of solar sources energy in terms of economic efficiency

5) classification of types of polymer waste as an alternative energy source;

6) analysis of the experience of wind, solar and polymer waste systems for use in Ukraine.

The problem of wastes utilization and recycling is present as complex research and analysis of energy- and resource saving processes for treatment of polymer wastes of various origin [6–11].

Energy is a fundamental input for economic systems. Current economic activity depends overwhelmingly on fossil fuels including oil, coal, and natural gas. These fuels are non-renewable. Renewable sources such as hydroelectric, wind, and solar power currently provide less than 10 % of global energy.

Conclusions

Many sources of renewable energy are available, and have been used for centuries. Most renewables are less available and/or have higher costs than fossil fuels used in the recent past. The costs of renewable energy resources are attributable in part to inherent characteristics, particularly their low net energy ratios, intermittent availability, and capital intensity. Development of new technology will reduce cost but may not make renewable energy cost competitive with market prices of fossil fuels in the near future unless fossil-fuel externalities are considered.

The speed of the transition to renewable energy will be highly influenced by policy choices. Potential policies include increasing energy research and development expenditures, feed-in tariffs, and renewable energy targets. Public policy can also aid in providing capital for renewable energy projects, and in providing a robust electricity grid for moving energy long distances.

Discussion questions for students:

1. In general, how do renewable energy sources differ from fossil fuels, i.e. what are some common characteristics of renewable energy sources that are different from characteristics of fossil fuels used in the past?

2. Explain the renewable energy sources principle in your own words. How would this apply to developing a portfolio of renewable energy sources in your home region?

3. Is energy conservation likely to be more important in a renewable energy economy than it has been in the past? Explain.

4. Hydropower is currently the largest source of renewably generated electricity in the world, and there is potential for expansion. In some parts of the world, a renewable energy portfolio could be based on hydropower and energy conservation alone. Yet hydropower is also controversial, chiefly because of associated negative externalities. Describe some of these. Do you think more hydropower should be developed in the world?

5. How would you decide whether or not to develop a particular hydro project?

6. Why does public policy have such a prominent role in promoting renewable energy use, and in accelerating the transition to renewable energy?

7. What public policy approaches do you think will be most effective?

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REDUCING ENERGY CONSUMPTION AND REDUCING CO_2 EMISSIONS OF COKE PLANT

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Abstract. The efficient energy use of Coke Oven Plant is considered in this paper. The main objective is the reduction of energy consumption and reducing CO_2 emissions per production unit by use of waste heat for various needs of production site demands. The considered process consumes the external hot utilities 25.4 MW and cold utilities 24.9 MW. The use of waste heat for district heating and hot water supply allow reducing the external cold utilities by 23.5 MW. This heat can be used for heating of 1,869,825.6 m^3 in apartment buildings, municipal facilities, shopping malls and etc. The use of waste heat from flue gases for electricity production allows obtaining additionally about 7.5 MW of power that can be utilized for production needs and exported outside. The provided case studies show the pathway for an efficient retrofit of coke production and most profitable ways for investment.

Key words: Coke industry, waste heat, Total Site Integration, district heating, Energy efficiency in industry, CO_2 emissions.

1. Introduction

Due to the stable trend towards increasing the price on energy and high competition in energy-intensive industries, the problems of energy conservation in industry have become exclusively important. The most important point is the reduction of energy consumption in chemical and metallurgical industries, where the energy prices are the basic component of production cost. In recent years, Ukrainian enterprises have significantly reduced the steel production compared to 2011 by 17 % and cast iron by 15 % [1]. It is connected with a low energy efficiency of production but not only in metallurgical sector. The same situation is in the coke industry which is in production chain with metallurgy. In Ukraine, due to needs of extensive Metallurgical Industry 14 Coke-Oven factories have been set in operation. All of them were designed and built at the time of rather cheap energy resources and the design approaches did not pay attention to efficient energy use. Now all this factories, as a rule, are working far from optimum operation mode [2]. Reducing emissions is also an important challenge. For example, in 2011 Avdeevka Coke factory had 17759 tons of the harmful emission [3].

There are a lot of approaches in literature for utilization of waste heat of chemical processes that allow increasing the energy efficiency. Guang-yu M.A. et al have conducted analytical Research on utilization of waste heat of China and developed recommendations how to reduce the energy consumption for Iron & Steel Industry [4]. Shushuo Kang et al. in their work proposed a new utilization approach of the waste heat with mid-low temperature by integrating the CHP system and the ground source heat pump (GSHP) [5]. Gbemi Oluleye et al. present a ranking criterion for evaluating opportunities that utilize recovered energy from the available waste heat in process sites. Application of this methodology for petroleum refinery allowed to reduce the operating cost and CO_2 emissions by 26 % and 18 %

respectively when opportunities to use the recovered energy from waste heat within and outside the process site boundaries are explored [6].

Waste heat of the furnace, which is ejected from the flue gases can be used to generate electricity. Gabrielyan D.A. et al. have examined the potential use of magnetothermal power devices for recycling the waste heat from oil and gas companies and other waste heat sources [7]. Anton A. Kiss et al. proposed a novel selection scheme of energy efficient distillation technologies, with a special focus on heat pumps [8]. Hjaranson H. et al. described the application of the Rankine cycle to generate electricity at the ferrosilicon plant in Iceland [9].

There is high energy consumption for district heating needs in countries with a cold climate, such as Ukraine. Therefore, the potential of heat utilization for district heating must be considered. Fang Hao et al. have demonstrated potential for using low-grade industrial waste heat for district heating [10]. Jelena Ziemele et al multi-criteria model is developed to determine efficiency rating of the DH system [11]. Dario Brando et al considered the influence of the district heating temperature on the electric efficiency. . The results have highlighted that a decrease of the DH network temperature of 10 °C can improve the electric efficiency of the ORC generator of one percentage point [12].

Methods of increasing efficiency of Coke Plant by means of coke oven gas and coal gas using well described. For example Bermúdez et al. proposed a novel method of producing methanol from coke oven gas (COG), involving the CO_2 reforming of COG to obtain an appropriate syngas for the synthesis of methanol [13]. Lin et al. in the work offered a new polygeneration system with carbon capture is integrated, based on coal gas and coke oven gas inputs for methanol and power co-production. New system can achieve more than 5 % of primary energy saving ratio, and more than 50 % of exergy efficiency [14].

Formerly, Benzene Hydrocarbons Extraction and Coal Tar Distillation processes were examined by Tovazhnyansky et al during an inspection of Avdiivka Coke Plant [15]. With the help of stationary and portable devices, the measurements of process streams parameters were made. Next parameters were measured: streams temperatures, stream flow rates and compositions of the waste gases of the furnace. Cooling water stream flow rates and temperature of cooling water were measured as well as fuel consumption in the furnaces.

Partite integration of Coke Production processes were considered in the previous researches by Tovazhnyansky L et al that presented the research for reduction of energy consumption of Coal Tar distillation unit [15]. Later, Tovazhnyansky et al. presented the research for reduction of energy consumption of separation of crude benzene at a one-column unit [16] and separation of crude benzene on a two-column unit [17] that has shown the reduction of energy consumption by 19 %. Ulyev et al. use the total temperature profiles of the production complex for estimation of the target energy values for several processes [18] and also to consider the possibility of integration for a heat pump within the overall production complex [19]. The use of Grand Composite curves and Total Site Profiles has demonstrated the possibility of heat pumps integration, which allows decreasing the external hot utilities usage by 27 % and cold utilities usage by 26.7 %, respectively [19]. However, there is still a considerable potential of utilization of waste heat of the considered processes. Mentioned processes consume the external hot utilities 25.4 MW and cold utilities 24.9 MW after heat integration of several production units [19]. The utilisation of waste heat for different needs considered in this paper.

There are some systematic approaches for the system design of chemical processes that allow to recycle waste heat.

The first is mathematical programmingthat is is divided into linear and nonlinear [20]. The task of linear programming is to find the minimum (or maximum) linear function with linear constraints. So, Yang Y. et al. used a linear programming for optimal design of district-scale distributed energy resource systems. The proposed distributed energy resource systems are found to reduce the total annual cost by 14.1 % [21]. However, in the most engineering problems of mathematical models cannot be reduced to a linear programming problem. Most mathematical programming tasks that occur in research projects and in designing tasks – a problem of nonlinear programming. Holtbruegge J. et al. provided a memetic optimization algorithm and verified its ability to handle such problems by optimizing a benchmark function. This study has shown that alternatives using reactive dividing wall columns can improve economics for industrial scale production of dimethyl carbonate and propylene glycol process up to 35 % over the base-case process [22]. However, in the design of heat exchange systems and heat recovery systems for industrial plants, there are too many variables, which greatly complicates the use of mathematical programming for this purpose.

The second direction that allows to consider the integration of the production complex is Total Site Analysis (TSA) [23]. Dhole and Linnhoff demonstrated the potential for expanding of the Heat Integration concept from individual process level to a Total Site (TS) level, which comprises of several production processes or industrial clusters. [23]. Fodor et al. modified Total Site Heat Integration (TSI) methodology and shown the possibility of using the graphical methodologies and demonstrates using an industrial case study the implementation of a total site methodology using a stream specific ΔT_{cont} approach. The procedure allows making differences between heat transfer in the process streams inside the process and between process to utility and vise versa [24]. The paper Liew et al. demonstrated new method for calculating multiple utility levels in the Problem Table Algorithm. We further demonstrated that the Total Site Problem Table Algorithm yields more accurate results for Total Site Heat Integration analysis when compared with a graphical approach, which is prone to inaccuracies [25]. These methodologies are proposed for targeting of the minimum energy requirement of Total Site system. Velasco-Garcia et al. had put a lot of effort to show opportunities to optimize the utility system and cogeneration system in Total Site context [26]. Liew et al. [27] proposed the heat requirement targeting methodology for TSI considering the seasonal energy variation due to the integration of renewable energy and batch processes. Hackl R. et al. in [28, 29] analysed Sweden's largest chemical cluster with use of the TSA method. It shows that by site-wide collaboration it is possible to increase heat recovery and utilisation of excess heat in the chemical cluster. Proposed retrofit shown 50 % energy saving. Alaa Farhata et al. presented a new methodology that combines TSA and exergy analysis. The methodology allows for simultaneous use of both thermodynamic systems and heat exchangers networks. The combination of two types of utilities allows for better exploitation of the plants' energy profile [30]. Varbanov et al., considered advantages Total Site heat recovery targeting using multiple ΔT_{min} specifications for site processes [31]. Peng Yen Liew et al proposed methodology that able to design HEN with targeted energy requirement using Modified TS – Problem Table Algorithm and illustration on Modified TS Utility Distribution table [32]. Boldyryev et al in their work show a considerable potential for energy saving on Total Site level by heat recovery improvement by using intermediate utilities as well as capital cost reduction via minimum heat transfer area calculation [33]. Peng Yen Liew et al. in their work, an extended methodology is developed to target the minimum utility requirements in a steam system that considers the water sensible heat. The results demonstrate the significance of considering the sensible heat of water on the TS utility targets [34]. Kew Hong Chew et al. presented the research where showed extends the scope of the Pinch Analysis for process modifications of individual processes to total site heat integration [35, 36]. The Plus-Minus principle has been adapted to enable the beneficial process modification options to be selected in order to maximise energy savings in total site heat integration. The illustrative case study shows that the Pluse-Minus principle application in the total site heat integration context can further improve heat recovery [35].

The industrial applications of TSA to existing plants has grown recently. Boldyryev et al. presented research where the energy efficiency of bromine production site is analysed. PA and TSA were used for estimation of energy saving potential and design of retrofit project. It is shown that the process with improved heat integration consumes 57 % of hot and 97 % of cold utilities required by existing production site [37]. Matsuda et al. by means of TSA for a large steel plant was able to identify large energy saving potential, especially in cooler side (power generation of 21.1 MW) [38]. Sahafzadeh et al. presented research where the energy efficiency of ammonia process site is analysed. Combined Pinch and Exergy Analysis is applied to identify how exergy loss is distributed throughout heat transfer process. The results show that 4 MW of electricity can be produced in exchange of adding 7,350 kW of high pressure steam. Total amount of exergy loss is reduced by 3,323 kW, which indicates 19 % reduction compared to the existing process [39].

The specified theoretical developments, as a rule, it isn't supplemented with the corresponding appendices of methodology. Providing the corresponding case studies is important for management of industrial sites for implementation of methodology potential and to use it for achievement of real economy in their plants.

Analysis of energy efficiency of coke oven site is considered in this work. The approach is based on TSA with heat pumps with utilisation of waste heat and detailed utility analysis. The use of the Total Site Profiles of the production complex allows to make the estimation of the target energy values for several processes. In this paper, Total Site Integration for utilization of waste heat of Coke Plant is carried out accounting the features of coke industry in order to get solution, which is close to optimal, and provide the pathway for efficient retrofit and manager decisions.

This methodology provides a link between the stage of the preliminary TSA and the implementation of the retrofit project of coke production. The objective is to reduce specific energy consumption of production complex after application of processes integration at the level of individual units and industrial complex.

2. Methodology

2.1. Total site analysis

Total site analysis gives the most effective way of highlighting the key points in these interactions. The use of the total temperature profiles of the production complex has enabled the estimation of the target energy values for several processes. These profiles are constructed from the grand composite curves of individual processes that make up the production complex [40].

The use of the total temperature profiles of the production complex has enabled the estimation of the target energy values for several processes. The creation of a process profile is begun with the construction of individual Grand Composite Curves, which are further modified. The non monotonic parts of grand composite curves, i.e., so-called pockets, are isolated with vertical lines and cut off. After it is accomplished, the profiles of the source and sink of a Grand Composite Curve are shifted by ½ $\Delta T_{\min}$. In this case, the temperatures of the source profile elements are decreased by ½ $\Delta T_{\min}$, whereas the temperature of sink profile elements is increased by ½ $\Delta T_{\min}$. It is obvious that the temperature profiles are reduced to the real temperatures in each process using their own $\Delta T_{\min}$ [40].

2.2. Total Site Profiles analysis

Total Site profiles of integrated process (Fig. 1) provide an opportunity to assess the potential of heat recovery inside the industrial complex, and the potential use of heat for different needs. As can been seen from the Total Site Profiles (Fig. 1), $\Delta T_{\min}$ between hot and cold streams more than 50 ºC, it makes uneconomic use of the heat pump also excludes possibility of increase in a recuperation in industrial complex.

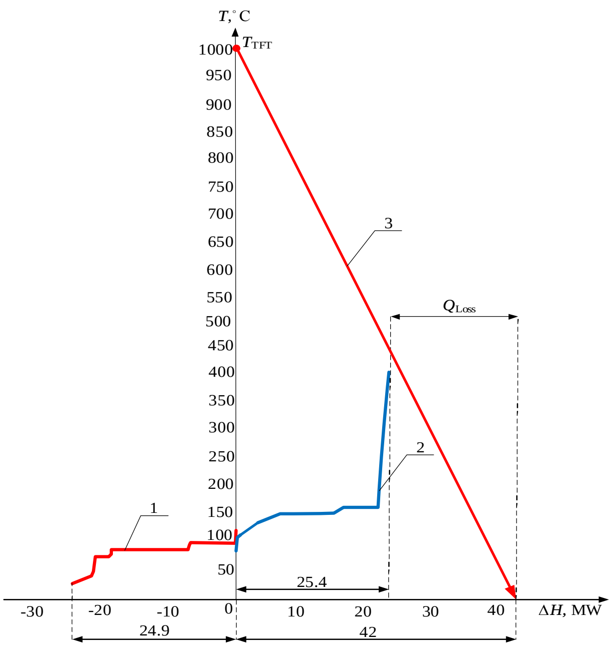

Fig. 1. Total Site Profiles of coke production^ 1 –Site Source Profile; 2 –Site Sink Profile, 3 – Profile of flue gas

2.2.1. Analysis of Site Source Profile

Site Source Profile (Fig. 1) has a 24.9 MW heat capacity. For achievement of target temperatures cold utilities (cooling water) are used. To reduce the specific energy consumption of the enterprise, it is proposed to consider the possibility of using heat capacity Site Source Profile for district heating system and hot water supply of the town Avdeevka.

