UDC 628.336.5
DOI: 10.15587/1729-4061.2016.86053

DEVELOPMENT OF ENVIRONMENTALLY SAFE TECHNOLOGICAL WATER DISPOSAL SCHEME OF AVIATION ENTERPRISE

S. Shamanskyi
PhD*
E-mail: shamanskiy_s_i@mail.ru
S. Boichenko
Doctor of Technical Sciences,
Professor, Head of Department*
E-mail: chemmotology@ukr.net
*Department of ecology
National Aviation University
Kosmonavta Komarova ave., 1,
Kyiv, Ukraine, 03058

Розроблено нову технологічну схему водовідведення. Її головні відмінності полягають в організації додаткового очищення господарчо-побутових стоків шляхом використання їх як середовища для культивування енергетичних мікроводоростей та в організації анаеробного зброджування осадів, отриманих після механічного і біологічного очищення стоків, та біомаси мікроводоростей, з врахуванням кінетики бродильних процесів. Технологічна схема дозволяє підвищити ступінь очищення стічних вод, а також отримувати екологічно безпечне органічне добриво, відновлювані енергоносії та вуглекислий газ

Ключові слова: авіапідприємство, очищення стічних вод, відновлювані енергоносії, утилізація осадів стічних вод, технологічна схема водовідведення

Разработана новая технологическая схема водоотведения. Ее главные особенности заключаются в организации дополнительной очистки хозяйственно-бытовых стоков путем использования их как среды для культивирования энергетических микроводорослей и в организации анаэробного сбраживания осадков, полученных после механической и биологической очистки стоков, а также биомассы микроводорослей, с учетом кинетики бродильных процессов. Технологическая схема позволяет повысить степень очистки сточных вод, а также получать экологически безопасное органическое удобрение, возобновляемые энергоносители и углекислый газ

Ключевые слова: авиапредприятие, очистка сточных вод, возобновляемые энергоносители, утилизация осадков сточных вод, технологическая схема водоотведения

1. Introduction

At the aviation enterprises, similar to enterprises of other industries, several types of wastewater are formed. They can be conditionally divided into industrial, industrial-household and surface wastewater [1, 2]. Water disposal systems typically consist of draining networks, pumping stations, purifying plants, and outlets. Technologies of purification depend on the type of wastewater and may significantly differ [3, 4]. At the purifying plants that treat all types of wastewater, significant amount of dangerous sediment is formed, which also needs recycling.

Experience shows that modern water disposal technologies are not always environmentally friendly. Wastewater treatment plants do not always provide for sufficient quality at the outlet (residual concentrations of contamination in them often exceed the established requirements); the ways of sediment recycling often have a significant negative impact on the environment. This leads to the occurrence of environmental risks in the operation of aviation enterprises.

However, the water disposal systems are the objects where, with a certain organization of processes, it is possible to obtain additional alternative energy sources, and due to this, partially or fully satisfy energy needs of an enterprise [5]. Thus, the search for ecologically safe methods of organization of water disposal systems and development of energy-efficient technological schemes of these processes is a relevant problem at present.

2. Literature review and problem statement

In the course of development of water disposal schemes of an aviation enterprise, it is necessary to take into consideration a number of factors, such as:

– amount and composition of formed wastewater;

– possibility and expediency of their treatment at local purifying plants;

– possibility of applying different purification technologies;

– possibility and expediency of separating valuable substances (materials) from wastewater and their further use;

– possibility of obtaining and recycling (using) of additional power resources at purification plants, etc.

All kinds of wastewater of an aviation enterprise are collected and transported by the system of sewer pipes and channels. These waters can be purified at local sewage treatment plants of an enterprise [6], or dumped into a city's sewer system for treatment at communal sewage treatment plants [7]. For example, surface wastewater of DP "International Airport "Boryspil" (Ukraine) is treated at its own sewage treatment plants, and industrial-household wastewater is dumped into the sewer network of the city of Boryspil.

There are several methods of organization of water disposal [8].

A general water disposal system (Fig. 1) has one common water disposal network when industrial, household and surface waters are fed to general sewage treatment plants. Such system is possible when industrial wastewater is close in composition to industrial-household wastewater and may be treated by the same technology.

The disadvantage of such a system is that during water disposal proess, mixing of different kinds of wastewater occurs. If industrial or surface wastewaters contain petroleum products and other aggressive elements, they may not be dumped into a city's sewer network, because their getting to municipal wastewater treatment plants can lead to disruption of purification technology. They may have especially negative impact on the operation of biological treatment plants. In this case, it is also difficult to organize the purification process at local sewage disposal plants [9].

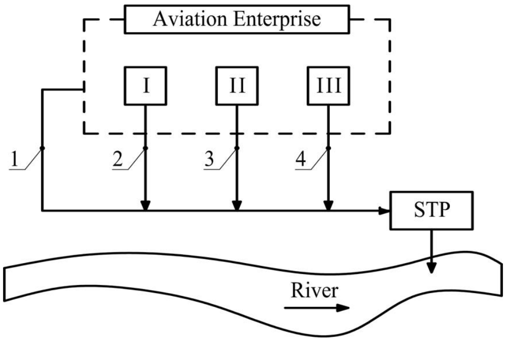

Fig. 1. Scheme of general water disposal system of aviation enterprise: I, II, III – various objects of aviation enterprise (including production halls); 1 – surface wastewater; 2, 3, 4 – industrial-household wastewater and wastewater similar in composition; STP – sewage treatment plant

Separate water disposal systems can be considered more acceptable for aviation enterprises. They can be organized in different ways. Their common feature is existence of different water disposal networks for different types of wastewater. The network for drainage of industrial-household (fecal) wastewater, the network for drainage of surface water (rain and snow water, as well as water from washing improved coatings on the territory of enterprises), the network for drainage of industrial wastewater (petroleum containing, acid containing, etc.). In this case, it may be considered appropriate to use one system to dispose of the wastewater, which:

– contains contaminations similar in properties, and therefore, require similar treatment methods;

– has the same aggressiveness;

– mixing of which facilitates the operation of water disposal system (e. g. mixing acid and alkali drainage may neutralize the aggressiveness of both).

