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DETERMINATION OF THE ENVIRONMENTAL EFFECT OF THE WATER PULVERIZING AERATOR IN THE CONDITIONS OF YAVORIV ARTIFICIAL LAKE

The paper describes the experience of restoration of the lands disturbed by the mining industry by applying proper water management of worked-out quarries reclamation. The necessity of works on regular maintenance of the *anthropogenic* techno-ecosystem and artificial reservoirs is highlighted. Water quality is considered to be one of the most important characteristics of water resources that determine the possibility of their rational use. Most artificial lakes are characterized by high water content of sulfate ions. Oxygen is one of the most important dissolved in water gases. The dynamics of its content is determined by physicochemical and biological processes, and the uneven vertical distribution of oxygen in the lake is accompanied by the formation of products of anaerobic decomposition of organic matter such as hydrogen sulfide, methane, and ammonia.The use of aeration systems in the world allows considering aeration as an effective tool in conditions that are critical for hydroecosystems. Aeration methods can enrich water with oxygen and improve the ecological condition of the artificial lake. The paper shows the environmental advantages of using wind energy compared to the energy generated by burning different types of fuel. In the course of research calculations were made for the operation of a water pulverizing aerator designed by Podsyadlovsky in the location of Yavoriv artificial lake (Western Ukraine). The location of the lake is favourable for tourism development as it can provide various types of recreation for both local and transit holidaymakers.The environmental advantages of the wind drive of the water pulverizing aerator designed by S. Podsiadlowski for reclamation of Yavoriv artificial lake are mathematically determined and analyzed. The environmental effect is related to the benefits of replacing the energy obtained by burning fossil fuels at a power plant with wind energy. The environmental effect, which is determined in the process of mathematical calculations and on the basis of regression equations, complements modern knowledge in the field of bottom water aeration with the use of a water pulverizing aerator based on the Podsiadlowskis concept.

Keywords: lake reclamation; water aerator; wind energy; CO_2 emission; dissolved oxygen.

Introduction

Transformations of worked-out lignite quarries into lakes with accompanying recreation areas have ensured the integration of former mining branches into local and regional business networks in Germany [3]. German experience of water management of reclamation of lands disturbed as a result of open mining is adopted in Poland [14]. Post-mining excavations filled with water become new artificial lakes [3, 5, 13, 14]. The creation of lake ecosystems increases the biodiversity of post-mining landscapes, contributing to their reproduction and the development of recreational potential [4]. An artificial lake 70 m deep with a total volume of over 200 million m³, which is the largest in Ukraine, was created on the site of the former Yavoriv sulfur quarry in the Lviv region. Its location allows meeting the needs of water recreation for local residents, as well as transit holidaymakers, in particular from the nearest major cities in Poland. For that purpose, it is necessary to provide appropriate conditions for the development and life of aquatic organisms in the lake.

The object of research is the environmental advantages of using the wind-driven water pulverizing aerator by the Podsiadlowskis concept to improve the qualitative and quantitative indicators of water of artificial reservoir water.

The subject of research is artificial aeration of water with the use of the wind-driven water pulverizing aerator by the Podsiadlowskis concept.

The purpose of research is to determine the environmental effect expressed in kilograms in relation to carbon dioxide emissions due to the replacement of energy obtained by burning fossil fuels by the energy of a wind-driven water pulverizing aerator in the location of Yavoriv artificial lake.

The task of the research was to obtain data on the environmental benefits of artificial aeration of water when using a wind-driven aerator.

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Novelty of the obtained materials is that for the first time the environmental effect of the aerator wind drive, expressed in kilograms of emission reductions due to the replacement of energy generated in the process of combustion of fossil fuels by wind energy. The results of the research can be used in the practice of planning works on water reclamation of post-mining landscapes of Ukraine to ensure nature protection and rational use of their resources according to the principles as close as possible to natural ones. The relevance of the research is to expand knowledge on improving the aerobic conditions of the bottom water of lakes while simultaneous removing gases formed during anaerobic decomposition of the bottom matter from the lake bottom into the atmosphere.