When designing the district heating systems water is used as a heat carrier, the temperature of which are taking according to SNIP [41]. In district heating systems for residential and public buildings coolant temperature should not exceed 95 °C for two-pipe heating systems [41].

The schedule of the heat supply has to coincide with the schedule of internal heating, which has the temperature range 95–70 ºC. It means that at a minimum outside air temperature the heat carrier (water) flows directly into the heating devices with a temperature 95 ºC, and exits the building heating system with a temperature 70 ºC.

2.2.2. Analysis of Site Sink Profile

Site Sink Profile has a 25.4 MW heat capacity. In order to achieve the target streams temperature, streams heat up in a coke oven or using the steam generated by the CHP.

Capacity of Hot utility (Q_{Hmin}) shows the payload for furnaces. The projection of the flue gas temperature profile to the horizontal axis determines the capacity that is produced by burning fuel in furnaces. Flow rate of waste gases after the Total Site Integration is 40.77 kg/s.

The slope of the temperature profile of waste gases determines the amount of fuel entering the furnace [42].

These data can be used to calculate the heat exchangers and furnaces, as well as providing recommendations for reconstruction furnace due to declining capacity.

3. Case study

3.1. Process description

After the Total Site Integration the considered processes consumes 24.9 MW and 25.4 MW by the external cold hot utilities and 42 MW produced by the combustion of the coke ovens gas. The potential use of this power in the industrial complex is limited due to the large temperature difference between the hot and cold streams (Fig. 1). However, this capacity can be used for the district heating needs, hot water supply system and the electricity production.

For use of waste heat for district heating needs and hot water supply, it is necessary to create new heat exchangers network. For this flow included in the source profile, recorded in stream data table 1.

Table. 1

Stream data for Site source profile

№	Stream	Type of stream	T_S, °C	T_T, °C	*W*, kg/s	*r* kJ/kg	*C*,kJ/ (kg·°C)	*CP*, kW/°C	ΔH, kW	*α*,kW/ (m²·°C)
1	Condensation of steam	Hot	100	100	5.55	1908	–	–	-8327,3	9
2.1	Condensation of steam	Hot	74	74	1.38	1816	–	–	-2298,3	8
2.2	Condensate from the column	Hot	74	30	1.38	–	3.23	4.45	-196	0.8
3	Refined absorption oil from the column	Hot	42	30	48.25	–	2.01	96.97	-1163,6	0.3
4	Refined absorption oil from the column	Hot	42	30	66.9	–	2.01	134.6	-1616	0.9
5.1	Condensation of steam	Hot	90	90	5.36	1908	–	–	-10227	9
5.2	Steam Cooling	Hot	90	30	5.36	–	3.23	17.32	-1039	0.56
6	Condensate of vaporizer water	Hot	90	50	0.160	–	4.19	0.670	28	0.8
7.1	Stream of light oil	Hot	135	100	0.043	–	2.03	0.087	3.04	0.5
7.2	Condensation of light oil stream	Hot	100	100	0.043	379	–	–	16.22	10
7.3	Condensate of light oil	Hot	100	45	0.043	–	2.03	0.087	4.77	0.5
8	Stripping fraction	Hot	100	80	0.642	–	1.567	1.006	20	0.3
9	Naphthalene fraction	Hot	100	95	0.428	–	1.785	0.764	4	0.3
10	Phenol fraction	Hot	100	50	0.171	–	1.823	0.312	16	0.3
11.1	Naphthalene in crystallizer	Hot	90	78	0.750	–	1.787	1.340	16.083	0.1
11.2	Crystallization of naphthalene	Hot	78	78	0.750	149.1	–	–	111.87	0.1
11.3	Naphthalene in crystallizer	Hot	78	60	0.750	–	1.787	1.340	24.125	0.1
12	District heating	Cold	70	95	173.5	–	4.38	760.4	19009	1
13	Water heating	Cold	10	65	12.79	–	4.32	83	3050	1
14	Water heating	Cold	10	65	6.31	–	4.32	83	1518	1

After analysing the data from Table 1, it can be concluded that not all streams may be used for district heating needs and hot water supply. Streams 7.3, 9 and 10 are very low heat load, which makes unprofitable inclusion of these streams in the heat exchange system. Heat capacity, which should be used is 23,552 kW.

Waste gases from the furnace consist mainly of air with small amounts of combustion products, therefore we stream heat capacity with high accuracy can be estimated by assuming that the stream consists only of air and assuming that the heat capacity air is equal to C = 1.03 kJ/(kg·K). Accordingly, the heat of flue gas generated by the combustion of fuel in furnaces, estimated from the equation (1):

$$Q_{\text{flue}} = G \cdot C \cdot \Delta T\,, \qquad (1)$$

where Q_{flue} – heat of flue gas, G – flow rate of waste gases = 43.9 kg/s, ΔT – the difference between the temperature of combustion and the temperature of ejection to the environment is 990 ºC.

Therefore, in furnaces by burning fuel is allocated 42 MW, equivalent to 4.89 tons of conventional combustion of fuel per hour.

3.2. District heating and water heating

In order to calculate the heat transfer equipment it is necessary to determine which streams can be used for district heating and which are for hot water supply system. It can be made by means of the Grid Diagram for the considered streams. (Fig. 2). In the diagram grid applied a new heat transfer equipment, capacity and temperature were calculated.

Having constructed the chart, we determined that capacity, which can be used for district heating, is 18,984 kW (Fig. 2), and capacity that can be used for hot water supply is 4,568 kW (Fig. 2).

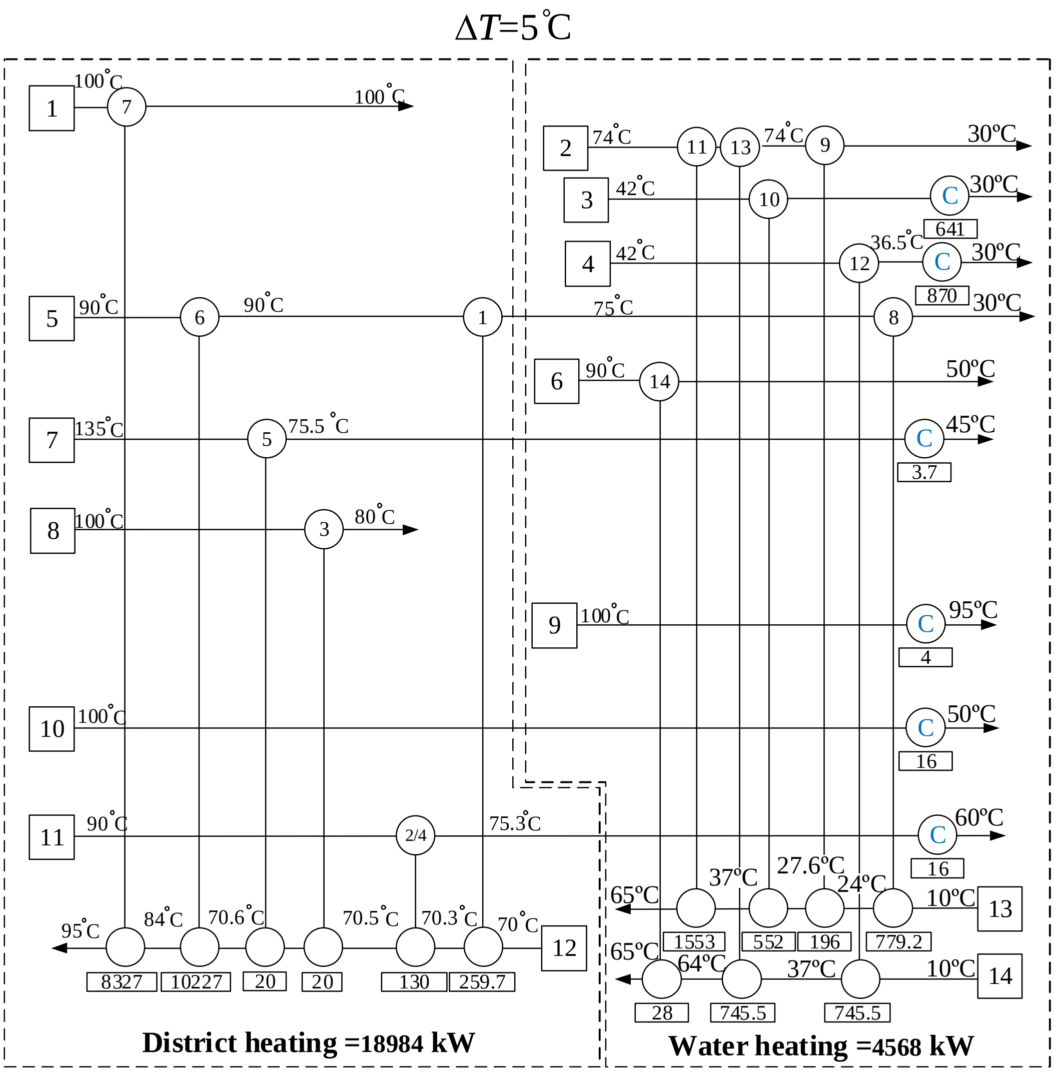

Fig. 2. Grid diagram of considered process

To calculate the mass flow rate of the water circulating in the district heating system, use the equation (2):

$$G_{\text{Water}} = \frac{Q_{\text{DH}}}{C_{\text{Water}} \cdot \Delta t}, \qquad (2)$$

where G_{Water} – the water mass flow, for district heating system; $Q_{\text{от}}$ – the maximum heat capacity of district heating system; C_{Water} – heat capacity for water; Δt_1 – the temperature difference between supply water and return water according to schedule, that is 25 °C.

The mass flow rate of the water circulating in the district heating system is 624.6 tons per hour. Based on the temperature chart, the maximum load is 18,984 kW.

The potential use of heat from the Site source profile for the hot water system is 4,568 kW. Hot water temperature should be 65 °C [41]. The mass flow rate of water to the hot water system is 68.3 tons per hour.

The brief characteristics of the new heat exchangers are listed in Tables 2–3. New plate Compablock heat exchangers (Alpha Laval) were installed in streams with phase change. In cases where the flow does not change the phase state, gasketed plate heat exchangers installed [43].

Table 2

Heat exchangers for the district heating system

Heat exchanger	Load, kW	Hot flow					Cold flow					Surface area, m^2
		stream no.	T_{init}, °C	T_{fin}, °C	Vapour fraction		stream no.	T_{init}, °C	T_{fin}, °C	Vapour fraction		
					init.	fin.				init	Fin	
T-1	259.5	5	90	75	0	0	12	70	70.34	0	0	28.82
T-2/T4	130	11	90	78	1	0	12	70.34	70.5	0	0	11.4
T-3	20.5	8	100	80	0	0	12	70.5	70.53	0	0	0.92
T-5	20	7	135	75.5	1	0	12	70.53	70.56	0	0	1
T-6	10227	5	90	90	1	0	12	70.56	84	0	0	166.1
T-7	8327	1	100	100	1	0	12	84	95	0	0	199.0
∑	18984	–	–	–	–	–	–	–	–	–	–	407.24

Having calculated parameters of heat exchangers, we can determine the potential volume of the heated buildings by a equation (3):

$$V = \frac{Q_{DH}}{a_{air} \cdot q_0 \cdot (t_{in} - t_{out})} \cdot L\,, \qquad (3)$$

where V – the volume of the heated buildings, Q_{DH} – the load on the heat exchange equipment, a_{air} – coefficient taking into account the change of the specific heat load, depending on climatic conditions = 1.06, t_{in} – the temperature inside the building = 18 °C, t_{out} – the outside temperature = -15 °C L – loss in the connecting pipes from the heat source (recuperative heat exchanger) to the building we accept 3 %.

Therefore, the volume of buildings that can be heated is 1,813,730.7 м^3. Similarly, we count a heat exchanger surface area for hot water supply (table 3).

Having presented profiles of new district heating system, hot water supply and a source profiles in one Figure, it is possible to see that the recuperation of warmth will make 23.5 MW, and use external cold utilities will be reduced to 1.4 MW (Fig. 3).

Table 3

Water heating

Heat exchanger	Load, kW	Hot flow					Cold flow					Surface area, m^2
		stream no.	T_{init}, °C	T_{fin}, °C	Vapour fraction		stream no.	T_{init}, °C	T_{fin}, °C	Vapour fraction		
					init.	fin.				init	fin	
T-8	779	5	75	30	0	0	13	10	24	0	0	10.34
T-9	196	2	74	30	0	0	13	24	27.6	0	0	5.94
T-10	522	3	42	36.6	0	0	13	27.6	36	0	0	123.3
T-11	1552.7	2	74	74	1	0.4	13	36	65	0	0	18.14
T-12	745.5	4	42	36.5	0	0	14	10	37	0	0	123.3
T-13	745.5	2	74	74	0.4	0	14	37	64	0	0	9.18
T-14	28	6	90	50	0	0	14	64	65	0	0	1
∑	4568	–	–	–	–	–	–	–	–	–	–	291.2

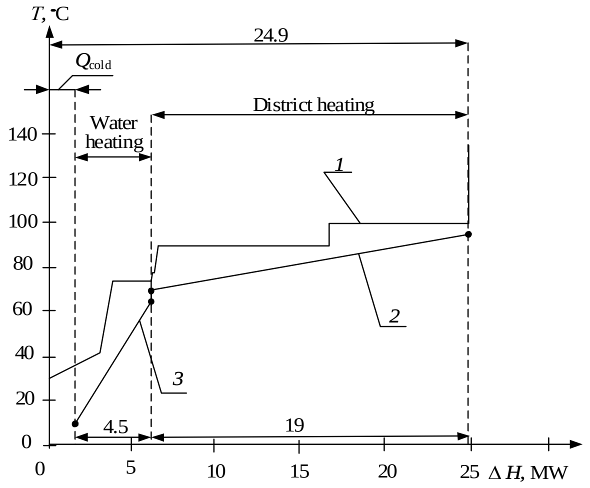

Fig. 3. Site source profile with new District heating and new water heating systems: *1* – Site source profile; *2* – District heating; 3 – Water heating

3.3. Use the energy of flue gases

After the TSI of during fuel combustion in furnaces produces 42 MW, while 16.6 MW are losses with the outgoing flue gases (Fig. 1). The use of waste heat for electricity production could significantly reduce the unit costs of the company. To assess the potential use of flue gases will consider Site sink profile (Fig. 4).

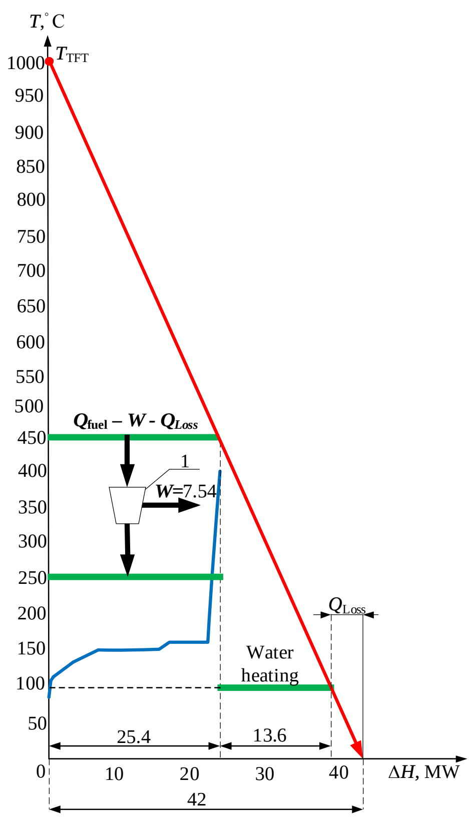

Fig. 4. Site sink profile with integrated turbine 1 – The turbine for electricity production

Let's define quantity of thermal energy which is supplied to the turbine [41]:

$$Q_{th}=Q_{fuel} - W - Q_{Loss}, \quad (4)$$

where Q_{fuel} – heat of flue gas, W – the turbine operation, Q_{Loss} – heat losses.

The amount of heat that is supplied to the turbine will be 25.4 MW.