Fig. 2 displays an example of separate scheme of water disposal, in which surface wastewater are drained separately from other wastewater and purified at separate treatment plants. It is advisable to accept such a system when industrial wastewater of an enterprise does not disrupt the operation of treatment plants and may also be treated together with industrial-household wastewater [10].

If industrial wastewater contains elements that do not allow feeding them to industrial-household sewage treatment plants immediately, it is advisable to use the scheme, displayed in Fig. 3. In such scheme, the surface wastewater is also treated separately. In addition, industrial wastewater containing specific contaminants, are first originally fed to the industrial wastewater treatment facilities, where these contaminants are neutralized. After that, this wastewater, together with industrial-household wastewater and industrial wastewater that is similar to them in composition, is sent to treatment facilities of the industrial-household sewage disposal system [11].

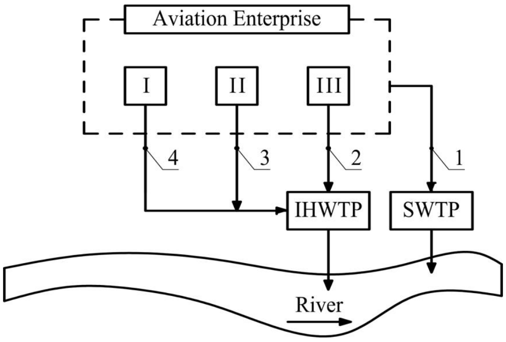

Fig. 2. Scheme of separate water disposal system of aviation enterprise with separate water disposal and treatment of surface wastewaters: I, II, III – various objects of aviation enterprise (including production halls); 1 – surface wastewater; 2, 3, 4 – industrial-household wastewater and industrial wastewater close to them in composition; IHWTP – industrial-household wastewater treatment plant; SWTP – surface wastewater treatment plant

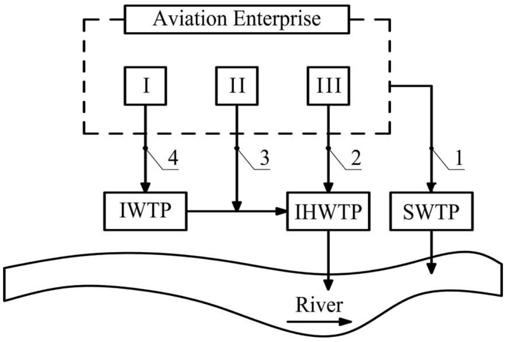

Fig. 3. Scheme of separate water disposal system of aviation enterprise with separate disposal and treatment of all types of wastewater: 1 – surface wastewater; 2 – industrial-household wastewater; 3 – industrial wastewater that can be treated at industrial-household wastewater treatment plants; 4 – industrial wastewater containing contaminants, unacceptable for purification at industrial-household treatment plants; IHWTP – industrial-household wastewater treatment plants; SWTP – surface wastewater treatment plants; IWTP – industrial wastewater treatment plant

The quality of purification of wastewater and treatment and recycling of their sediments at all types of sewage treatment plants defines their further impact on the environment, which may be considerable in case of large aviation enterprises [12].

For example, the state enterprise "Boryspil International Airport" has a separate wastewater disposal system. Surface wastewater of this enterprise is treated at its own surface wastewater treatment plants, and industrial-household wastewater and wastewater of similar composition are dumped into the communal sewer network of the city of Boryspil. However, municipal sewage system of the city of Boryspil today is represented by filtration fields, which are not only morally obsolete, but their technical condition can not be considered satisfactory. This is the reason why the uncontrolled amount of contaminants enters the soil and groundwater along with drainage. This is one of the reasons for significant deterioration of the quality of underground waters and significant rise in their level in the vicinity of the city of Boryspil. In turn, this creates significant environmental risks, when using wells, and causes problems with flooded basements and cellars belonging to the population of the neighboring villages, as well as problems with flooding of some airport facilities. To remedy the situation and to improve the environmental safety of the airport operation it is necessary to construct sewage treatment plant of the city of Boryspil (instead of filtration fields) with reception and treatment of industrial-household wastewater of the airport (the project of construction of such sewage treatment plant is being implemented today), or construction of own sewage treatment facilities of the airport water disposal system.

According to "The Concept of development of the state enterprise "Boryspil International Airport" [13], when full technical capacity of the airport is reached, which is supposed to account for 66.5 million passengers a year, dumping of only household wastewater by this enterprise will comprise 18 500 m^3 per day. With such volumes of water disposal, the amount of sediment that is formed at sewage disposal plants will reach 180 m^3 per day. These sediment will require recycling. Under conditions of insufficient supply of water resources and in terms of technical problems with discharging the purified sewage into water objects, there arises the problem of possibility of reusing purified wastewater for technical needs [14]. It also requires improving the treatment quality. According to the same Concept, the need of the enterprises for electrical power in future will account for more than 88 MW, and the need for thermal power for heating and hot water supply will exceed 280 MW. In the face of shortage of energy resources, there appears the problem of partial provision of aviation enterprise with alternative power sources of their own.

For rational organization of water disposal of the enterprise, the choice of wastewater treatment technology and purification techniques and ways of recycling of their sediments is very important. Various methods of mechanical and biological or biochemical treatment are mostly used for treatment of industrial-household wastewater and wastewater that is similar in composition.