Literature review. The experience of water reclamation in the process of liquidation of coal enterprises of the Dnieper lignite basin showed that the intensity of hydrogen sulfide formation depended on the amount of organic matter in the water [13]. Reducing the content of sulfate ions in water and preventing pollution are the main conditions to prevent the biogenic formation of hydrogen sulfide [3, 5, 6, 10, 11, 12, 13].

Lake reclamation projects may include such kinds of work as clearing the water body from bottom sediments, removal of mechanical clogging of water bodies, aeration of water bodies, algolization, various types of biological reclamation of water bodies, bioplateau creation, biogenic consolidation of coastal slopes and shoreline within coastal protection strips, siltation and consolidation by shrub vegetation using geogrids and geotextiles, and elimination of accumulated pollution within protective strips [11].

One of the methods improving the environmental condition of the lake is the artificial aeration of its water using a wind-driven water aerator of the Podsyadlovsky concept [12]. In the process of aeration of the lake water, the Podsiadlowskis spray aerator improves the aerobic conditions of its bottom zones while simultaneously removing gases formed by anaerobic decomposition of the bottom substance into the atmosphere. There are known works on the occurrence and release of gases into the environment through the blade of the aerator of the spray aerator of water [10] and methods for determining the operating parameters of the aerator in the process of aeration of the lake [6]. The question was to determine the environmental effect of the aerator wind engine, expressed in kilograms of emission reductions by replacing the energy produced in the combustion of fossil fuels with wind energy.

Methodology. The environmental effect of the water pulverizing aerator with Savonius vertical-axis wind turbine was determined considering the meteorological conditions of the Yavorivsk artificial lake location. The assessment of air pollution by carbon dioxide was performed using the parameters of emissions from the power plant in the process of the combustion of bituminous coal and lignite, fuel oil and natural gas with different calorific values and sulfur content (Table).

Estimation of energy intensity of the wind-driven water pulverizing aerator was performed on the basis of the analysis of three-hour average wind speeds $v \geq 2.0$ m·s^{-1} during the period of 2007-2017 according to the Rava-Ruska meteorological station [1]. The constant mass density of an air stream $\rho = 1.168$ kg·m^{-3} according to International Standard Atmosphere (ISA) (t = 25 °C, $p = 100$ kPa) is accepted for calculations. The wind capacity factor (c) using the Savonius wind turbine system is 0.2. The width of the wind turbine (a) is 4 m; its height (b) is 5 m. The distance from the reservoir surface (l) is 2 m.

Table. Power Plant Emissions Indices from Fossil Fuel Combustion

Type of fuel	Heat capacity, MJ·kg^{-1}	Sulfur content, %	*Carbon* dioxide *emission index,* [g·(kW·h)$^{-1}$]
Bituminous coal	29.20	0.9	781
Lignite	08.45	0.3	1015
Fuel oil	42.70	0.2	858
Natural gas	43.60	–	348

Note: for natural gas, the heat capacity is expressed in MJ·m^{-3}; *carbon* dioxide *emission index in* [m^3·(kW·h)$^{-1}$]

The energy in the vertical profile at a height of 10 m is determined in relation to a flat surface perpendicular to the wind direction (A), with an area of 1 m^2, according to the formula [7]:

$$E_{10} = \frac{\rho_n \cdot A \cdot c_p \cdot v^3 \cdot t_v}{2} \cdot 10^{-3}, \quad (1)$$

where: E_{10} = three-hour energy in the cross section of the horizontal wind flow of *10 m* above *open* flat ground, kW·h; ρ_p = air flow density, kg·m^{-3}; A = a flat surface perpendicular to the wind direction, m^2; c_r = capacity factor of a Savonius wind turbine, –; t_v = wind duration, h; 10^{-3} = unit conversion unit (W to kW).

The energy (1) decreased every 1 m in the b-profile of the height of the wind drive of the water pulverizing aerator based on the dependence [9], changed to:

$$E_b = E_{10} \cdot \left(\frac{b}{10}\right)^{3 \cdot \alpha}, \quad (2)$$

where: E_b = three-hour energy at the analyzed height b of the wind drive of the water pulverizing aerator, kW·h; E_{10} = three-hour energy in the cross section of the horizontal wind flow of *10 m* above *open* flat ground, kW·h (1); 10 = energy height E_{10}, m; b = energy height E_b, m; α = parameter for calculating the exponential function, –.