The quantity of electricity generated by the turbine can be estimated by following equation (5):

$$W = Q_{fuel} \cdot Ck\cdot(1\text{-}0.01), \quad (5)$$

where W – the turbine operation; Q_{fuel} – heat of flue gas; Ck – conversion level of thermal energy in the electric power = 0.3 [44]. Thus it is necessary to consider that about 1 % of the developed electric power is spent for needs of the unit itself [44].

Thus, in the conversion of waste gases produced 7.54 megawatts of electricity. The utilization of 13.6 MW of heat flue gas by installing a heat exchanger (air-water) for heating water for the needs of hot water supply is also considered. Calculation of heat transfer surface is carried out using the following equation (6):

$$F = \frac{Q_{WH}}{K \cdot \Delta t_{mean}}, \quad (6)$$

where Q_{WH} – the heat load on the hot water supply; K – heat transfer coefficient; Δt_{cp} – mean temperature difference. The heat transfer coefficient is calculated by the equation (7):

$$K = \frac{1}{\frac{1}{a_{WG}} + \frac{1}{a_{Water}} + \left(\frac{d}{l} + R\right)}, \quad (7)$$

where α_{WG} и α_{W} – heat-transfer coefficient for the stream of waste gases = 50 W/m·K for the water stream = 700 W/m·K; δ – wall thickness; R – the thermal resistance of the wall material and pollution = 0.0001 m·K/W.

Surface area for new heat exchanger (air-water) is 5966 м^2.

4. Results and discussion

Using waste heat from coke plant for district heating and hot water supply, allows to reduce the consumption of external cold utilities by 23.5 kW at installation 698.4 m^2 heat exchange surface area. Must consider that the heating season lasts six months, and hot water supply for a year. Capacity which during the winter period is used for district heating needs, comes to the summer period on heating of water for hot water supply. The payback period is estimated by the equation (8):

$$P_1 = \frac{A_{ht} + B_{ht}\,(S)^c}{(Q_{Cold} - Q_{NEWCold}) \cdot S_{Cold} + (Q_{DH} \cdot S_{DH} + G_{WH1} \cdot S_{WH} \cdot 8000 + G_{WH2} \cdot S_{WH} \cdot 4000)}, \tag{8}$$

where A_{ht} = 50,000 USD, B_{ht} = 500 USD for gasketed plate heat exchangers and 700 USD for Compablock heat exchangers, S is the heat exchange surface area, m^2, and, as a rule, c = 0.87 for plate heat exchangers [43], Q_{cold} – requirement for cold utility before integration, $Q_{NEWcold}$ – requirement for cold utility after integration S_{Cold} – the cost of cold utilities = 30 USD/(kW yr.), Q_{DH} – requirement for District heating system, G_{WH1} – hot water consumption = 68.4 m^3/h, G_{WH1} – hot water consumption = 283.7 m^3/h, S_{DH} – cost of 1 kW of heat energy for district heating system = =92.9 USD/(kW yr.) S_{WH} – the price for one cubic meter of hot water = 1.68 USD, 8000 and 4000 – is the amount working hours for the hot water system.

Capital costs is 899,853.9 USD. The annual profit from the implementation of the project is 3,532,386.9 USD, Payback period 3 months. Using the energy waste gases allows obtaining 7.54 MW of electricity.

The heat exchanger with surface area is 5,966 m^2 must be installed for use 13.6 MW heat capacity from the waste gases for hot water supply needs. Payback period estimated by the formula (9):

$$P_2 = \frac{A_{ht} + B_{ht}\,(S)^c}{G_{WH} \cdot S_{WH}} \tag{9}$$

where A_{ht} = 50,000 USD, B_{ht} = 500 USD, S is the heat exchange surface area, m^2, and, as a rule, c = 0.87 for plate heat exchangers [43], G_{WH1} – hot water consumption= =203.6 m^3/h, S_{DH} – cost of 1 kW of heat energy for district heating system = 92.9 USD/(kW yr.) S_{WH} – the price for one cubic meter of hot water = 1.68 USD.

Capital cost is 1,013,448 USD. The annual profit from the implementation of the project is 2,731,516.8 USD. Payback period of 0.37 years.

The results can be represented graphically on Total Site profiles (Fig. 5).

Numerical estimates of the energy consumption and recuperation in the existing and proposed projects are given in Table 3. The integration of individual processes and the integration of the TSA have been published previously.

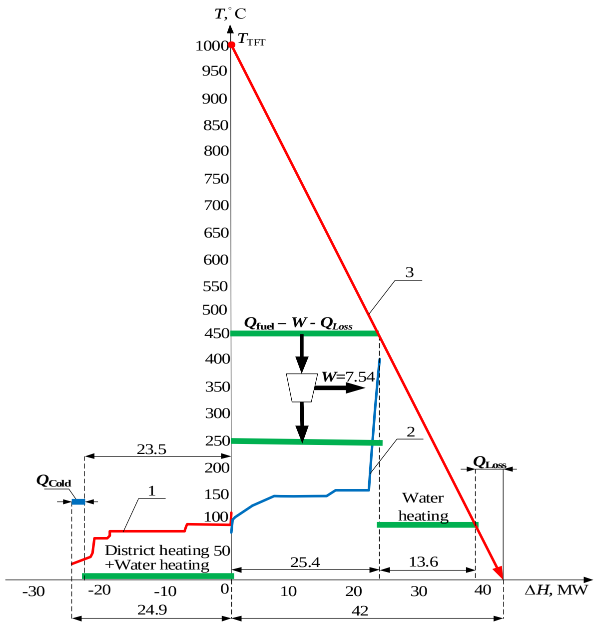

Fig. 5. Heat recovery potential on Total Site level: *1* – Site source profile; *2* – Site sink profile, 3 – Profile of flue gas

Table 3

Energy consumption and recuperation in the existing heat exchange system and the heat exchange system from the proposed project of reconstruction

Energy characteristic of the process	Process with existing heat exchange system	Integration individual processes	Total Site Integration	Integration after TSI
Power of hot outer energy carriers, MW	34.782	28.2389	25.3914	17.85
Power of cold outer energy carriers, MW	33.5091	26.9993	24.906	1.4
Heat recuperation power, MW	17.44	23.97	26.82	63.92

Despite the fact that this methodology has high efficiency, the project can face difficulties because of the imperfection of the legislative framework in the field of energy regulation.

5. Conclusion

The methodology to determine the potential use of waste heat after Total Site integration has been proposed. The use heat of Site source profile for new district heating system and water heating system allows reducing the external cold utilities usage by 23,522 kW. The heat transfer area and number of heat exchangers for a retrofitted heat exchanger network have been identified. The annual profit from the implementation of the project is 3,532,386.9 USD, and the payback period is three months.

The use of waste heat from flue gases for electricity production allows obtaining about 7.5 MW of power that can be utilized for production needs and exported outside. Harmful emissions in the atmosphere are reduced in proportion to reduction of hot utilities (furnace payload).

The ability to use the waste gases for heating the water has been considered and the parameters of the heat exchanger were calculated. The heat loss from the waste gases decreased from 16.6 MW to 3 MW. The annual profit from the implementation of the project is 2,731,516.8 USD, and the payback period is 0.37 year.

The provided case studies show the pathway for efficient retrofit of coke production and most profitable ways for investment. The results of this work can be used in coke and other industries for efficient energy use, CO2 mitigation and sustainability improvement of industrial regions.

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Nomenclature

ΔH – change of enthalpy;

C – heat capacity;

CP – flowrate heat capacity;

Q_{Cmin} – requirement for cold utility;

T_{S} – supply temperature, °C;

T_{T} – target temperature, °C;

T_{TFT} combustion temperature of flue gas, ºC;

α – heat transfer coefficient;

c – coefficient characterizing the linear dependence between the cost of a heat exchanger and its heat-exchange surface area;

W – flowrate;

r – heat of vaporization

P – payback period;

A_{HE} – cost of the installation of a heat exchanger;

B_{T} – rate equivalent to the cost of 1 m^2 surface area of heat transfer;

S_{cold} – cost of external utilities, USD;

W – turbine operation, kW.

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MATHEMATICAL MODELLING OF THE POPULATION DYNAMICS OF HUNTING MAMMALS BASED ON RECURRENT EQUATION SYSTEM

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Abstract. Regression analysis of the population dynamics of hunting mammals based on Khmilnytskyi forestry was made. Correlation analysis of the observations results between the populations of spotted deer and wisent, spotted deer and wild boar, lepus and fox was made. Modelling of the population dynamics of hunting mammals was done using Mathcad based on the system of recurrent logistics equations and the adequacy of the model by the Pearson's criteria was proved.

Key words: mathematical modelling, population dynamics, hunting mammals, regression analysis, interspecies interaction, dynamics model.

Introduction. The use of mathematical modelling opens up new possibilities for creating a model of population dynamics and forecasting of the population, which greatly facilitates the analysis of primary data. At the same time, there are some difficulties: a) simulation data requires a fairly long period of time (as the accuracy of the model is determined by the amount of data in number); b) it is difficult to reflect the impact of certain factors and interspecies relationships in conventional models [2–5].

1. The analysis of the populations of hunting mammals in Khmilnytskyi forestry

Based on the statistics of the population dynamics of hunting mammals in Khmilnitskyi forestry, a regression analysis was made using Statistica 6.1. Program. Exponential function was used as a regression model that corresponds to modelling the dynamics of individual populations without interspecies interaction. The results of the regression analysis are shown in Fig. 1.

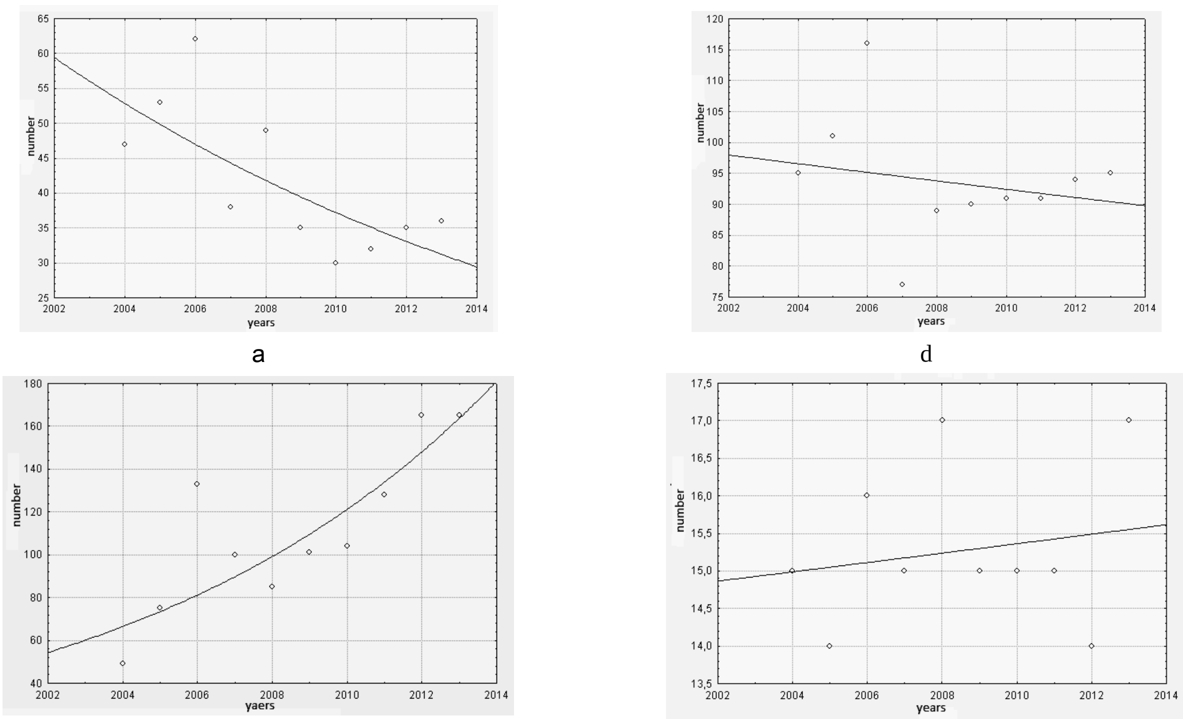
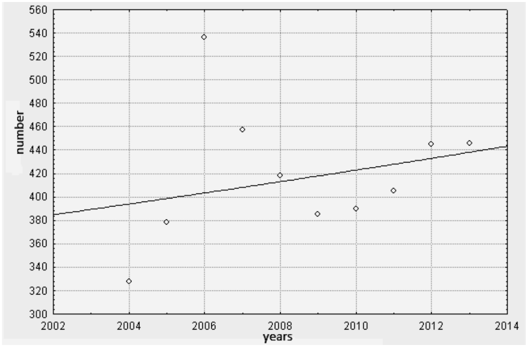


Fig. 1. Regression analysis of observations of population in Khmilnitskyi forestry:
a – spotted deer, b – wild boar, d – wisent; e – fox



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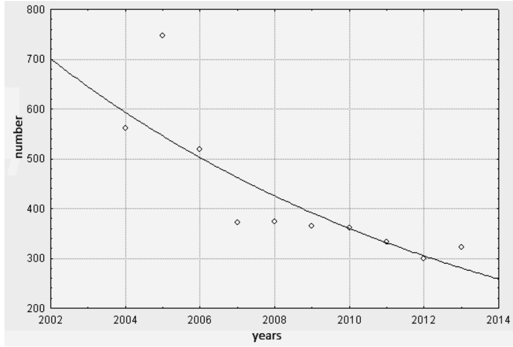

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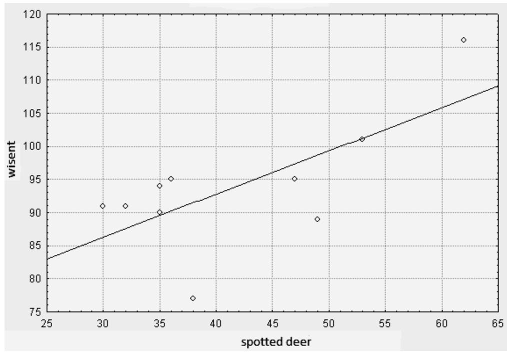
Continuation Fig. 1. Regression analysis of observations of population in Khmilnitskyi forestry:
c – European roe deer; f – lepus

As a result of the regression analysis, mathematical models of changes in the number of individual populations of hunting animals in exponential approximation were obtained. Moreover, the function index includes parameters for fertility, mortality, migration and human impacts (hunting shooting, poaching, agricultural operations, transportation systems, etc.).

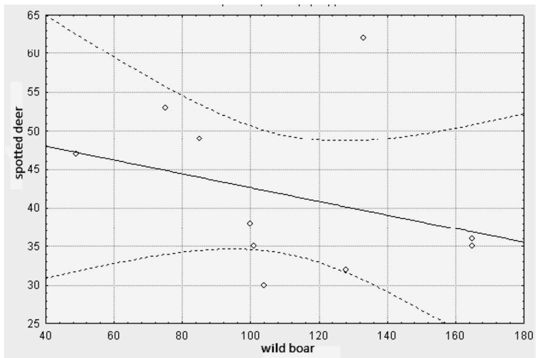
The correlation between the populations of certain species of hunting mammals in Khmilnitskyi forestry was analyzed. In particular, the dependence between the populations of spotted deer and wisent, fox and lepus, spotted deer and wild boar was set Fig. 2.

As a result of the correlation analysis between the populations of spotted deer and wisent in Khmilnitskyi forestry the correlation coefficient of 0.69 was obtained, which indicates close relationship between these populations. This is because the ecological niches of wisent and spotted deer coincide. Though, the population of spotted deer is much wider because of better adaptation to the existence in small forests. Spotted deer and wisent, in terms of trophic relationships, do not compete. In this case, such a high correlation coefficient is due to the fact, that wisent competes with deer, as a factor of disturbance. In spring and summer when ungulates are calving, deer are trying to avoid encounters with other animals. Herewith, in most cases overgrown cuttings and young forests are the places of the growth of the young ones. While eating, wisents use the same overgrown cuttings and young forests. The herd disperses throughout all the territory, making a loud noise and crackle. Other animals that brought the young ones try to leave this place, what is accompanied by the death of some young animals [1–5].