An example of one of the ways of water disposal arrangement is given in paper [15]. Industrial-household wastewater gets to sandcollectors, preaerators and the primary settling basins for mechanical treatment. Sediment that is formed in primary settling basins is fed to methane tanks for digestion. Wastewater after mechanical treatment is fed for biological treatment to aerotanks, after which it is directed to secondary settling basins to remove active sludge. A part of removed sludge is directed again to aerotanks, and the rest of it is fed to sludge compactors to reduce humidity. After compaction, silt, together with sediment of primary settling basins, is fed to methane tanks. The sediment after anaerobic digestion is directed to the sludge ground for drying. Purified wastewater is disinfected by chlorination, and then dumped in a natural waterway.

This way of arrangement has a number of disadvantages. Mechanical and biological treatment do not always receive the necessary wastewater quality at the outlet of wastewater treatment plants, especially if the content of pollutants in wastewater, which is subjected to treatment, changes. Wastewater is not subjected to additional treatment and, as a result, the potential of obtaining additional power sources is not used. For anaerobic digestion, the methane tanks of a traditional design, which do not take into account the kinetics of digestion process, are used. As a result, poor quality biogas with high content of carbon dioxide is received.

An example of a different way of organizing the wastewater disposal system may be the one, described in [16]. In this way, industrial and household wastewater is mixed in neutralizers, after that it is supplied to primary settling basins. Biological treatment is also carried out in aerotanks, and removal of active sludge is performed in secondary settling basins. Purified wastewater after disinfection by chlorination is used in technological processes. Sediment of primary and secondary settling basins is directed for digestion in methane tanks. Biogas which is obtained during digestion is combusted at the local boiler to produce thermal energy. Sludge, digested in methane tanks, is dehydrated and used as a fertilizer.

The shortcomings of this method of organization is that wastewater is not exposed to additional treatment, and digestion is performed by traditional technologies without considering kinetics of digestion processes.

There are many methods of additional wastewater treatment.

The most common include the following:

Feeding wastewater, treated by conventional methods, to biological ponds, which are arranged in the form of artificially created water bodies, where it is treated through natural processes of self-purification [17].

Directing wastewater to bioplatos of hydroponic type, which are made in the form of open containers, filled with hydroponics that performs the function of filtration load. Hydroplato has a system of drainage pipes for draining filtered water. Higher aquatic plants, which are planted into hydroponics, and which absorb contamination from filtered wastewater during their vital process, are used for purification [18, 19].

Feeding wastewater to special artificial ground facilities for filtering through the soil, on which the soil plants, capable of absorbing pollution from the filtered water, are planted [20].

These methods really allow the improvement of the quality of treated wastewater, but they do not allow receiving significant additional power sources. In addition, a common disadvantage of the following ways of additional treatment is that the described plants require allocation of large land areas directly for their location, as well as for arranging sanitary-protective zones around them.

An analysis of recent research indicates that purified wastewater may be directly used for the cultivation of aquatic organisms, capable of removing contamination from them. Microalgae, which may be good raw material for manufacturing liquid biofuel of the third generation, are the most perspective for cultivation; their rate of biomass increase sometimes exceeds the rate of biomass increase of higher aquatic organisms [21, 22]. Among microalgae, suitable for cultivation, we may distinguish culture *Botryococcus brounii*, within which it is possible to distinguish three races; the dry biomass of most perspective race A contains up to 85 % of hydrocarbons, the composition of which is close to the composition of crude oil [23, 24].

Despite this, an analysis of modern cultivation technologies reveals the existence of substantial problems, associated, above all, with their essential shortcomings, in particular, technological imperfection of plants which are used.

Cultivation is, in fact, a conversion of solar energy into biomass by photosynthesis, which is conducted in photobioreactors. We distinguish the open type and the closed type reactors.

The open-type plants are open containers, to which cultural liquid with microalgae seeds, as well as carbon dioxide and other required elements, are fed [25]. Sunlight comes to microalgae through the open surface of the liquid. Stirring, which is essential for more uniform illumination of the entire microalgae mass, is usually provided by bubbling of carbon dioxide through the cultural liquid. Common shortcoming of such plants is that they are very susceptible to weather conditions. In addition, the efficiency of using carbon dioxide in them is not high, because at bubbling, its contact with microalgae, and therefore, assimilation by them is negligible. The solubility of carbon dioxide in water under normal conditions is not considerable either, and therefore a significant part of it is lost, coming through an open surface of the liquid into the atmosphere.

The close-type plants are closed tanks, made of transparent material, inside of which the cultural liquid with microalgae is fed [26]. The plants of this type also have disadvantages. They are not susceptible to weather conditions, but their performance is also limited due to low solubility of carbon dioxide in water and because of the complexity of saturation of cultural liquid with it. In addition, at common plants of this type it is difficult to provide for the continuity of the cultivation process.

Initial sediment and active sludge are formed (mechanical treatment) at the stage of mechanical and biological wastewater treatment with the use of conventional plants. Among the basic methods of their recycling, the following methods may be distinguished: combustion, using as building material, burying, using as a filler in recultivation of disturbed areas, using as organic fertilizer on agricultural fields, etc.

Thus, we can conclude that the existing technological water disposal schemes have many shortcomings, do not provide for the proper level of ecological safety of their operation and do not realize the potential capacities for obtaining additional renewable energy carriers during wastewater treatment, processing and recycling of their sediments. It is necessary to develop a new technological scheme, which will make it possible to eliminate these shortcomings.

3. The aim and tasks of research

The aim of present research is development of environmentally safe and energy efficient technological scheme of water disposal. This scheme should improve the quality of treated wastewater and allow obtaining renewable energy so as to cover partially the energy needs of the enterprise.