The value of the parameter α is 0.14 in accordance with Trepinskas recommendations [17] for wind speed (v) over 10 m·s^{-1}. The results of calculations (2) were used to determine the energy consumed by the water pulverizing aerator for forced volumetric water flow and pulverizing aeration. The formula for calculations is as follows:

$$E_A = a \cdot \sum_{i=1}^{n} E_{b_i}, \quad (3)$$

where: E_A = the three-hour energy consumed by the wind-driven water pulverizing aerator for forced volumetric water flow and pulverizing aeration in the open space, kW·h; a = the width of the wind generator of the water pulverizing aerator in the axis of rotation, m; E_{b_i} = three-hour energy at i height b of the wind engine of the water pulverizing aerator, kW·h (2).

The weighted environmental effect was determined on the basis of emission indicators (Table 1) and three-hour energy demand (3) of the wind-driven water pulverizing aerator according to the following formula:

$$e = E_A \cdot W_e \cdot 10^{-3}, \quad (4)$$

where: e = environmental effect, kg; E_A = wind energy demand for the water pulverizing aerator, kW·h (3); W_e = emission index, g·(kW·h)$^{-1}$.

The results of calculations (4) on the basis of data on wind speed for 2007-2017 are sorted by months every 1 m·s[-1]. The weighted average value was determined by the following statistical formula:

$$x_{śr} = \sum_{i=1}^{n} z_i N_i \Big/ \sum_{i=1}^{n} N_i \,, \qquad (5)$$

where: x_{sr} = weighted average value of the environmental effect, kg; z_1, z_2, z_n = maximum values of distribution series; N_1, N_2, N_n = number of observations (number) in the distribution series.

The weighted average environmental effect (5) for the considered fuel types of the power plants is presented in the form of four nomograms. For statistical analysis, the dependent variables were described by polynomial regression equations of the 6[th] degree, where the independent variable is the number of month. The regression equation was developed using Microsoft Excel spreadsheet application. Considering the practical aspect of the obtained nomograms, the analysis of their data, the description of regression equations and graphs is narrowed to the value of the coefficient of determination (R^2), and the degree and correctness of the polynomial are based on the standard deviation of the random component (Se) and the expression coefficient (V_{Se}).

Results and Discussions

The use of wind energy has environmental benefits associated with avoiding emissions of greenhouse gases and other pollutants from energy production [16]. Reducing the amount of pollutants that enter the environment by replacing energy from conventional sources with energy from renewable sources provides the environmental effect. This factor is quantified in units of mass of pollutants emitted [15]. The water pulverizing aerator by the Podsiadlowskis concept has the environmental effect mentioned due to the Savonius wind turbine system with a vertical axis of rotation, which is used to drive the working elements of the aerator in the process of water aeration in the bottom zone [12]. Despite the recreational attractiveness of Yavoriv artificial lake, the development of tourism and fishing, as well as the advantages of the water pulverizing aerator by the Podsiadlowskis concept to improve the purity of the lakes, the environmental effect of the wind drive of the water pulverizing aerator to replace the energy produced by burning fossil fuels with wind energy is determined. The results of calculations (5) of the environmental effect (*e*, kg) are summarized on the graph by months, type of fossil fuel and in the form of dependent variables described by regression equations of the t 6[th] degree (Figure). The environmental effect described by the regression equations is of practical importance for the initial assessment of the reduction of carbon dioxide emissions from the combustion of bituminous coal, lignite, fuel oil and natural gas of different calorific value and with different sulfur content in the reclamation of Yavoriv artificial lake. The relatively high value of the coefficient of determination (R^2), 89 %, and the small coefficients of the random component (Se), ranging from 0.0046 to 0.0133, and the coefficients of expression (V_{Se}), ranging from 0.0208 to 0.1000, prove the correctness of the equations regression used and proper drawing of the diagram for assessing the environmental effect.