The lack of significant correlation relationship between the populations of fox and lepus in Khmilnitskyi forestry is explained by strong anthropogenic interference into ecological niches of animals and substantive hunting compared to interspecies interaction of “predator-prey”. No evident correlation relationship between the populations of deer and wild boar was found, although their ecological niches coincide. This is because their number is small and they are not disturbing factors for each other. In terms of trophic relationships, they also do not significantly compete. Wild boar is able to live in any forestlands as well as wetlands. It is omnivorous, which allows repeated changing of food base throughout the year.



a



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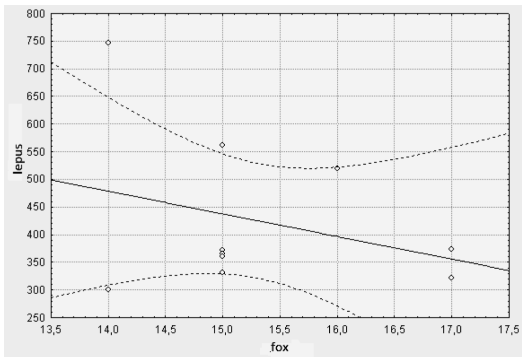


c

Fig. 2. Correlation analysis of observations between the populations in Khmelnytskiy forestry:
a – spotted deer and wisent, b – spotted deer and wild boar, c – lepus and fox

2. Modelling of the population dynamics of hunting mammals in Khmilnitskyi forestry using Mathcad

Mathematical model of dynamics of the amount of separate population under conditions with sufficient food, lack of overcrowding and enemies is described by the following equation:

$$N(t) = N_0 e^{r(t-t_0)}; \qquad (1)$$

where N_0 – population amount at the initial time; r – specific rate of reproduction.

Equation (1) is received by solving Malthus differential equation $\frac{dN}{dt} = rN$.

Under adverse conditions, specific mortality rate d exceeds specific birth rate b, while the specific rate of reproduction $r = d - b$ is negative.

When taking crowding into account, the population dynamics of a separate population is described by the following equation:

$$N(t) = \frac{K}{1 + e^{\ln\left(\frac{K-N_0}{N_0}\right) - r(t-t_0)}}; \qquad (2)$$

where K – the maximum possible amount of the population.

Equation (2) is received by solving logistics differential equation $\frac{dN}{dt} = rN - \frac{r}{K}N^2$.

In consideration of interspecies interactions, it is necessary to solve a system of differential equations:

$$\begin{cases} \dfrac{dN_1}{dt} = r_1 N_1 - \dfrac{r_1}{K_1} N_1^2 + g_1 N_1 N_2; \\ \dfrac{dN_2}{dt} = r_2 N_2 - \dfrac{r_2}{K_2} N_2^2 + g_2 N_2 N_1. \end{cases} \qquad (3)$$

where γ_1 and γ_2 – factors that take into account the interaction of species.

A more accurate study of the dynamics of interspecies interaction is possible with the use of systems of nonlinear Lotka-Volterra differential equations, which take into account food digestion of the predator, predator's hunting strategy, defensive reaction of the victim, the presence of hiding places for the victim, etc.

With some loss of accuracy in the analysis and replacement of dt by Δt, the system of nonlinear differential equations may be replaced by the system of recurrent equations. This can significantly simplify the calculations and make them transparent and visible. For example, system (3) is converted into the following system:

$$\begin{cases} N_{i+1} = N_i + \left(r_n N_i - \dfrac{r_n}{K_n} N_i^2 + g_n N_i M_i \right); \\ M_{i+1} = M_i + \left(r_m M_i - \dfrac{r_m}{K_m} M_i^2 + g_m M_i N_i \right). \end{cases} \qquad (4)$$

System (4) uses discrete time i which corresponds to the step of real time (average breeding season $T=\min(T_n, T_m)$).

Modelling of the population dynamics in the ecosystem with six most common populations of hunting mammals was carried out. Initial data for the simulation are shown in Table 1.

Table 1

Initial data for the simulation of the population dynamics

Species	Initial amount	Specific rate of change in population	Maximum population size	
Spotted deer	564	-0,0585	200	$N1_i$
Wild boar	49	0,1003	160	$N2_i$
European roe deer	384	0,0262	800	$N3_i$
Wisent	96	-0,0073	100	$N4_i$
Lepus	584	-0,0932	600	$N5_i$
Fox	15	0,0041	17	$N6_i$

Logistics system of recurrent equations for modelling the population dynamics:

$$\begin{pmatrix} N1_{i+1} \\ N2_{i+1} \\ N3_{i+1} \\ N4_{i+1} \\ N5_{i+1} \\ N6_{i+1} \\ N7_{i+1} \end{pmatrix} := \begin{bmatrix} N1_i + m1 \cdot N1_i - \frac{m1}{K1} \cdot (N1_i)^2 + \gamma12 \cdot N1_i \cdot N2_i + \gamma13 \cdot N1_i \cdot N3_i + \gamma14 \cdot N1_i \cdot N4_i + \gamma15 \cdot N1_i \cdot N5_i + \gamma16 \cdot N1_i \cdot N6_i + \gamma17 \cdot N1_i \cdot N7_i \\ N2_i + m2 \cdot N2_i - \frac{m2}{K2} \cdot (N2_i)^2 + \gamma21 \cdot N2_i \cdot N1_i + \gamma23 \cdot N2_i \cdot N3_i + \gamma24 \cdot N2_i \cdot N4_i + \gamma25 \cdot N2_i \cdot N5_i + \gamma26 \cdot N2_i \cdot N6_i + \gamma27 \cdot N2_i \cdot N7_i \\ N3_i + m3 \cdot N3_i - \frac{m3}{K3} \cdot (N3_i)^2 + \gamma31 \cdot N3_i \cdot N1_i + \gamma32 \cdot N3_i \cdot N2_i + \gamma34 \cdot N3_i \cdot N4_i + \gamma35 \cdot N3_i \cdot N5_i + \gamma36 \cdot N3_i \cdot N6_i + \gamma37 \cdot N3_i \cdot N7_i \\ N4_i + m4 \cdot N4_i - \frac{m4}{K4} \cdot (N4_i)^2 + \gamma41 \cdot N4_i \cdot N1_i + \gamma42 \cdot N4_i \cdot N2_i + \gamma43 \cdot N4_i \cdot N3_i + \gamma45 \cdot N4_i \cdot N5_i + \gamma46 \cdot N4_i \cdot N6_i + \gamma47 \cdot N4_i \cdot N7_i \\ N5_i + m5 \cdot N5_i - \frac{m5}{K5} \cdot (N5_i)^2 + \gamma51 \cdot N5_i \cdot N1_i + \gamma52 \cdot N5_i \cdot N2_i + \gamma53 \cdot N5_i \cdot N3_i + \gamma54 \cdot N5_i \cdot N4_i + \gamma56 \cdot N5_i \cdot N6_i + \gamma57 \cdot N5_i \cdot N7_i \\ N6_i + m6 \cdot N6_i - \frac{m6}{K6} \cdot (N6_i)^2 + \gamma61 \cdot N6_i \cdot N1_i + \gamma62 \cdot N6_i \cdot N2_i + \gamma63 \cdot N6_i \cdot N3_i + \gamma64 \cdot N6_i \cdot N4_i + \gamma65 \cdot N6_i \cdot N5_i + \gamma67 \cdot N6_i \cdot N7_i \\ N7_i + m7 \cdot N7_i - \frac{m7}{K7} \cdot (N7_i)^2 + \gamma71 \cdot N7_i \cdot N1_i + \gamma72 \cdot N7_i \cdot N2_i + \gamma73 \cdot N7_i \cdot N3_i + \gamma74 \cdot N7_i \cdot N4_i + \gamma75 \cdot N7_i \cdot N5_i + \gamma76 \cdot N7_i \cdot N6_i \end{bmatrix} \qquad (5)$$

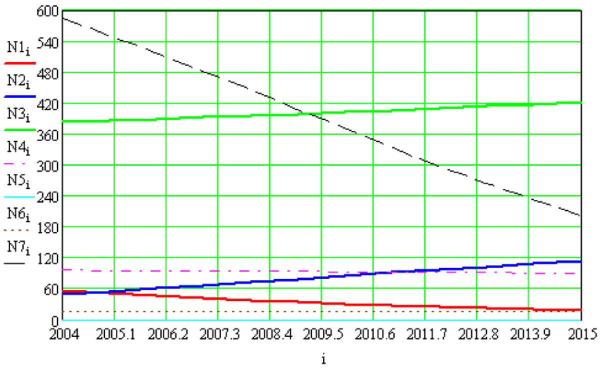


Fig. 3. The dynamics of the population amount of hunting mammals in Khmilnitskyi forestry

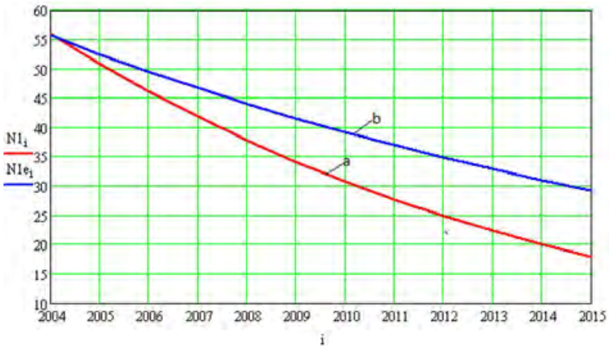
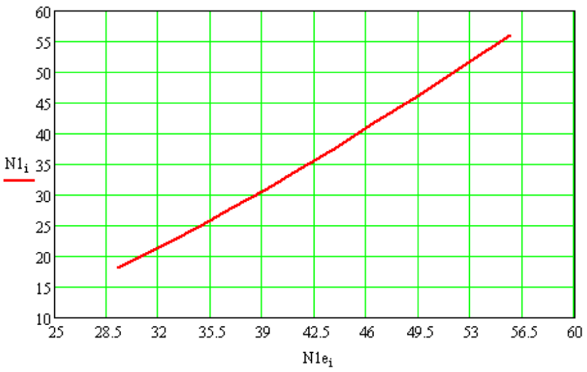


Fig. 4. Changes in the number of deer populations in Khmilnitskyi forestry (a – simulation results of equations (5), b – exponential regression of observations)



Simulation results are shown in Fig. 3.

Compare the results of modelling the dynamics of populations of spotted deer in Khmilnitskyi forestry from the system of recurrent equations with regression model based on the processing of observations using the exponential function. For comparison, we use the Pearson criteria. Since χ^2=0,998, it indicates the adequacy of the model based on the system of recurrent equations to the results of observations (Fig. 4).

The analysis of the adequacy of the data model of observations on the example of the dynamics of the populations of spotted deer (the Pearson criteria χ^2=0,998).

4. Conclusions

The obtained model is somewhat arbitrary and cannot be used as a completely accurate prediction of the populations of hunting mammals. However, the scenarios of the population dynamics are recommended for the development of measures for the integrated management of the groups of hunting mammals both for Khmilnitskyi forestry hunting, and all hunting lands of Podillia region.

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QUALITATIVE AND QUANTITATIVE CHARACTERISTICS OF BIOGAS OF CYANEA ORGANIC MASS

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Abstract. The article discusses the results of studies of the methane production from cyan biomass based on the data obtained in the course of a laboratory experiments. The yield of biogas was calculated from the substrate per unit volume, and its energy properties were determined. Experimental data indicates the feasibility and economic viability of this biotechnology.

Key words: cyanobacteria, algal bloom, biogas, methanogenesis, heat of combustion.

Introduction

The problem of so-called "flowering" of water bodies caused by the intensive development of photosynthetic microorganisms in particular cyanobacteria becomes more acute in the cascade of the Dnieper reservoirs from year to year. This is facilitated by a complex of factors, the most significant of which are the changes in the hydrological regime of the river due to construction of reservoirs cascade and formation of the optimal conditions for the growth of phytoplankton organic mass. Researches show [1, 2, 3] and the bulk of the excess biomass is necessary for the type of blue-green algae *Microcystis aeruginosa*. Emissions of algotoxins and mass extinction of cyan followed by oxidation processes in the water volume can cause large-scale aquatic mortality [4].

A radical solution to this environmental problem requires a comprehensive approach and global hydro-technical activities over large areas and therefore significant capital expenditures, which now seems hardly a feasible project. However, the negative cyanea impact on the river ecosystem can be substantially reduced by the mechanical extraction of biomass from the reservoir and its further processing.

Achieving a balance between environmental and economic aspects of the problem is possible due to full utilization of the organic matter recovered from hydro-ecosystems. To collect and concentrate the substrate on an industrial scale, special concentration columns are located in the areas of maximum natural thickening of cyanea biomass (Fig. 1).

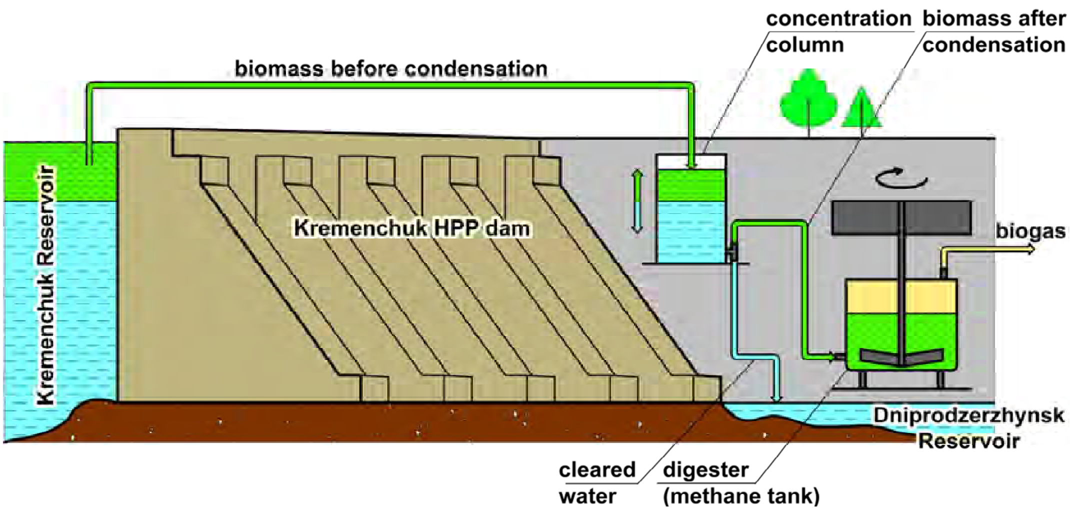

Fig. 1. The circuit arrangement of processing units of industrial installations for the production of biogas

Biomethanogenesis is the process of obtaining the gas mixture, the main component of which is methane, can be considered among the possible ways of cyano bioconversion as the most promising possibility. The substrate spent in the process of methanogenesis can be recognized as a sufficient one since the series of substances concentration used in various fields of economy reaches the values that lead to the economic feasibility of their industrial extraction. In addition, the waste biomass is an effective fertilizer, ready for the use in agriculture and forestry.

Classical technology for biogas producing from organic wastes of agrogene origin is based on the symbiotic interaction of three groups of microorganisms. At one of its stages the process of biosynthesis of a gases mixture by methanobacteria with prevalence of methane (more than a half of the volume) and impurities of other gases in the presence of which methanogens are developed (H_2 and CO_2) or repressed (O_2). *Methanobacterium formicicum* and *Methanospirillum hungati* species dominate in the process of methanogenesis [5].

Effective use of this technology by applying cyanea biomass as a substrate requires a number of research results of which are discussed in this article.

Material and methods

To study the properties of the organic cyan matter in the upper Dniprodzerzhynsk reservoir in the city of Kremenchug there was selected about 10 kgs of aqueous concentrate. Species composition and the number of cells in the selected substrate were determined by hemocytometer (Goryaev's camera), light microscope Ningbo Shengheng XS – 3330 with a video attachment "micro med" and a computer program for the "ISCapture" image processing.To accomplish this, a drop of cyanea cells from the condensation was placed in the center of a chamber and covered with special cover glass, carefully lapping at the edges of the chamber until Newton rings appear. In this case, the thickness of the liquid layer in the chamber above the grid is corresponded to 0.1 mm, and the volume of the chamber is approximately 1 mm^3. Each small square limits the amount of fluid in the 1/4000 mm^3.