To achieve this aim, the following tasks were to be solved:

– to explore energy balance during sediment combustion and to demonstrate inexpediency of its application in the new technological scheme;

– to demonstrate the expediency of applying additional wastewater treatment in photobioreactors of the closed type, as well as the appropriateness of wastewater sediment stabilization with the use of anaerobic digestion, organizing the process in accordance with the kinetics of digestion processes and subsequent use of digested mass as organic fertilizer;

– to develop a technological scheme of an environmentally safe and energy efficient organization of waster disposal of the aviation enterprise.

4. Development of a new technological scheme of water disposal system

4. 1. Study of energy balance during sediment combustion

The method of combustion is becoming increasingly popular in Ukraine. In particular, PAT "AK "Kyivvodokanal" is implementing the project of construction of sludge combustion line at Bortnitska aeration station, where a significant amount of sludge was accumulated on the sludge fields. The use of this method makes it possible to get rid quickly of large amount of sediments. However it has a number of significant shortcomings. Sediment, removed from settling basins, is moist and requires considerable energy consumption for reducing this humidity and for evaporation its residues before combustion.

Let us consider in detail the thermal balance at the combustion of sediments of traditional wastewater treatment plants of industrial-household sewage, namely the ratio between the amount of thermal energy that is released at combustion of dry organic parts of sediments and the amount of thermal energy which is consumed for moisture evaporation in sediments.

The amount of thermal energy that is released at combustion depends on the content of organic compounds in sediment and specific heat of their combustion. This heat can be defined by the formula

$$Q_{\text{comb.}} = q_{\text{org.}} \cdot m_{\text{org.}}, \ [\text{MJ/kg}], \tag{1}$$

where $q_{\text{org.}}$ is the lower heat from combustion of the dry organic part of sediment, MJ/kg; $m_{\text{org.}}$ is the part of dry organic mass per 1 kg of moist sediment, kg/kg.

The proportion of dry organic mass in moist sediment depends on two magnitudes: sediment humidity w, which is determined by the percentage of water content in it (%), and content of organic part in its dry mass c, which. in turn, is determined by the mass percentage (%). Thus, this part may be defined by the formula

$$m_{\text{org.}} = \left(1 - \frac{w}{100}\right) \cdot \frac{c}{100}, \ [\text{kg/kg}]. \tag{2}$$

The amount of thermal energy, which is necessary to consume for evaporation of moisture is completely determined by sediment humidity and may be defined by the formula

$$Q_{\text{evapor.}} = q_{\text{evapor.}} \cdot \frac{w}{100}, \ [\text{MJ/kg}], \tag{3}$$

where $q_{\text{evapor.}}$ is the total amount of energy, which is necessary to consume for heating and evaporating 1 kg of water, MJ/kg.

The humidity of sediment, removed from settling basins and compacted in sludge compactors, ranges mainly within 96...98 % and the organic matter content in their dry mass mostly ranges from 65 % to 75 % [17]. Dependence of magnitude of the part of dry organic mass of raw sediment on their humidity for two extreme values of the organic matter content in their dry mass, is calculated by (2), and displayed in Fig. 4.

Fig. 4 shows that at the change in sediment humidity only by 2 %, the part of dry organic mass in sediment changes twice as much. This demonstrates one of the key roles of humidity in combustion process.

The lower heat of combustion of dry organic sediment part $q_{org.}$ depends on the composition of wastewater and may fluctuate within 16.8...27.8 MJ/kg. The total amount of thermal energy that is consumed for heating and evaporation of 1 kg of water makes $q_{evapor.}$=4,2 MJ/kg [17].

Fig. 5 shows the dependence of the amount of heat, released during combustion of one kilogram of sludge, compacted in sludge compacting plants for two extreme values of the lower heat of combustion of their dry organic parts at two extreme values of the organic matter content in the dry mass, on their humidity, calculated by (1). It also shows the dependence of the amount of thermal energy, which is consumed for evaporation of moisture from one kilogram of such sediments, on their moisture content, calculated by (3).

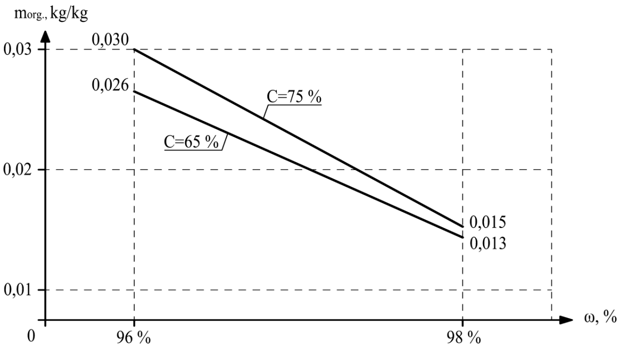

Fig. 4. Dependence of magnitude of part of dry organic mass in raw sediment $m_{org.}$ on their humidity w for two extreme values of content of organic matter in their dry mass c=65 % and c=75 %

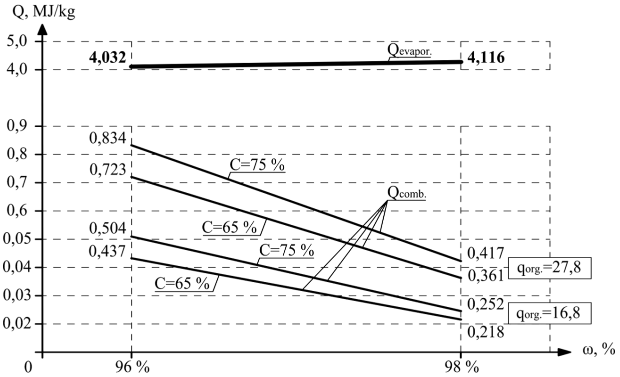

Fig. 5. Dependence of amount of heat, released during combustion of one kilogram of sediment, compacted at sludge compacting plants for two extreme values of lower heat of combustion of their dry organic part q_{org}=16.8 MJ/kg and q_{org}=27.8 MJ/kg at two extreme values of the content of organic matter in their dry mass c=65 % and c=75 %, as well as dependence of the amount of thermal energy that is consumed for evaporation of moisture from one kilogram of such sediments on their humidity