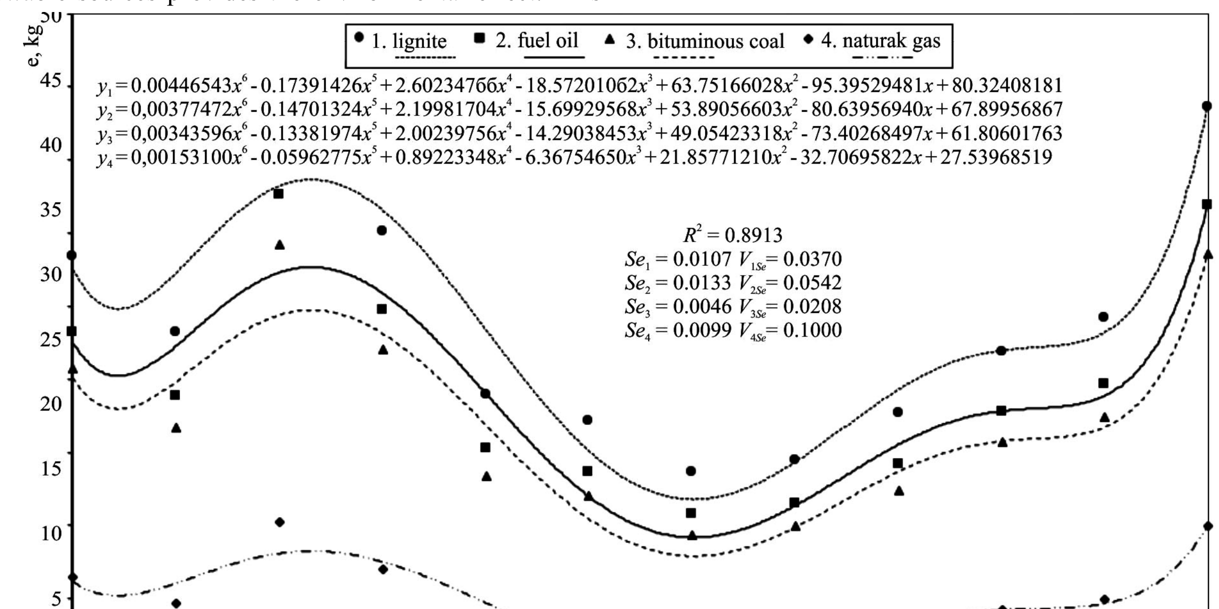

Figure. The environmental effect (e, kg) by months and power plant fuel, associated with the decrease in the amount of carbon dioxide in Yavoriv artificial lake to replace the energy produced by the energy of the wind-driven water pulverizing aerator (authors own study based on the analysis of average three-hour wind speeds for 2007-2017).

The analysis of the weighted average values (5) obtained on the basis of calculations (4) has shown the greatest environmental effect for the environment, ranging from 18.689 to 44.486 kg, when replacing the electricity obtained by lignite combustion, and the lowest environmental effect ranging from 6.408 to 15.252 kg due to replacing of electricity obtained by combustion of natural gas. The reason for this is that lignite has the highest pollutant emissions into the environment, and natural gas is the cleanest fuel, which does not cause emissions of dust, ash and sulfur dioxide in the process of combustion [2]. The calculated environmental effect in reducing carbon dioxide emissions based on the combustion of fuel oil and coal for individual months ranges consistently from 15.798 to 37.605 kg and from 14.380 to 34.230 kg. In the case of analysis of the minimum and maximum weighted average values of the environmental effect associated with the considered power plants and individual months, their lowest values are in the range from

6.408 to 19.487 kg, they occur in July and August, and the largest values are in March (ranging from 15.252 up to 44.486 kg) and December (ranging from 14.957 to 43.624 kg). The lowest environmental effect is the result of relatively low wind speeds in summer [1], which averages 3 $m \cdot s^{-1}$ at the Rava Ruska weather station, and, consequently, from the reduction of energy consumption (on average from 0.018 to 0.019 kW·h) by wind turbine of the pulverizing aerator in the process of aeration of the bottom zones water. The maximum values of the ecological effect are observed in winter at an average wind speed of 3.8-3.9 $m \cdot s^{-1}$ and the amount of energy that the wind turbine of the water pulverizing aerator requires averages from 0.036 to 0.043 kW·h.