Counting of cells in the hemocytometer began after 3–5 minutes after its filling when the cells settled and located in the same plane. After this, calculation was made in 20 small squares moving on them diagonally. To achieve the results with sufficient reliability of the test, 3 or 4 samples were taken from organisms suspension for mounting a camera.

Microscopy of samples was performed at a 160 times magnification and showed that the concentration of the *Microcystis aeruginosa* has exceeded 1 million. cl./cm^3 (Fig. 2).

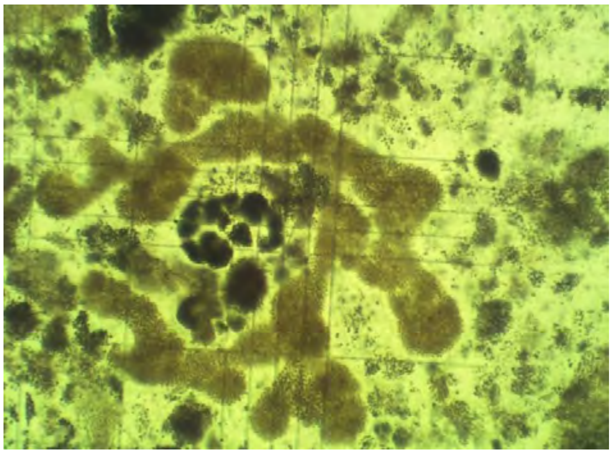

Fig. 2. Photomicrograph of *Microcystis aeruginosa* cells in hemocytometer (Goryaev's camera) (×160)

To obtain dry residue, liquid concentrate was exhibited for 96 hours at average daily temperature of 28 ºC. Drying was carried out in shallow flat-bottomed cuvettes with the volume from 0.5 to 1.5 dm^3. As a result, dry samples with the average weight of 18 g from 1 dm^3 of biomass were obtained and that allows to attribute the reservoir site, where samples were taken, to the fifth class of flowering (hyper-flowering) [6].

To determine the mineral content in the dry mass, three 10 g samples have been burn in a muffle furnace ПМ–8 at 800 °C on 40 minutes. After complete combustion of organic matter, the weight of the test portions was 1.7 g, 2.0 g and 2.0 g respectively (with average of 19 % of the dry mass).

The chemical composition of the gas mixture obtained during the experiment, as well as its density and calorific value were determined using a gas chromatograph Crystal–2000M [7].

The research of quantitative measures of fermentation dynamics was carried out by measuring the amount of emitted gas per time unit. In addition, the mechanism of methane fermentation "launch" and the effect of fermentation rate temperature are researched.

The changes in the biogas volume during the inoculation of fresh cyanea mass with and without the substrate were determined. The reserch has shown that fermentation is successfully held at the temperature in the range of 20–30 °C. In this case, 1.2 m^3 of biogas is extracted from 1.0 m^3 of substrate per week. The fermentation process ends average in a month.

At the same time, the analysis showed the absence of heavy metals and other contaminants in the substrate. This makes it possible to classify the remainder as an organic fertilizer of wide application range.

Extracted biogas contains 85 % of methane (Table 1).

Table 1

The chemical composition of biogas (by Nykyforov V. V.)

gas	volume, %
methane	75–85
carbon dioxide	10–20
carbon monoxide	1
hydrogen	1

Results. An experimental installation for methanogenesis process simulation at industrial conditions for the first time was assembled and tested in the Department of Natural Sciences of Bioenergy laboratory [8] and seven years later modeled and put into operation in the Department of Biotechnology and Human Health laboratory at Kremenchuk Mykhailo Ostrohradskyi National University [9]. The experiment was conducted in a dry-air electric thermostat TC-80M at 30 °C.

During the experiment there were used two samples of cyan biomass ($V = 0.5$ dm^3) selected from Dniprodzerzhynsk reservoir (nearby the "Neptune" pool) in September, 2015. Based on the data from a number of studies [10, 11], in which determined the effectiveness of applying pre-processed cyanobacteria biomass by using hydromechanical methods, one of the samples has been previously subjected to a process of mechanical cavitation for 7.5 minutes.

The emission of the first volume of biogas, which was collected in the relevant measuring cylinders by means of "water gate", was recorded in a day after the start of the experiment. The formation of biogas from the substrate, which was not carried to cavitation process is marked on the chart with a dark color, and from the sample after cavitation marked with a lighter one (Fig. 3).

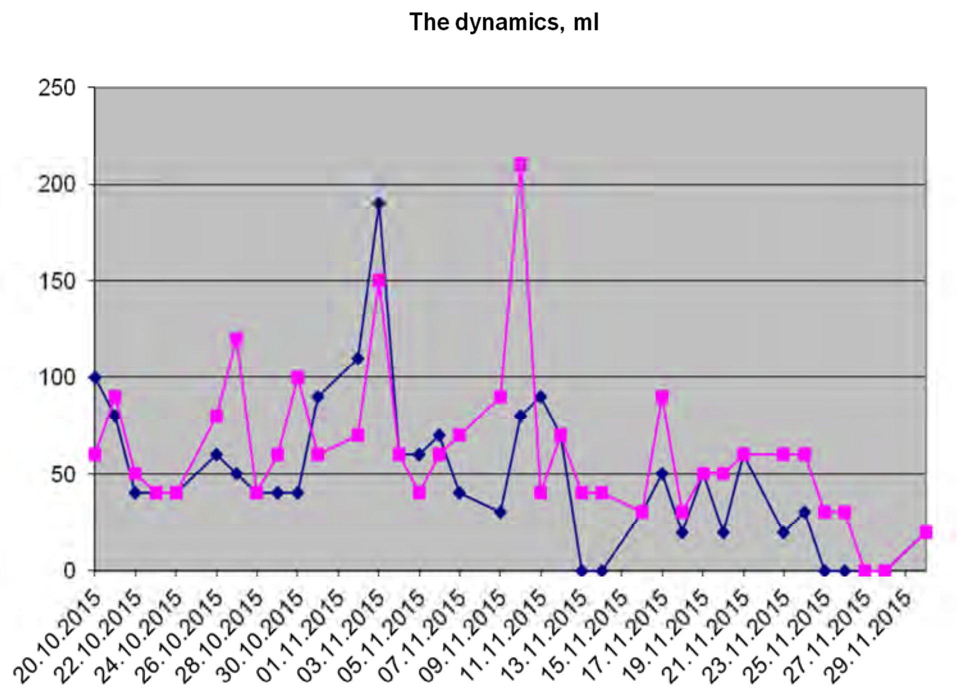

Fig. 3. Chart of laboratory productivity of biogas plants (the 0Y-axis describes the volume of biogas, cm^3)

As a result, during the whole experiment while gas released from 1 dm^3 of non-cavitated substrate an 1.72 dm^3 of biogas mixture was obtained (on 37 days), and from the same volume but cavitated substrate respectively 2.19 dm^3 (42 days) – an increase of 21.5 %. These samples were analyzed by a gas chromatograph Crystal–2000M and chemical composition of the gas mixture as well as its density and the calorific value have been defined basing on that analysis. Qualitative and quantitative characteristics of gas mixture formed in case of the cyanobacteria organic matter bioconversion, regardless of it has been subjected to pre-cavitation or not did not differ fundamentally.

Absorption analysis of biogas samples showed the presence of arithmetic mean amounts of methane (CH_4) and hydrogen (H_2) – 71.33 %, carbon dioxide (CO_2) – 20.35 %, nitrogen (N_2) – 6.45 %, oxygen (O_2) – 0.42 %, hydrogen sulfide (H_2S) – trace (0.01 %), carbon monoxide (CO) – 0.18 %, as well as other gases – 1.26 % (Table 2). The gas density was 0.915 – 0.925 kg/m^3 with a calorific value of Q = 5100 – 5200 kJ/m^3, which are in its parameters close to natural gas (propane-butane mixture).

Table 2

The chemical composition of biogas (%) obtained from the cyanogen during November, 2015

№	date	CH_4+H_2	CO_2	N_2	O_2	CO	H_2S	other
1	02.11	70,10	20,05	8,15	0,36	0,15	0,04	1,15
2	03.11	72,00	19,07	7,05	0,49	0,22	–	1,17
3	04.11	71,75	20,77	6,75	0,73	–	–	–
4	05.11	71,90	20,00	7,23	0,43	0,22	–	0,22
5	06.11	70,14	22,04	7,34	0,34	0,11	0,03	–
6	07.11	71,15	21,05	7,30	0,33	0,12	–	0,05
7	09.11	73,09	20,14	6,13	–	0,54	–	0,10
8	10.11	72,05	19,05	7,02	0,03	0,02	0,09	1,74
9	11.11	70,30	21,05	7,25	0,80	0,60	–	–
10	12.11	71,11	20,01	6,30	0,55	–	–	2,03
11	13.11	73,00	19,11	5,98	0,30	0,29	–	1,32
12	14.11	71,15	20,05	5,41	0,18	0,10	–	3,11
13	16.11	71,56	20,28	6,02	0,42	0,16	–	1,56
14	17.11	71,74	19,95	7,31	0,59	0,27	–	0,14
15	18.11	70,25	20,21	5,47	0,85	0,15	0,07	3,00
16	19.11	72,77	19,18	6,12	0,27	0,13	–	1,53
17	20.11	70,26	21,09	6,54	0,21	0,23	–	1,67
18	21.11	72,05	19,54	7,00	0,48	0,25	–	0,68
19	23.11	69,78	22,87	5,97	0,35	–	–	1,03
20	24.11	67,99	24,14	6,18	0,30	0,18	–	1,21
21	25.11	72,54	19,91	5,11	0,41	0,09	–	1,94
22	26.11	70,97	20,10	7,00	0,43	0,11	–	1,39
23	27.11	73,25	18,88	5,01	0,55	–	–	2,31
24	28.11	72,14	19,14	6,05	0,61	0,21	–	1,85
25	30.11	70,23	21,13	5,55	0,40	0,24	0,05	2,40
$\Sigma_{aver.}$	**–**	**71,33**	**20,35**	**6,45**	**0,42**	**0,18**	**0,01**	**1,26**

Conclusions

Experimental data indicates the feasibility and economic viability of using cyanea organic mass extracted from flowering spots in the water of the Dnieper reservoirs for industrial production of biogas, followed by the application of the waste substrate as a balanced organic and mineral fertilizers in forestry and agriculture. Research results generally confirm the earlier calculations of average yield of biogas per week in amount of about 0.7 dm^3 per 1 dm^3 of concentrated substrate at the optimum temperature of 30 °C [12] and the data on the prospects of the biological substrate pre-treatment in a cavitation field as the preparatory process for its further bioconversion [13].

Experiments on the production of biogas confirmed that cavitation pre-treatment by using hydrodynamic cavitation field, as the production of biogas from algae occurred much faster and the amount of produced biogas is much higher (approximately 30 %). Process kinetics of biodegradation of biomass of cyanobacteria is described by S-shaped curves indicating a complex chain process of biochemical reactions that accompanies the formation of biogas.

Obtaining certain biologically active substances used in pharmaceutical and cosmetic from phytoplankton biomass can also be perspective.

Thus, we can estimate the ability of using cyanobacteria to obtain biogas in Kremenchuk reservoir with water surface area of 2250 km^2. By collecting seston in “flowering” spots in the amount up to 50 kg/m^3 [15] in the water volume of 828 million m^3 (depth up to 2 m; 18.4 % of the reservoir area) its biomass will be 4.14×10^7 tons during the growing season. Subjecting the biomass to fermentation in the process of methane “fermentation” it’s possible to receive up to 28.98 million m^3 of biogas (≈18.837 million m^3 of methane), which is equivalent to 20000 tons of oil, or 17000 tons of diesel fuel.

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REDUCTION OF ENVIRONMENTAL HAZARD OF HUDROGEN SULFIDE EMISSION FROM SEWERAGE PIPELINES AND VISUAL POLLUTION, FORMED BY DEGASSING UNITS

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Abstract. At some sites of the sewage collector in Kharkov concentration of hydrogen sulfide in the underroof space exceeds in thousands of times daily average MPC. As a result the gaseous emissions from the sewage network in the city atmosphere the content of hydrogen sulfide in the atmosphere of residential development area may exceed the MPCd.a. The degasifier, installed above the sewage shaft efficiently rectifies gas releases. Design solutions are developed, which allow to harmonize degasifiers on sewerage nets with urban environment of different application.

Key words: sewerage pipelines, hydrogen sulfide, atmosphere, videoecology, degasifier

Introduction

The sewage disposal by the sewerage pipelines brings a range of risks for environmental safety of air, water and soil environments in settlements. Thus formation and emission of gas compounds from the sewer nets through the shafts and wells pollute the atmosphere in neighboring urban districts, as in these emissions concentration of series of the compounds mainly sulfur-containing – hydrogen sulfide, sulfur dioxide, mercaptan (alkyl sulphydrate), dimethyl sulphide (DMS), exceeds not only daily average MPC for residential areas, but also MPC for working ones. The highest rate of maximum permissible concentration (MPC) excess in gas release from the sewer nets is marked for hydrogen sulfide – highly toxic and chemically active compound of the second hazard category (MPC working area – 10, MPC daily average – 0,008 mg/m^3). Besides, the concentration of hydrogen sulfide, its derivatives and oxidation products in operational environments of the concrete sewerage pipelines (fine water, underroof space, condensate water on the roof) activate biogenic sulfuric corrosion of the roof, that reduces operating life of these pipelines (from planned 50 to 10–15 years). [1–6]. Gravity sewerage pipeline is a particular biological contact "reactor", in which spontaneous chemical and microbiological processes take place. They in particular cause forming of gas compounds in sewage disposal, which are released in the atmosphere of the underroof space of gravity sewerage pipelines. These compounds partially dissolve in condensate water on the building vault or interact with concrete directly, or after microbiological transforms. But main volume of gas compounds accumulates in the underroof space (Table 1) and is released through open shafts and wells into urban atmosphere.

Table 1

Chemical compounds in the underroof space atmosphere of sewerage pipelines [6].

Sr. No.	Compound	Arrangement of concentration by volume
1	Carbon dioxide	0,2–1,2 %
2	Hydrocarbons and their chlorinated derivatives	
	a. Hydrocarbons, mainly aliphatic C6-C14, C8-C12 (benzines)	to 500 ppm
	b. Chlorinated derivatives of hydrocarbons, mainly trichloroethene, dichloride of etherin and carbon tetrachloride	10–100 ppm
3	Hydrogen sulfide	0,2–10 ppm
4	Odorous gases and vapors	
	a. Sulfides (mainly mercaptan, DMS, some ethyl mercaptan)	10–50 ppb
	b. Amines (mainly trimethylamine and dimethylamine, some diethylamine)	10–50 ppb
	c. Aldehyds (mainly butyl aldehyd)	10–100 ppb

Formation of hydrogen sulfide in the sewage disposal results from microbiological processes of disassimilation sulfate reduction (renovation of sulfates with the hydrogen sulfide emission), which obligate aerobic sulfate-reducing bacteria perform. The activity level of hydrogen sulfide formation and its emissions in the air of the pipeline depends on many factors: COD of sewage water, concentration ratio of sulfates and COD, temperature, pH and Eh of sewage water, flow turbulence and others.Thus the hydrogen sulfide concentration in the underroof space of different sections fluctuates very significantly even within 24 hours [7]. The processes of hydrogen sulfide emission through the sewer shafts into the urban environment and its dispersion are studied rather partially, but the particular calculations and measurements testify high ecological hazard of the process for the urban environment/

Providing ecological safety of sewerage pipelines running and protection of urban atmosphere from pollution of toxic gas compounds, released from sewerage pipelines, various engineering solutions are developed: suppression of hydrogen sulfide formation in sewage disposal, suppression of hydrogen sulfide elutriation from sewage disposal in the underroof space, clearing of gas releases. In Ukraine there is some experience of usage of gas-cleaning plants– PU "Kharkovvodokanal". On its basis such protective measure of urban atmosphere is recommended by regulatory documents of Ukraine – Ukrainian national construction regulation [8]. However, under installation among residential buildings, park areas, recreation areas, especially in city districts, which have historical value, such degasifiers form strong visual discomfort – videopollution. At present special attention is paid to the issues of ecological safety of visual environment all over the world. That is why without harmonization of degasifiers at sewerage pipelines with current built-up area, their usage in cities is appeared as environmentally hazardous.