Fig. 5 displays that at the combustion of sediments, compacted in sludge compactors, the amount of thermal energy, required for evaporation of moisture by some times exceeds the amount of thermal energy released during combustion. That is, energy balance under such conditions is negative and the process requires additional fuel for combustion.

After mechanical dehydration, the sediment humidity may range within 75...85 %. Fig. 6 displays dependence of the magnitude of the part of dry organic mass on humidity of such sediment for two extreme values of the content of organic matter in their dry mass, calculated by (2).

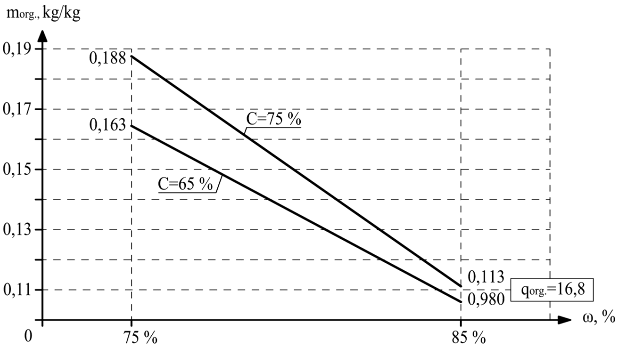

Fig. 6. Dependence of magnitude of the part of dry organic mass in mechanically dehydrated sediments $m_{org.}$ on their humidity w for two extreme values of content of organic matter in their dry mass c=65 % and c=75 %

From Fig. 4, 6 it is seen that the part of dry organic mass in mechanically dehydrated sediments exceeds such part in sediments, that went through sludge compressors by more than 6 times.

Fig. 7, similarly to Fig. 5, displays dependences of the amount of heat, released during combustion of one kilogram of mechanically dehydrated sediments and the amount of thermal energy, which is consumed for the evaporation of moisture from one kilogram of such sediments, on their humidity.

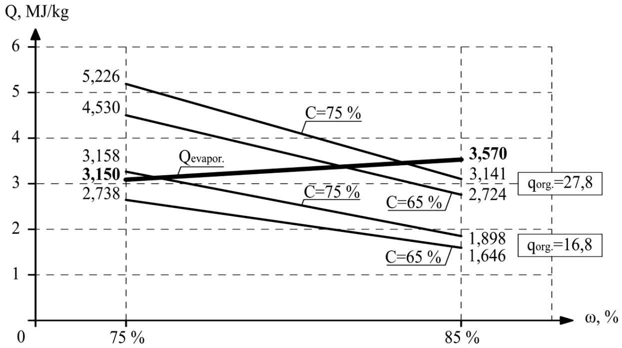

Fig. 7. Dependence of amount of heat, released during combustion of one kilogram of mechanically dehydrated sediments, for two extreme values of the lower heat of combustion of their dry organic part q_{org}=16.8 MJ/kg and q_{org}=27.8 MJ/kg at two extreme values of the content of organic matter in their dry mass c=65 % and c=75 %, as well as dependence of the amount of thermal energy, which is consumed for the evaporation of moisture from one kilogram of such sediments, on their humidity

From Fig. 7 it may be seen that during the combustion of sediments with lower heat of combustion of their dry organic part q_{org}=16.8 MJ/kg, even their compactness to humidity of 75 %, almost never gives a positive energy balance. During combustion of sediments with lower heat of combustion of their dry organic part q_{org} =27.8 MJ/kg and the organic matter content in their dry mass of c=75 %, in order to obtain positive energy balance, it is necessary to compact sediments to humidity of less than 83.2 %, while at c=65 % – to humidity of less than 81.1 %.

When making final decisions on appropriateness of applying this method of disposing of sediments, it is necessary to take into account the energy consumption for their mechanical dehydration. Thus, the lack of significant power gains at combustion makes the use of this method of sediment recycling impractical in a new technological water disposal scheme.

It should be noted that during sediments recycling by using them as an additive to building materials or for recultivation of disturbed areas, the need for considerable energy consumption for the preliminary drying also arises.

They do not allow receiving potentially possible renewable sources of energy either.

The use of sediments as organic fertilizers on agricultural fields requires its preliminary stabilization. Unstabilized sediment is environmentally hazardous because it might contain pathogenic microflora, the larvae of which are able to survive in the environment for years. In addition, such sediments tend to rot with releasing greenhouse gases to the atmosphere: methane and carbon dioxide.

One of the most promising methods of stabilization may be anaerobic digestion, which makes it possible to get energetically valuable biogas and environmentally safe organic fertilizer [27, 28].