Conclusions

The environmental benefits of a wind-driven turbine of the aerator due to replacement of energy obtained by combustion of fossil fuels at a power plant with wind energy are mathematically identified and analyzed in view of the attractive location of Yavoriv artificial lake for tourism and fishing, as well as the need to maintain its water purity, in particular with the use of the water pulverizing aerator designed by Podsiadlowski. The ecological effect determined in the process of mathematical calculations and on the basis of regression equations complements modern knowledge in the field of bottom water aeration with the use of the water pulverizing aerator of Podsiadlowski s concept.

Based on the obtained results of the study, the following conclusions are drawn:

1. The environmental result is to reduce the negative impact on the environment, improve its condition by reducing the amount of carbon dioxide entering the environment due to the use of electricity obtained by the combustion of fossil fuels with different calories and sulfur content, replacing it with the electricity obtained by the wind turbine of water pulverizing aerator. Quantitative measurement of the environmental effect is expressed in kilograms of carbon dioxide.
2. The greatest environmental effect as a result of the use of the wind-driven water pulverizing aerator is to reduce carbon dioxide emissions from 18.689 to 44.486 kg compared to the use of electricity obtained by lignite combustion. The lowest value of the environmental effect ranges from 6.408 to 15.252 kg of carbon dioxide emissions due to the use of electricity generated by natural gas combustion.
3. The magnitude of the environmental effect of the water pulverizing aerator depends on the wind speed and, as a consequence, the energy consumed by the wind turbine for aeration of bottom waters. Considering studied fuels for the power plant, the lowest value of the environmental effect ranging from 6.408 to 19.487 kg is observed in the conditions of Yavoriv artificial lake during July and August, which corresponds to the aerator energy in the range from 0.018 to 0.019 kW·h. The greatest value of the ecological effect is observed in March ranging from 15.252 to 44.486 kg, and in December – from 14.957 to 43.624 kg – with energy of 0.036 and 0.043 kW·h.

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ВИЗНАЧЕННЯ ЕКОЛОГІЧНОГО ЕФЕКТУ ПУЛЬВЕРИЗАЦІЙНОГО АЕРАТОРА ВОДИ В УМОВАХ ЯВОРІВСЬКОГО ШТУЧНОГО ОЗЕРА

Розглянуто досвід відтворення порушених гірничодобувною промисловістю земель способом застосування водогосподарського безпосередньо рекультивації відпрацьованих кар'єрів. Відзначено потребу робіт із регулярного підтримування штучно створеної техноекосистеми та обслуговування штучних водойм. Якість води належить до найважливіших характеристик водних ресурсів, що визначають можливість їх раціонального використання. Для більшості штучних озер характерний підвищений вміст у воді сульфат-іонів. Кисень є одним із найважливіших розчинених газів у воді. Динаміка його вмісту визначається фізико-хімічними і біологічними процесами, а нерівномірний вертикальний розподіл кисню в озері супроводжується утворенням продуктів анаеробного розкладу органічних речовин – сірководню, метану й аміаку. Застосування аераційних установок у світі дає змогу розглядати аерацію як ефективний засіб у критичних для гідроекосистем умовах. Аераційні методи дають змогу збагатити воду киснем і покращити екологічний стан штучного озера. У цьому дослідженні показано екологічні переваги використання вітрової енергії порівняно із енергією, утвореною спалюванням різних видів палива. Розрахунки здійснено для роботи пульверизаційного аератора води конструкції Подсядловського в умовах розташування Яворівського штучного озера (Західна Україна). Це озеро має сприятливе розташування для розвитку туризму. Воно забезпечує різні види рекреації місцевим і транзитним відпочивальникам. Математично визначено та проаналізовано екологічні переваги вітрового приводу пульверизаційного аератора води конструкції Подсядловського для рекультивації Яворівського штучного озера. Екологічний ефект полягає у перевагах внаслідок заміни енергії, отриманої спалюванням викопного палива на електростанції, енергією вітру. Визначений у процесі математичних розрахунків та на основі регресійних рівнянь екологічний ефект доповнює сучасні знання в галузі аерації придонних вод із застосуванням пульверизаційного аератора води концепції Подсядловського.

Ключові слова: рекультивація озера; аератор води; вітрова енергія; емісія CO_2; розчинений кисень.