The research objective is experimental estimation of environmental hazard of gas releases from sewerage pipelines of Kharkov for residential areas of the city, and also improvement of videoecological characteristics of degassing plants at sewerage nets.

Objects and research methods

Experimental researches were carried out at the sewerage pipelines nets of Kharkov. Measurements of hydrogen sulfide concentration in the atmosphere of underroof space were performed with three gas analyzers: UG-2, "Dozor", a mine interferometer ShI-11. The obtained data was applied for the calculation of the hydrogen sulfide concentration in the gaseous emission according to the method, developed in [9] and for calculation of its dispersion in the environment of the particular districts in Kharkov. The calculation of hydrogen sulfide dispersion was performed with the program "EOL +". OND-86 (National statutory document) "Calculation procedure of repugnant substances concentration in open air, contained in emissions of enterprises" is basically applied to the calculation.

Results and discussion

The chemical composition of the underroof space atmosphere of the sewerage pipelines, identified in different shafts in Kharkov, is presented in Table 2.

Table 2

The ecologically hazardous concentration of gas compounds in the underroof atmosphere of the sewerage pipelines at collector section in Kharkov

Measure-ment date	Mine No.	Concentration of gas compounds							
		SO_2, mg/m^3	Rate of MPC excess working area/ daily average, quantity of MPC	H_2S, mg/m^3	Rate of MPC excess working area/ daily average, quantity of MPC	CO, mg/m^3	Rate of MPC excess working area/ daily average, quantity of MPC	CO_2, volu-me %	CH_4, volu-me %
1	2	3	4	5	6	7	8	9	10
01.02.13	4	35	3,5/70	24,6	2,46/3075	0	–	0,75	0
28.03.13		35	3,5/70	42,7	4,27/5337	0	–	0,57	
15.05.13		35	3,5/70	137	13,7/17125	0	–	0,63	
04.07.13		35	3,5/70	126,6	12,6/15825	0	–	0,63	
08.08.13		35	3,5/70	188,1	18,8/23512	4,2	–	0,84	
01.02.13	6	35	3,5/70	9,5	-/1187	0	–	0,57	0,57
28.03.13		0	–	7,6	-/950	0	–	0,38	0,19
15.05.13		0	–	12,6	1,26/1575	0	–	0,42	0,21
04.07.13		0	–	11,6	1,16/1450	0	–	0,42	0,21
08.08.13		35	3,5/70	17,8	1,78/2225	0	–	0,63	0,42
01.02.13	8	0	–	4	-/500	0	–	0,2	0,2
28.03.13		0	–	6	-/750	0	–	0,2	0,4
15.05.13		0	–	6	-/750	0	–	0,2	0,4
04.07.13		0	–	12	1,2/1500	0	–	0,2	0,6
08.08.13		0	–	12	1,2/1500	0	–	0,4	0,4

1	2	3	4	5	6	7	8	9	10
01.02.13	10	35	3,5/70	10,4	0,4/1300	0	–	0,19	0
28.03.13		0	–	9,5	-/1188	0	–	0,57	0,38
15.05.13		0	–	8,4	-/1050	0	–	0,21	0,21
04.07.13		0	–	12,5	1,25/1563	0	–	0,62	0,42
08.08.13		35	3,5/70	20,9	2,9/2613	0	–	0,63	0,84
01.02.13	11	0	–	12	1,2/1500	0	–	0,2	0,2
28.03.13		0	–	18	1,8/2250	0	–	0,4	0,4
15.05.13		0	–	23	2,3/2875	0	–	0,4	0,4
04.07.13		0	–	24	2,4/3000	0	–	0,4	0,6
08.08.13		0	–	28	2,8/3500	0	–	0,4	0,6
01.02.13	12	35	3,5/70	52,1	5,21/6513	0	–	0,76	0,76
28.03.13		35	3,5/70	113,7	11,37/14213	3,9	–	0,76	0,57
15.05.13		35	3,5/70	36,9	3,69/4612,5	0	–	0,42	0,42
04.07.13		35	3,5/70	38	3,8/4750	0	–	0,63	0,21
08.08.13		35	3,5/70	250,8	25,08/31350	0	–	1,25	1,25

As it is seen from the table data, hydrogen sulfide has the highest excess of MPCworking area/daily average, in gas environment of the underroof space of sewerage pipelines (in tens/hundreds times). Shafts No.11 and 12, in gas environment of the underroof space, whose hydrogen sulfide concentration accesses 31350 MPC daily average, are extremely close to residential development (from 35 to 50 m). At the whole explored section of the collector, these mines are represented as the most ecologically hazardous for urban atmosphere and safety life-sustaining ability of population, living in the area of their location.

The calculation of gas emissions dispersion in the district, where the shaft No.11 is located, was performed. Daily average MPC was taken as a standard indicator. The map of hydrogen sulfide dispersion, released from the shaft No.11 in the atmosphere of the particular city district, is represented in Fig. 1.

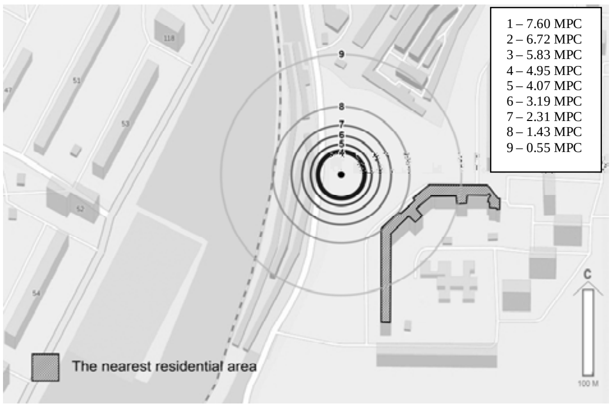


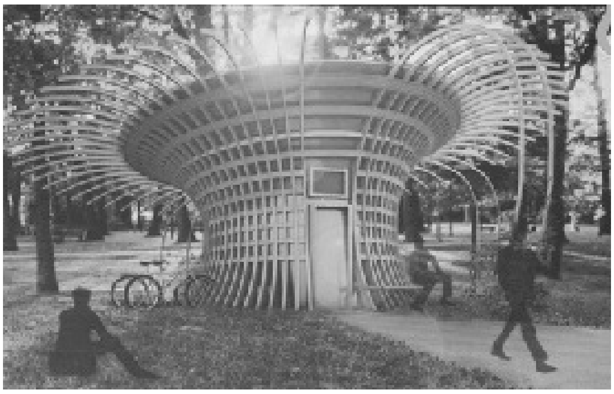
Fig. 1. The map of hydrogen sulfide dispersion, released from shaft No.11 (the Collector of KhTZ) in the city atmosphere

Calculation of hydrogen sulfide dispersion in the explored area has shown, that in the nearest point, located in residential construction (42 m), hydrogen sulfide concentration is equal to 0,0091 mg/m^3 , that in 1,14 times excesses daily average MPC. The distance to ecologically safe area is 105 m [8, 9].

At the shaft No.12 in 2014 of PU "Kharkovvodokanal" a filter-degasifier was installed for protection of urban environment from ecologically hazardous emissions from sewerage pipelines (plant of dry chemical filtration), that provided the effect of hydrogen sulfide removal 98–100 %. This environmentally friendly mechanism can be referred to hardscaping, which pollute visual environment very much (Fig. 2). This plant, located among park area, creates strong visual discomfort and cause fair blames of the population.

Fig. 2. Current plants of dry chemical filtration among park areas

Without solution of videoecological problems, that are caused by such environmental constructions, their usage is represented as little long-term and ecologically hazardous. With interview method of the staff and students of the architectural faculty of KNUCA (250 people) grade estimation of degassing plants, which are run at present (Fig. 2) and of designer solutions, recommended for these plants (Fig. 3) for harmonization with environment (Table 3), was performed. Estimation was performed in 10-grade scale as per 6 factors: outline, altitude restriction of a building, coloristic solutions, intension of environment, connection of artificial and natural environment, creation of enclosed space [10–13].



a)

b)

Fig. 3. Designer solutions, that are recommended for the degassing plants: a) park area, b) residential area

Table 3

The grade estimation of visual harmonization of a degassing plant with environment

Sr. No.	Outline	Altitude restriction of a building	Coloristic solutions	Intension of environment	Connection of artificial and natural environment	Creation of enclosed space
Current condition	3	8*	0	3**	0	9***
Project proposal	10	8	10	8	9	9

* Urrent solution unreasonably occupies a lot of space;

** Current solution supercharges environment, and project proposal vice-versa harmonizes a plant with environment, that decreases;

*** At places, where the given plant is, there are no wide gaps.

Physical form of the current plant got 23 grades, and project proposal concerning improvement of visual characteristics of the degassing plant got 54 grades. Proposed design solutions harmonize degassing plants with environment.

Conclusions

1. The performed measurements of hydrogen sulfide content in the atmosphere of the underroof space of the sewerage collector have shown, that at some sections it accesses 31350 of daily average MPC.
2. The performed calculations of hydrogen sulfide dispersion, released from the shafts, have shown, that the residential development is located in the section of above-level hydrogen sulfide content (daily average MPC). Ecologically safe section is located in the distance of 105–150 m from the shafts.
3. Installed above the shaft degasifier cleans effectively gas emissions from the shaft, however its visual characteristics form videopollution of the urban environment and affect adversely on psycho-physical condition of population.
4. Design solutions have been developed, which allow to harmonize degasifiers at sewerage nets with urban environment of different application.

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ENVIRONMENTAL PROBLEMS

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COMPLEX WATER TREATMENT OF AGROINDUSTRIAL COMPLEXES

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Abstract. The aim of this work was studying the process of phosphate adsorption on natural and synthesized adsorbents such as aluminosilicates. Sorption properties of natural zeolite concerning phosphates in static and dynamic conditions were investigated. It was found that phosphates were absorbed better in an acidic environment. Zeolites based on fly ashes of Dobrotvir heat power plant were synthesized and modified. The equilibrium values of adsorption capacity were established and the proper isotherms at a temperature 20 °C were built.

Key words: phosphates, ammonium, zeolite, equilibrium, adsorption, wastewaters

1. Introduction

As a result of heterogeneity of contaminations of industrial flow waters, after composition there is the necessity to apply a complex of methods for industrial wastewaters treating. For this purpose, in particular, mechanical, biological, chemical and physical – chemical methods are applied. However, in some cases there is a necessity to combine them. During water treatment by an adsorption method, natural and synthetic materials were used. Therefore problems of investigation of adsorption mechanisms are actual, to find the expedience of subsequent sorbent regeneration. The choice of the optimum method for implementation of adsorbtion-desorbtion processes is an essential requirement in technological processes of water treatment.

2. Experimental research

Research of phosphates adsorption by the zeolite of clinoptilolite type was carried out in static conditions using monobasic, dibasic and substituted by three atoms potassium phosphates and orthophosphoric acid.

Zeolites, which are synthesized from fly ashes**.** The experiment was carried out in Teflon crucibles with the use of the stove equipped with a temperature controller and in a thermostatic bath equipped with a mixer.

Specimens of fly ashes (40 g) were mixed with a solution of NaOH (160 ml), whereupon the mixture was crystallized at interval 90 °C …107 °C. Sediment was filtered, washed by the distilled water to pH =10 and dried out at 105 °C during 12 hours.

Determination of adsorption capacity of zeolites relatively to ammonium

To investigate the adsorption capacity of zeolite relatively to ammonium, 200 sm^3 of SM3 solution was placed in glass retorts. Ammonium chloride was removed in distilled water at different initial concentrations (C = 0.0125 – 5 g/dm^3), and zeolite (~1 г) was dipped. The range of concentrations was conformable to concentration of NH^{4+} in real wastewaters. Retorts were hermetically closed and left at periodic interfusion for two days at +20 °C. Sorbent was separated from the solution, which was analyzed for the presence of NH^{4+} on photo-colorimeter after the known method [1]

Determination of adsorption capacity of zeolites relatively to the phosphates

The essence of the method consists in the hydrolysis of phosphates into orthophosphoric acid, getting of the colored complex substance of this acid with ammonium molibdate-vanadate and determining of the colored solution optical density.

The specimens were diluted 0–50 times in a 100 ml volumetric flask, added to 25 ml of reagent and then analyzed on photo-colorimeter CFC-2-2.

3. Results and Discussion

Zeolites synthesis based on fly ashes of Dobrotvir heat power plant.

Morphology of the surface and chemical composition of the got specimens were studied by applying a scanning electronic microscope. The diameter of the electronic bunch was 1 mcm, potential acceleration was 15 cV. The elements analysis was carried out for different specimens with specific surface of 100 mcm^2 by using the scanning electronic probe, whereupon the obtained results have been averaged out. Electronic microscopic images of particles surface of fly ash and synthesized zeolites obtained by a scanning electron microscope are shown in Fig. 1.

Places marked by figures specify the numbers of spectra, chemical composition of which is shown in Table 1.

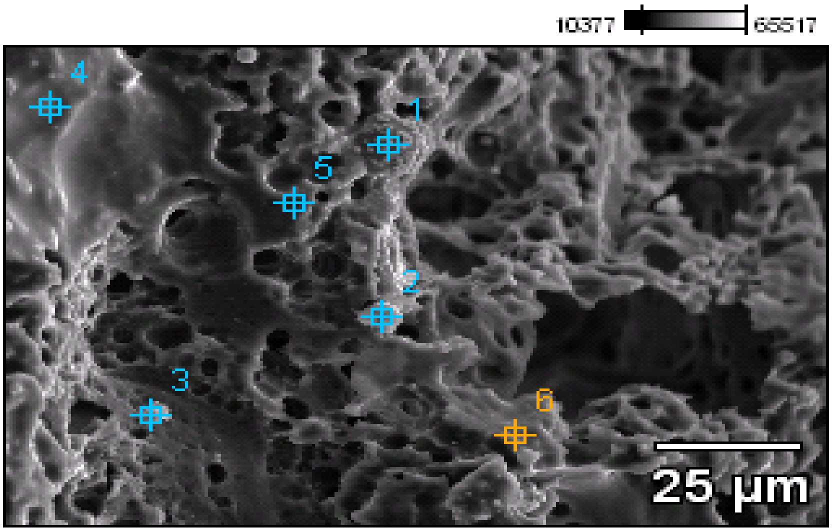


Fig. 1. Electronic microscopic images of the surface of the particles of synthesized zeolites

Table 1

Concentration of atoms, at. %

No. of spectra	Be-K	C-K	O-K	Na-K	Mg-K	Al-K	Si-K	Ca-K	Ti-K	K-K	Mn-K	Fe-K
1		45.19	32.92		0.36	0.91	1.27				0.30	19.06
2	24.07	36.19	29.36	0.07	0.41	1.00	1.66	0.19		0.12	0.15	6.77
3	26.65	32.67	29.13	0.18	0.34	2.63	6.79		0.08	0.70		0.84
4	50.19	26.71	9.17		0.15	1.22	1.81	0.30		0.25		10.21

Continuation of Table 1

Concentration of atoms, at. %

No. of spectra	C-K	O-K	Na-K	Mg-K	Al-K	Si-K	P-K	S-K	K-K	Ca-K	Ti-K	Mn-K	Fe-K
1	43.91	40.69		0.83	2.95	1.04				0.17		0.33	10.09
2	49.44	38.79	0.29	0.21	4.37	5.58	0.02	0.06	0.54	0.10	0.09		0.45
3	46.44	42.23	0.36	0.20	3.99	5.46			0.60		0.14		0.57
4	91.67	7.51	0.08	0.06	0.12	0.13		0.16		0.17			0.08
5	99.93							0.07					
6	96.90	2.88		0.04	0.04	0.06		0.06		0.02			

To determine the adsorption capacity of zeolite in relation to phosphate-ions, solutions of H_3PO_4, KH_2PO_4, K_2HPO_4 and K_3PO_4, prepared in the distilled water, at different initial concentrations (C = 25–750 mg/dm^3) were placed in 200 sm^3 glass retorts, and identical specimens of zeolite (~1 g) were added.

The experiment was carried out in Teflon crucibles with the use of the stove equipped with a temperature controller and in a thermostatic bath equipped with a mixer.