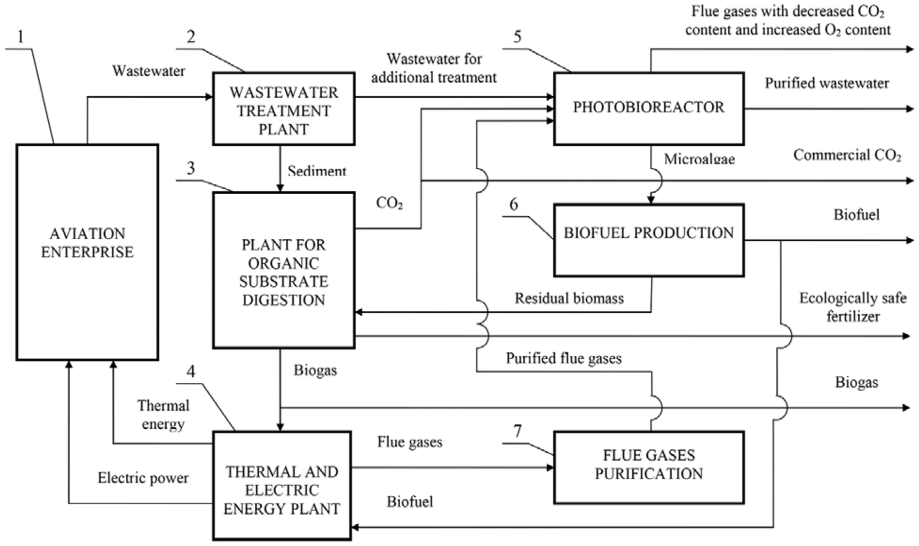

Fig. 8. Technological water disposal scheme of aviation enterprise

4. 2. Formation of a new technological water disposal scheme of aviation enterprise

The proposed technological wastewater disposal scheme of the aviation enterprise is based on the previously developed technologies and design decisions. Its components include the previously developed design of photobioreactor of the closed type, proposed in [29], as well as developed earlier technology of stabilization of wastewater sediments by intense anaerobic digestion, proposed in [30]. This technological scheme also involves the use of traditional plants for purifying industrial-household wastewater by methods of mechanical and biological treatment.

Technological water disposal scheme of the aviation enterprise is shown in Fig. 8. For its implementation, the water disposal system must be separate. The technological scheme operates in the following way. Industrial-household wastewater and wastewater similar to it in composition from the objects of enterprise 1 arrive at treatment plant 2, which consist of traditional plants of mechanical and biological treatment. After the sewage treatment plants, wastewater is directed for additional treatment to photobiocollector 5, the design of which was made considering the proposals from [29]. Microalgae for cultivation, as well as the part of carbon dioxide, obtained from plant of anaerobic digestion 3, are fed to the photobioreactor. In addition, smoke gases form local power plants, which also contain carbon dioxide, required for photosynthesis, which were purified form unwanted impurities at plant 7, are also fed to the photobioreactor. The wastewater, additionally treated during cultivation, is fed for discharging to the water bodies and flue gases with lower content of carbon dioxide, saturated with oxygen, which was produced during the process of photosynthesis, are discharged into the atmosphere.

The harvest of microalgae, removed from the photobioreactor, is fed to the plant, which removes oils and produces liquid biofuel of the third generation 6. A part of the produced biofuels is fed to the local thermal and electric power station 4 to generate thermal and electrical energy, and the rest is used as commercial biofuel. The residual microalgae biomass that remained after removing oils is fed to the plant of anaerobic digestion 3.

The wastewater sediment, which is formed during mechanical and biological processes of purification at sewage treatment plants 2, is mixed with microalgae biomass and fed to the plant of anaerobic stabilization (digestion) 3, technological scheme of which is organised by the proposals [32]. A part of the biogas, produced at plant 3 is directed to the local thermal and electric power station 4, equipped with cogeneration plants, for combustion and production of thermal and electric power. The biogas surplus is used as commercial biofuel. Thermal and electric energy, produced by thermal and electric power plant, is used to meet the needs of the enterprise.

Flue gases of cogeneration plants of thermal and electric power plants are sent to plant for flue gases treatment 7, after which they are fed in photobioreactor 5 for using carbon dioxide, existing it them, in the photosynthesis.

5. Discussion of a new technological water disposal scheme of the aviation enterprise

We proposed the organization of additional wastewater treatment by using them as cultural liquid for growing microalgae *Botryococcus brounii* in photobioreactors of the closed type with continuous organization of the cultivation process, which must be constructed using the design, proposed in [29]. The main structural element is the cylindrical photounit made of transparent material, located horizontally, to which the purified wastewater with added microalgae seeds is periodically fed through the inlet opening and is removed with their harvest through the inlet opening. The photounit is equipped with devices for feeding carbon dioxide and microelements inside. In addition, its gives the opportunity to work under excessive pressure, increasing the solubility of carbon dioxide in water, improving its assimilation by microalgae and increasing their growth rate.

The wastewater, removed from photounit, is proposed to be directed for microalgae separation from it, which can be carried out by centrifuging, and after disinfection it is proposed to be used for technical water supply of the aviation enterprise or to be discharged into water. A part of the cultivated microalgae is proposed to be fed back to the photounit along with a new portion of wastewater for further cultivation. The rest of wastewater is directed to the plans for removing oils rich in hydrocarbons with further production of liquid biofuels of the third generation [31, 32]. After removing oils, the microalgae biomass is proposed to be directed to the anaerobic digestion plant along with the sediment, obtained during the mechanical and biological wastewater treatment.