Samples of zeolite were obtained by mixing fly ashes (40 g) with NaOH (160 ml) solution of, whereupon a mixture was crystalized at 90 °C and 107 °C. Sediment was filtered, washed by the distilled water to pH =10 and dried out at 105 °C during 12 hours.

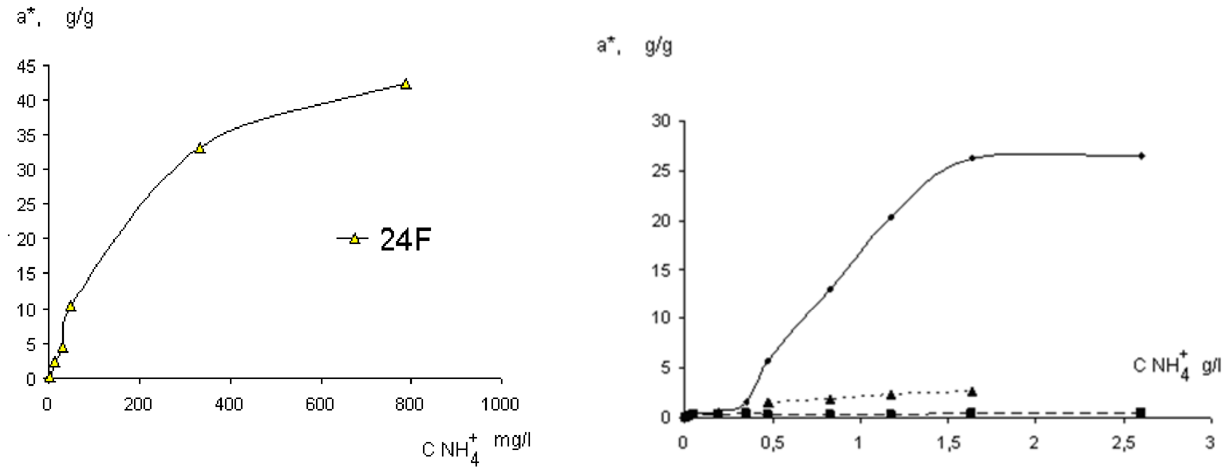
Adsorption removing of ammonium from wastewater using natural and synthetic zeolites.

Agro-industrial complexes are among the greatest water users, abstractors and simultaneously pollutants of surface and ground waters. In particular, meatpacking plants need a lot of fresh water for their activity, 95 % of which is discharged from production workshops as strongly muddy wastewaters. Adsorption properties of natural zeolite of the Socirnitsa deposit were investigated in relation to the contaminating components of wastewaters of meatpacking plants, especially amonium nitrogen, concentration of which is regulated by norms. [3, 4]

The equilibrium values of adsorption capacity were set and proper isotherms of adsorption at 20 °C were built. It was found that absorption of ammonium passes partly through the mechanism of ionic exchange. The volumes of substitution of exchange ions of sodium and calcium on an ammonium were experimentally explored.

The sorbtion capacity of zeolite of the Socirnitsa deposit in relation to ammonium ions was investigated. The mechanism of ionic adsorption of ammonium ions by zeolite is confirmed, that is accompanied with replacement of compensating ions of calcium and sodium, and also ions H^+ that are localized on bond Si-OH-Al on ammonium ions [5, 6].

It was found that the amount of adsorbed ammonium 8,7 times exceeds the amount of Ca^{2+} and Na^+ ions disengaged as a result of ionic exchange. Adsorption of ammonium ions on natural aluminosilicates was experimentally investigated. The obtained experimental results and calculation data were generalized.



1 2

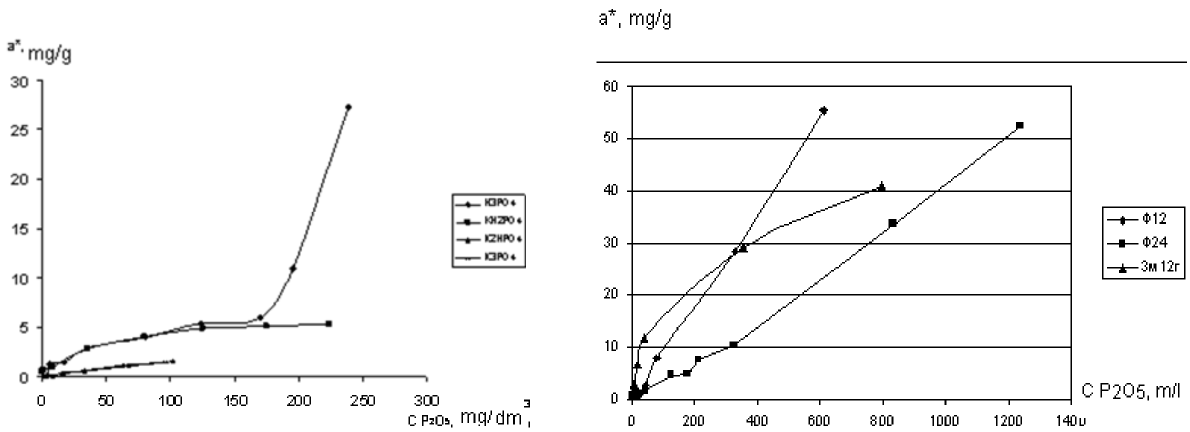
Fig. 2. Isotherms of ammonium adsorption on natural zeolite (1) on synthetic zeolite (2)

During the hydrolysis of ammonium chloride the process passes the following reaction: an ion H^+ is adsorbed on the Lyois acid centers and results in the break of communications between oxygen and aluminum, Pursuant to literary data the leaching of aluminum ion from zeolite occurs by substitution of aluminum by four hydroxyl groups. As a result, there is a destruction of zeolite surface and leaching of ion Al^{3+} into the solution. Thus $Na[AlCl_3]$ appears in the solution. This phenomenon is confirmed by the increase of optical density of the tested solution after the adsorption of ammonium salts. ΔD = 0.15–0.2, that testifies the presence of dispersed and colloid particles in the explored solution. At destruction of the surface, new adsorption centers, contained in the adsorbent are freed.

Adsorption removing of phosphate ions from wastewaters using natural and synthetic zeolites.

Investigation is devoted to water treatment. The aim of this work was to study the process of phosphate adsorption on natural adsorbents such as aluminosilicates. Sorption properties of natural zeolite (clinoptilolite of Sokyrnytsia mineral deposits) of phosphate in static and dynamic conditions were investigated. Values of equilibrium adsorption capacity were calculated and the corresponding isotherm at 20 ºC was built. It was found that phosphates were absorbed better in acidic environment.

The carried out researches showed that the process of adsorption substantially relied on the degree of substitution of phosphate ions by alkaline metals [7]. Analyzing Fig. 1, it is possible to assert that phosphates were better adsorbed in acidic environment. Thus in the value area of initial concentrations 2,5–150 mg/l isotherms of sorption of orthophosphoric acid and potassium of digidrophosphfates are practically identical, however with increasing concentration of the initial KH_2PO_4 solutions is taken less. During the initial concentration above 100 mg/l equilibrium is set. In the given range of concentrations, there is practically the same tendency at the adsorption of K_2HPO_4 and K_3PO_4 solutions. For H_3PO_4 concentrations, over 150 mg P_2O_5/dm^3 there is a sharp increase in the adsorption capacity of zeolite.



1 2

Fig. 3. Isotherms of phosphates adsorption: On natural zeolite (1), KH_2PO_4 on synthetic zeolites (2)

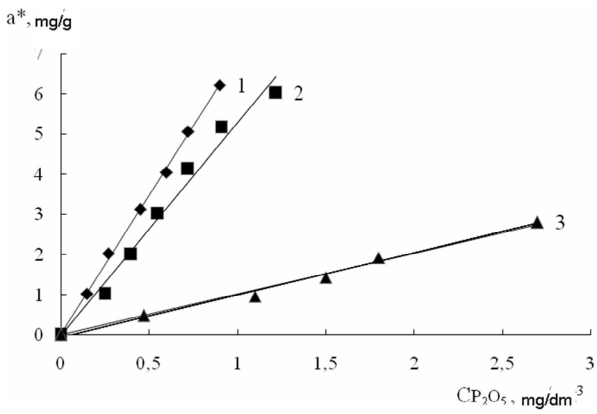


Fig. 4. Isotherms of phosphates, (KH_2PO_4) adsorption on natural zeolite (1), jointly with ammonium nitrogen (2), jointly with ammonium nitrogen and albumin (3)

Adsorption capacity of clinoptilolite relative to un-substituted phosphates is higher and decreases with substitution of orthophosphoric acid by alkali metal ions.

Essential influence of pH on the sorption properties of clinoptilolite to P_2O_5 was shown.

Research data and the known theoretical relations were identified. Kinetic coefficients of adsorption process were calculated. Coefficients of the Langmuir equation for adsorption of phosphates by zeolites were calculated by graphical and numerical methods.

Diffusion coefficient of P_2O_5 in the pores of zeolite in dynamic conditions under intensive mixing was estimated.

Conclusions

Adsorption properties of natural zeolite were investigated concerning the contaminating components of flow waters of meatpacking plants, from ammonium and phosphates.

The equilibrium values of adsorption capacity were expected and the proper isotherms were built at 20°C. It was found, that phosphates are taken in better than ammonium nitrogen.

It was explored, that adsorption ability of clinoptilolite in relation to single-phase systems is higher and diminishes in the process of simultaneous adsorption of two components from the solution.

Taking into account large supplies and cheapness of this natural sorbent, it may be used for wastewater treatment of meatpacking plants from the given contaminations. Work on their application for wastewaters treatment was carried out.

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ENVIRONMENTAL SAFETY OF WATER BODIES AND COASTAL AREAS USING THE METHOD OF WATER ENVIRONMENT BIOINDICATION BY MEANS OF MACROPHYTES

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Annotation. The purpose of this work is to improve the ecological state of water bodies and coastal area of the “Enerhoharant” LLC company by implementing a series of environmental measures based on research of their ecosystems and environmental-economic assessment that will enable largely to solve the problem of optimal use of natural resources for the recreational purposes.

Key words: ecological safety, water bodies, macrophytes, bioindication, Eichornia crassipes, vegetation

Introduction

Human life is closely connected with water, that is why significant deterioration of water quality in natural reservoirs is an extremely serious problem for the world in general and Ukraine in particular. Human activity results in a large variety of pollutants, which enter water reservoirs with industrial, municipal and agricultural runoff and accumulate there. Today it is not only dangerous to drink water from our lakes or rivers without multi-stage water purification, but also to swim in some of them without risk for health. That is why it is important to objectively assess water quality in reservoirs used for fishery and recreational purposes at the enterprise “Enerhoharant” LLC and offer effective environmental solutions to improve the ecological state of these objects.

Thus, the purpose of this work is to improve the ecological state of water bodies and coastal area of the “Enerhoharant” LLC company by implementing a series of environmental measures based on the research of their ecosystems, and environmental-economic assessment that will enable largely to solve the problem of optimal use of natural resources for the recreational purposes.

To achieve this goal it is necessary to solve the following problems:

– study of the ecosystem of water bodies and coastal areas;

– analysis of biochemical parameters of pond water;

– environmental and economic assessment and development of environmental measures for water bodies and coastal areas;

– implementation of bio-filtration of pond water with macrophytes (water hyacinth, Eichornia crassipes).

Experimental part

Water macrophytes, perform many functions in water for various purposes: meliorative, energy-accumulative, biotechnical, regulatory, resource, indicative. The most important as for the impact of macrophytes on water quality status (enriching it with oxygen, carbon dioxide absorbtion, pH changes, nutrients and heavy metals accumulation, water isotopes of radioactive elements purification), is, of course, a meliorative one.

The use of Eichornia crassipes for biological treatment of wastewater runoffs in Polissya was highly effective [1–3].

Eyhorniya is a typical hydrophyte. For ecological and biological characteristics and habitat conditions, it refers to a group of plants with leaves floating on the water surface. It is a plant, that grows in shallow waters off the coast of the rivers, lakes, ponds, canals, etc, mainly in the waters of tropical and subtropical regions of South America, and it can cover not flowing parts of lakes and ponds by dense thickets [1, 4].

In Vinnitsa region, Eichornia crassipes growing season can last from 4 to 7 months. In autumn, when reaching the average water temperature below 14 °C, water hyacinth, protected from the wind, can endure short-term lowering of the temperature to 6 °C at night and still looks quite viable, with no signs of dying. However, the mass increase of the plant stops.

Monitoring of vital functions of water hyacinth plants showed that this plant has successfully adapted to the conditions of the polluted and clean water environment because biomass of the plants grew quite rapidly, and formed to 8–15 subsidiary plants per month.

The study of the plants that grow in different polluted environments was conducted. The scape diameter ranged from 4.5±1.5 cm. The growth of the root system was the norm - up to 1 cm per week. Cilia on the root system were 0.5±0.2 cm long, black and completely overgrown with dirt, but in a relatively clean pond during one week, the plants considerably differed among themselves for a number of indicators. Their leaves were light green, the seedlings of the leaves were white, with slight greenish tint, the root system grew rapidly (3±1 cm per week), root cilia were 1,0±0,5 cm long, and bright. The diameter of the leaf stalks reached 7±1,5 cm.

Such difference in plant development can be explained by the fact that in the first case these symptoms are associated with lack of organic and mineral substances in water, hence the need to increase the area of the root system through which the plant absorbs contaminants from water (elongated root cilia, a longer root system). In a clean environment, compared to the polluted one an increase in a diameter of leaf stalks is observed (Fig. 1).

In these conditions, the plants were large in size,, sometimes even reached a diameter of 45±5 cm, the leaves were of dark green saturated color. The plants very quickly formed a large number of lateral shoots with subsidiary plants; the increase amounted to 13±3 pieces of seedlings per unit a month, and in some cases reached 15–18 pieces. The number of leaves on one plant was 20±5.

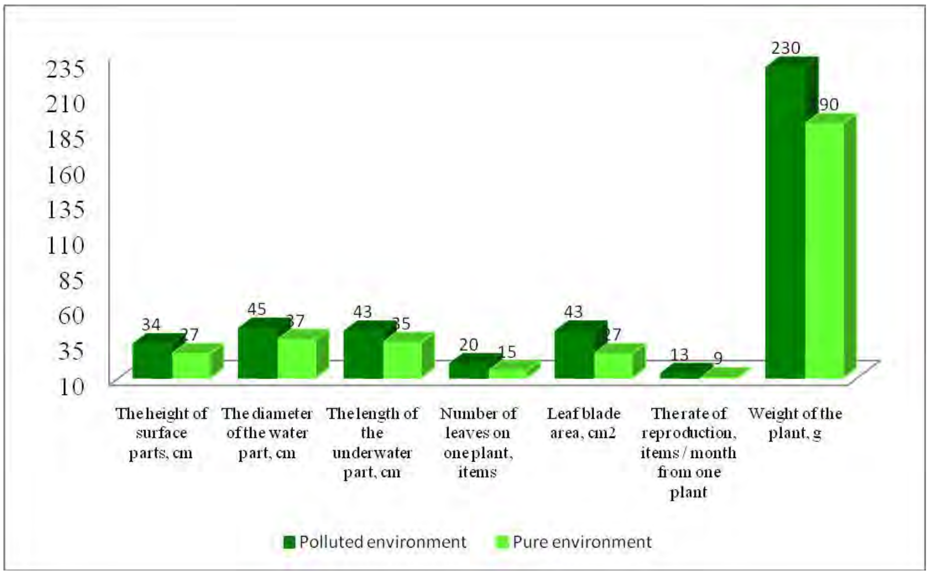

Fig. 1. The growth and development of water hyacinth plants under different growth conditions

The height of the surface part was within 34 ± 5 cm. The length of the root system reached 43 ± 3 cm, and in some instances it reached 50 cm, and the area of leaf plates ranged from 43 ± 7 cm^2. The weight per plant was 230±30 g, the biomass productivity of these plants was in total 1250±40 t/ha. The reason is that the landfills have a lot of substances of organic origin, which water hyacinth digests best. For clean environment the biomass productivity is 900±30 t/ha.