The proposed technological scheme implies anaerobic stabilization (anaerobic fermentation of wastewater sediments along with the waste of microalgae biomass at plants, implementing the process, described in [30]. It involves four successive stages of digestion process, such as hydrolysis, acidogenesis, acetogenesis, and methanogenesis in accordance with the kinetics of digestion processes. The optimal medium conditions for various stages are known to be different. In some cases, they are almost opposite [33]. For example, the acid environment with low pH is favorable for effective functioning of acidogenic microorganisms that provide for a flow of acidogenic stage. In this case, the high activity of acidogenes makes it even lower. However, it is not favorable to the metabolism of methanogenic microorganisms, responsible for producing methane at the methanogenic stage and decreases the final biogas output. Alkaline medium with high pH is favorable for methanogenes, but inhibits the activity of acidogenic microorganisms. This leads to the fact that at the stage of acidogenesis, a smaller quantity of acids is formed, which is in future the material for the formation of acetate at the stage of acetogenesis and then of methane at the stage of methanogenesis. The final outcome is also a decrease in the output of biogas. If the whole process of grinding takes place in the same tank, it is very difficult to maintain the optimal balance of pH for activity of both acidogenes and methanogenes. It is clear that a perspective method of the intensification of digestion process as a whole is separation of its individual stages in space. Accordingly, the plant for digestion consists of four separate tanks, in which the optimal conditions for hydrolysis, acetogenesis, acidogenesis and methanogenesis are successively created. The hydrolysis stage flows without release of gaseous products. At the stages of acidogenesis and acetogenesis, the conditions for active formation of acids and active release of carbon dioxide in gaseous form with its independent removal from the plant are created and methane formation is prevented. At the stage of methanogenesis, the conditions for the active conversion of acetogenesis products into methane are created and carbon dioxide formation is prevented [32]. Thus, at the outlet from the digestion plant it is possible to obtain an organic fertilizer, in particular carbon dioxide, which is used to provide for the process of photosynthesis in photounit, as well as biogas with a high content of methane (up to 95 %) to use for the production of thermal and electric power at cogeneration plants.

Thus, the technological water disposal scheme of the aviation enterprise is a continuation of previous developments. It involves the use of both structural elements of the technological scheme of anaerobic stabilization of wastewater sediment, proposed in [30], and of previously developed design of the photobioreactor, proposed in [29]. Unlike traditional technological schemes, the implementation of the developed technological scheme will allow realization of the potential possibilities of obtaining renewable energy resources in the process of wastewater treatment.

For successful implementation of this technological scheme, it is necessary to carry out further research concerning the influence on the processes of microalgae cultivation and anaerobic stabilization of organic substrates of concentration of various impurities that may be contained in wastewater. In particular, for its application at aviation enterprises, it is necessary to define maximum permissible concentrations of petroleum products in wastewater, and for its use at municipal water treatment plants, it is essential to define maximum permissible concentrations of heavy metals in wastewater sediments.

7. Conclusions

1. It was determined that to improve environmental safety of aviation enterprises, when using both the general water disposal system and the separate water disposal system, and applying traditional mechanical and biological treatment methods, there is a need for additional purification of wastewater and for improving the ways of treatment and recycling of their sediments.

2. It was found that when using modern methods of additional wastewater treatment, there is a need for allocating large areas for the location of water treatment plants, as well as for arranging sanitary-protective zones around them. It was also found that modern methods of sediment disposal do not allow in sufficient degree receiving the potentially possible renewable energy sources.

3. It was determined that an expedient method of additional wastewater treatment is to use wastewater as a medium for cultivation of energy microalgae in photobioreactors of the closed type with subsequent production of liquid biofuels of the third generation. *Botryococcus braunii* was defined as an appropriate culture for cultivating. It was also determined that the method of sediment combustion is impractical for using. Instead, the expedient method of treatment and recycling is anaerobic digestion when the process is organized in compliance with the kinetics of digestion processes and subsequent use of digested masses as organic fertilizer.

4. A technological wastewater disposal scheme of the aviation enterprise was developed, which allows us to obtain an environmentally safe organic fertilizer, completely or partially to provide for own needs in thermal and electrical energy, to obtain commercial biogas, liquid motor fuel and carbon dioxide. This technological scheme involves a partial use of the wastes of one of its constituent elements as a raw material for obtaining products at its other components. Thus, the scheme functions as a partially closed techno-ecosystem of the second type.

References

1. Dolina, L. F. Practical training on sewarage of industrial enterprises [Text] / L. F. Dolina. – Dnepropetrovsk: Kontinent, 2007. – 132 p.
2. Boichenko, S. V. Aviation ecology [Text]: manual / S. V. Boichenko, M. M. Radomska, L. M. Chernjak, O. V. Rjabchevsky, L. I. Pavljukh. – Kyiv: NAU, 2014. – 152 p.