The plants grew quite intensively during the period of study. The average monthly growth of the surface part was 4.8 cm, the highest increase was observed during the first months of life and reached 11–13 cm, and the minimum of 1 cm was during the 5^{th} and the 6^{th} months of life.

The increase in the number of eyhonia plant leaves increases with the increase of the average air temperature (Fig. 2). Correlation-regression analysis showed that there is relationship between the growth rates of leaf mass and temperature conditions with correlation coefficient r = 0,84, which can be described as very high.

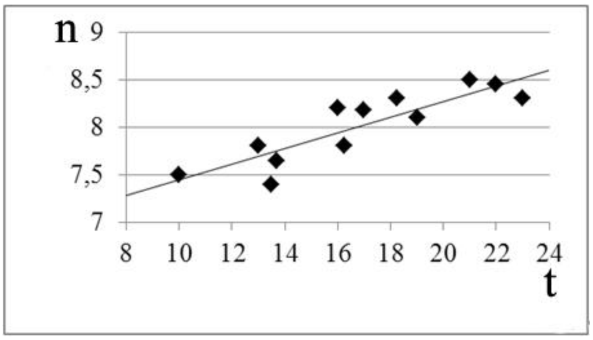

Fig. 2. Growth of assimilation system (n, items) for temperature conditions (t)

The average monthly growth of underwater part was 7.3 cm; the maximum increase was 15 cm during the 2^{nd} and

3rd months of life, the minimum – 1–2 cm – during the 5th and 6th months of life (Fig. 3). Correlation-regression analysis showed that there is relationship between the growth rate of the root system and temperature conditions with correlation coefficient r = 0,79, which can be described as high.

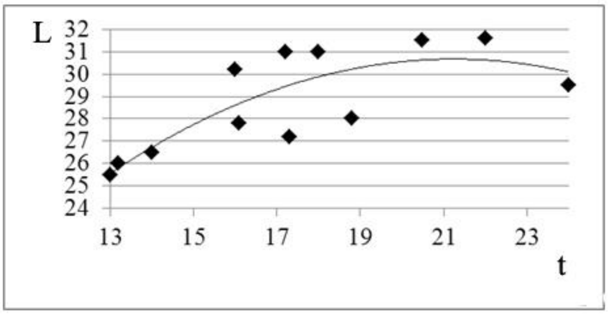

Fig. 3. Growth of the root system (L, cm) with temperature increase (t, ° C)

The average monthly increase in biomass plants of water hyacinth is 39.2 g. The total increase by one plant for 6 months is 186–206 g. The maximum monthly increase was 58 grams in six-month specimens of plants and the minimum was 27 g in one-month plants.

Correlation-regression analysis showed that the increase in biomass of water hyacinth is quite fast both in the length of surface and underwater parts – up to 13–15 cm per month, the average monthly increase is 39.2 g. For all the indicators there are relations with a coefficient of determination R2 = 0.89–94, which can be described as very high.

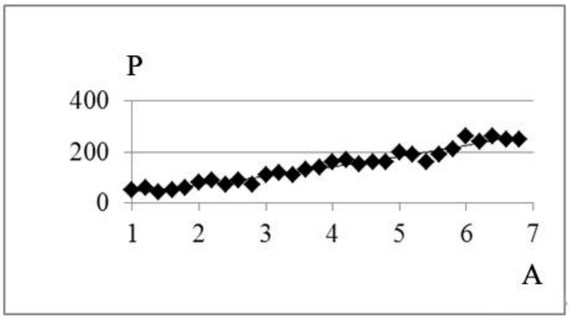

Fig. 4. Growth of biomass (P, g) of water hyacinth over time (A, months)

Further cooling caused the transfer of plants in artificial conditions, and some were left in the landfills and covered with foil (such as floating greenhouse). Water hyacinth representatives remaining in the chamber conditions evolved quite well. At water temperature of 20–30 °C, air temperature of 20–36 °C, with regular top-dressing of plants with silt every two days, Eyhornia vegetation and reproduction were quite successful.

1. Vegetation period of water hyacinth can last from 4 to 7 months in Vinnitsa region.

2. Water hyacinth has successfully adapted to the growing conditions, as biomass plants grew quite rapidly and formed to 8–15 subsidiary plants per month.

3. The most active vegetation of plants occurred in the reservoir, which was constantly affected with pulp of granite processing.

4. The average monthly increase of water part was 4.8 cm, the highest increase was observed in the first months of life and reached 11–13 cm, and the minimum of 1 cm – on the 5th and 6th months of life.

5. The average monthly increase of underwater part was 7.3 cm, the maximum increase was 15 cm in the 2nd – 3rd months of life, the minimum – 1–2 cm – 5th –6th month.

Research results

The average and maximum values of dry and wet water hyacinth biomass were established depending on the growth conditions (depth of water, % of water surface coverage, trophic level of ponds). According to the data the growth curve was constructed, its phases were defined and a model of water hyacinth growth was created.

Increase or decrease in the number of individual populations of plants is the result of physical, chemical and biological changes. In general, these changes are caused by the uncontrolled flow of nutrition elements from urban, agricultural and industrial centers.

Water hyacinth, due to its life cycle and survival strategy has significant advantages over other types of aquatic plants. Its adaptations to many environmental factors make extinction of this species almost impossible.

Westlake qualified water hyacinth as a very productive plant. According to the data obtained in Louisiana (USA) and in the waters of the river Nile (Africa), it was estimated that this kind under optimal conditions could produce up to 110–150 tons of organic matter per hectare per year [5, 6].

A wide range of productivity of this plant is noted in literature. These figures were calculated in different ways (Gopal [7]), Kipling and others [8] estimate that the annual production may be between 269 t/ha. Boyd [8] received the average productivity of 194 kg/ha/day in the enriched nutrient reservoir. This indicates that water hyacinth has a wide range of productivity.

The aim of this work is a description of the initial population of water hyacinth regarding environmental factors, creation of a model of optimum quantity of water hyacinth in water bodies and determination of the amount of biomass needed to remove the object in case of overcrowding.

Biomass was determined as the amount of organic matter in relation to the area or volume. Biomass and water volume in this case are directly proportional as the plant biomass grows in the presence of nutrient resource.

The plants biomass was studied by weighing samples, measuring of the studied area and defining the biomass of the entire population. From one square meter, the samples were collected, drained for 5–7 minutes, and their weight was determined.

7 ponds areas were selected to measure the growth and 1 kg of plants samples were researched (healthy, intact, with 3–5 leaves, of the same weight – from 30 to 45 g each and placed at each site.)

The growth of the plants was determined by weighing the increase in water hyacinth mass per unit of area and for a unit of time i.e. its productivity. Quantitative rate of the growth is essential to control the number of water hyacinth. The rate of this index depends on the following factors: plant age, climate, space and density of plants.

The studies described three parameters (biomass, density and growth rates). The main characteristics of the objects are shown in Table 2. Reservoirs were classified as mesotrophic if phosphorus concentrations were between 10 and 35 mg/m^3 or eutrophic if the concentration of phosphorus ranged from 35 to 100 mg/m^3

The highest average values of biomass were 49.6 (2.79) 42.6 (2.39) and 45.7 (2.57) kg/m^2 and the maximum values of 76 (4.27) 57 (3.20) and 67 (3.76) kg/m^2, were in reservoirs areas 2, 3 and 7. These were the smallest studied reservoirs and they had the highest density. Generally, these values are similar to those obtained in other parts of the world [1; 9–11]. The maximum surface coverage was generally observed when the area coverage was minimal, and therefore the volume was the smallest.

It should also be noted that the growth of water hyacinth plants is the highest in waters with little depth, and the lowest recorded productivity was observed in the deepest waters.

Table 2

Parameters of water object

Water body	Parameters of water reservoir					
	temperature, °C	precipitations, mm	surface area, m^2	volume, th.m^3	depth, m	trophical level
1	17,2	1096	38,79	89,22	2,30	mezotrophic
2	22,0	900	10,00	4,00	0,40	eutrophic
3	24,4	814	5,70	21,60	0,90	mezotrophic
4	25,3	734	24,00	79,83	14,00	eutrophic
5	15,4	553	17,30	27,00	5,00	eutrophic
6	17.0	609	8,43	126,45	15,00	eutrophic
7	21,1	1237	5,40	33,56	1,94	mezotrophic

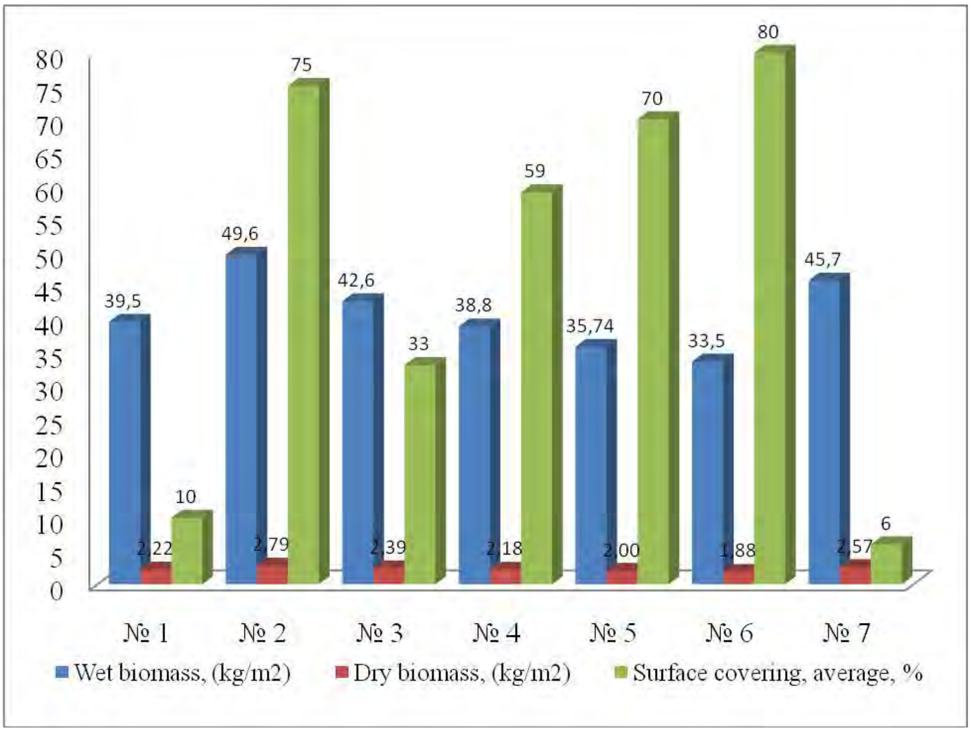

Fig. 5. The total biomass of plants Eichhornia crassipes (Mart.) Solms in vivo environment of water

The studies have also shown the highest rates of biomass observed in reservoirs 2 (49.6 kg / m^2 of wet and 2,79 kg/m^2 of dry biomass), 3 (42.6 kg/m^2 of wet and 2.39 kg/m^2 of dry biomass) and 7 (45.7 kg/m^2 of wet and 2.57 kg/m^2 of dry biomass). Obviously, this is due to the optimum growth of temperature conditions (21,1–24,4 ° C). Minimum rates of biomass were observed in reservoirs 1 (39.5 kg/m^2 of wet and 2.22 kg/m^2 of dry biomass), 4 (38.8 kg/m^2 of wet and 2.18 kg/m^2 of dry biomass), 5 (35, 74 kg/m^2 of wet and 2,0 kg/m^2 of dry biomass) and 6 (33.5 kg/m^2 of wet and 1.88 kg/m^2 of dry biomass).

The percentage of the water surface coverage is associated with trophic level of the reservoir. The nutrients that cause eutrophication, primarily include nitrogen, phosphorus and silicon in a variety of compounds. The most important are phosphorus and nitrogen, which are binding elements of any living organism's tissues.

The concentration of nutrients and their mode depends on the intensity of biological and biochemical processes in the reservoir and the amount of nutrients entering the pond with sewage and surface runoff in the catchment area. The concentrations of nitrogen and phosphorus characterize "trophicality" ("nutrition") of the reservoir.

Excessive water eutrophication begins at nitrogen concentration of 0.2–0.3 mg/l and phosphorus – 0.01–0.02 mg/l.

In the transition from oligotrophic ponds to mesotrophic and eutrophic ones, the content of ammonia nitrogen significantly increases in its total amount.

Thus, areas of water bodies that had a significant level of eutrophication, were characterized by high percentage of water surface coverage (59–80 %), and mesotrophic (with medium eutrophication) had low surface coverage (6–33 %).

In assessing the growth processes of the plants cultivated in version 5, the characteristics of the growth of water hyacinth are defined.

According to the obtained data, one can see that the growth curve is characterized by three phases:

1) phase of delay, represented by exponential growth;
2) phase of linear growth,
3) a slow phase of exponential growth.

Maximum productivity was achieved during the period when maximum biomass of 51 kg/m^2 was obtained in the period from July to February, 51 kg/m^2 from December to March and 55 kg/m^2 from April to June. So maximum biomass was determined, that was about 2,300 g/m^2 in dry weight, with the range of values within 2,101–3.916 g/m^2. The research in all the periods showed a clear linear relationship of biomass growth during the time with determination coefficients of R^2 = = 0.96–0,87, which can be described as very reliable.

Concerning the growth rate, the average rate of 52 g/m^2/day was observed in June and July, with a maximum value of 64 g/m^2/day. In option 5 the rates 59.1 and 60.4 g/m^2/day were defined from July to February and from April to June. The growth rate in both periods was calculated according to the inclination of the growth curve.

If we consider the average growth rate of 0.551 t/ha/day during the increase season (from April to November, 244 days), we can consider, that annual growth can be about 134.4 tons/ha.

As seen in Fig. 6, the seasonal dynamics of water hyacinth growth is distributed as follows: the highest relative growth rate is typical for spring (9.34 %) and summer (8.20 %) periods. During the autumn cold spells, relative growth rate falls (2.03 %). The time of biomass doubling in spring and summer is the highest – 7.42 and 8.45 days, respectively, in the autumn period the time of biomass doubling is much longer, reaching 34.60 days. According to these data, the rate of exponential growth is calculated. It is determined, that in spring and summer this figure is 0.072 and 0.049 g/day, and in autumn it falls to 0.016 g/day.

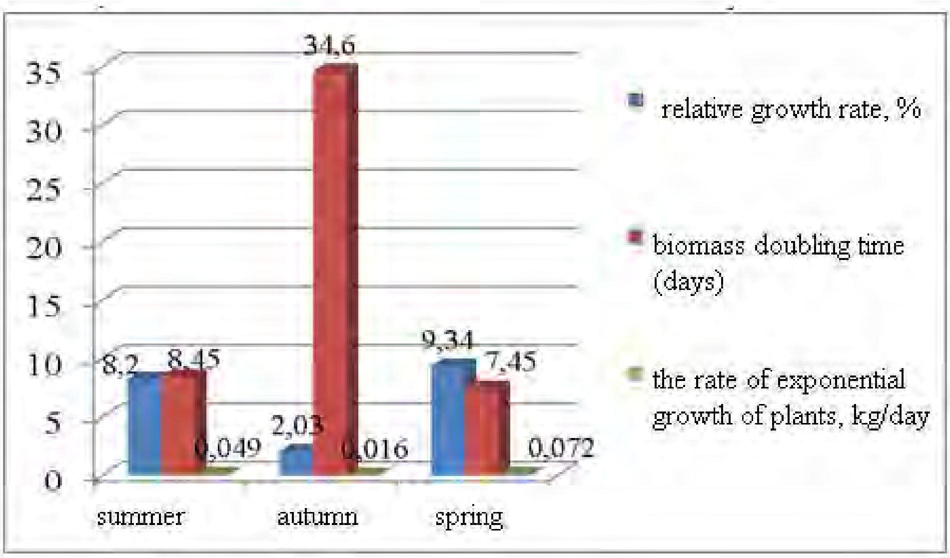

Fig. 6. Relative growth rate, doubling time, the density of the plants and the growth rate of the water hyacinth

Conclusions

The main problem for the studied water objects is the excess of maximum permissible levels of nutrients.

To solve this problem it was proposed to use such environmental measures as bio-filtration of water by means of macrophytes (higher aquatic plants), namely water hyacinth.

The results of the studies of the plants growth and development under conditions of eutrophycation waters are presented.

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