3. TM 10-2015. Informational-technological manual on the best available technologies. Sewage water treatment with centralized sewage systems of settlements and citys districts [Text]. – Moscow: Buro NDT, 2015. – 377 p.
4. Danilovich, D. A. The best available technologies for municipal sewarage [Text] / D. A. Danilovich // Water suppsy and sewage technics. – 2012. – Issue 3. – P. 6–13.
5. Danilovich, D. A. Energy and resource aproach to sewage water and sewage sludge treament [Text] / D. A. Danilovich // The best available technologies of water supply and sewarage. – 2014. – Issue 4. – P. 36–47.
6. Sidorov, U. I. Local sewage treatment plants [Text] / U. I. Sidorov // Biotechnologia. – 2011. – Vol. 4, Issue 3. – P. 18–28.
7. Tevjashev, A. D. Progressive informational resource-saving and environmental technology in sewage systems [Text] / A. D. Tevjashev, I. V. Korin'ko, V. S. Esilevskij, A. G. Dolgobrod, K. V. Kobylinskij, Ju. V. Jaroshenko, G. V. Nikitenko // Eastern-European Journal of Enterprise Technologies. – 2005. – Vol. 2, Issue 1 (14). – P. 50–61.
8. Steele, J. C. Heuristic Optimization Model for the Optimal Layout and Pipe Design of Sewer Systems [Text] / J. C. Steele, K. Mahoney, O. Karovic, L. W. Mays // Water Resources Management. – 2016. – Vol. 30, Issue 5. – P. 1605–1620. doi: 10.1007/s11269-015-1191-8
9. Rybka, I. Causes and effects of events during water supply and sewerage system construction [Text] / I. Rybka, E. Bondar-Nowakowska, M. Polonski // Archives of Civil Engineering. – 2016. – Vol. 62, Issue 1. doi: 10.1515/ace-2015-0059
10. Pryszcz, M. Operation of the household sewage treatment plants in Poland [Text] / M. Pryszcz, B. Mrowiec // Inzynieria Ekologiczna. – 2015. – Vol. 41. – P. 133–141. doi: 10.12912/23920629/1837
11. Rybka, I. Cost risk in water and sewerage systems construction projects [Text] / I. Rybka, E. Bondar-Nowakowska, M. Polonski // Procedia Engineering. – 2016. – Vol. 161. – P. 163–167. doi: 10.1016/j.proeng.2016.08.517
12. Sachnovska, V. M. Determination of basic and additional factors, which influence on reliability and ecological safety of water supply and sewage networks [Text] / V. M. Sachnovska // Kommunalnoe hozjajstvo gorogov. – Kyiv: Technika, 2010. – Issue 93. – P. 376–383.
13. Development conception of State enterprise «International airport Borispol» [Text]. – UKRAEROPROECT, 2005.
14. Radosavljevic, M. R. Wastewater reuse [Text] / M. Radosavljevic, V. Sustersic // Vojnotehnicki glasnik. – 2013. – Vol. 61, Issue 4. – P. 213–232. doi: 10.5937/vojtehg61-2023
15. Kalitsun, V. I. Hydraulics, water supply and sewarage [ТеКст] / V. I. Kalitsun, V. S. Kedrov, Y. M. Laskov, P. V. Safonov. – 3-rd ed., rev. and suppl. – Moscow: Strojizdat,, 1980. – 359 p.
16. Apostoljuk, S. O. Industrial ecology [Text]: tutorial / S. O. Apostoljuk, V. S. Djigirey, I. A. Sokolovskiy, G. V. Somar, N. G. Lukjanchuk. – 2-nd rev. and suppl. – Kyiv: Znannja, 2012. – 430 p.
17. Jakovlev, S. V. Sewerage [Text] / S. V. Jakovlev, J. A. Karelin, A. I. Zhukov, S. K. Kolobanov. – Moscow: Strojizdat, 1975. – 632 p.
18. Direnko, A. A. Employing higher aquatic plants for sewage water and grey water treatment [Text] / A. A. Direnko, E. M. Kotsar // PHC (plumbing, heating, conditioning). – 2006. – Issue 4 (28). – P. 12–15.
19. Bulavenko, R. V. Aftertreatment of food manufacturing industry's sewage water with bioplateau installations [Text] / R. V. Bulavenko, O. V. Stepova, V. V. Roma // Proceedings of Poltava state agricultural academy. – 2012. – Issue 4. – P. 145–148.
20. Kadam, A. Municipal wastewater treatment using novel constructed soil filter system [Text] / A. Kadam, G. Oza, P. Nemade, S. Dutta, H. Shankar // Chemosphere. – 2008. – Vol. 71, Issue 5. – P. 975–981. doi: 10.1016/j.chemosphere.2007.11.048
21. Shamanskyi, S. I. Bioconversion of Solar Energy as a Perspective Direction in Alternative Energy [Text]: conference / S. I. Shamanskyi, D. M. Nestorjak // Green Energy. – Kyiv, 2012. – P. 371–372.
22. Kravchenko, I. P. To the question of reasonability to cuiltivate and utilize microalgae for motor biofuel production [Text]: conference / I. P. Kravchenko // Green Energy. – Kyiv, 2012. – P. 55–63.
23. Sorokina, K. N. Potential of microalgae using as raw material for bioenergetic [Text] / K. N. Sorokina, V. A. Yakovlev, A. V. Piligaev et. al. // Katalix in industry. – 2012. – Issue 2. – P. 63–72.
24. Sasikanth, K. Studies on cultivation of lipid accumulating Botryococcus Braunii from North Gujarat inland waters for generation of 3rd generation biofuels [Text] / K. Sasikanth, T. Jyotsna, P. Anjali, M. C. Sharma // Indian journal of applied research. – 2014. – Vol. 4, Issue 9. – P. 31–35.
25. Chen, Y. Forced Light/Dark Circulation Operation of Open Pond for Microalgae Cultivation [Text] / Y. Chen, J. Wang, W. Zhang, L. Chen, L. Gao, T. Liu // Biomass and Bioenergy. – 2013. – Vol. 56. – P. 464–470. doi: 10.1016/j.biombioe.2013.05.034
26. Sato, T. Invention of Outdoor Closed Type Photobioreactor for Microalgae [Text] / T. Sato, S. Usui, Y. Tsuchiya Y. Kondo // Energy Conversion and Management. – 2006. – Vol. 47, Issue 6. – P. 791–799. doi: 10.1016/j.enconman.2005.06.010
27. Babaev, V. N. Energy potential of methane formation at mesophilous anaerobic digestion of waste organic component [Text] / V. N. Babaev, N. P. Goroh, I. V. Korin'ko // Eastern-European journal of enterprise technologies. – 2011. – Vol. 4, Issue 6 (52). – P. 59–65. – Available at: http://journals.uran.ua/eejet/article/view/1427/1325
28. Fesjuk, V. O. Prospects assessment of biogas production out of sewage sludge of Lutsk city's sewage water treatment plant [Text] / V. O. Fesjuk // Nature of Western Polesye and adjoining areas. – 2010. – Issue 7. – P. 84–90.
29. Shamanskyi, S. Construction Arrangement for Cultivating Microalgae for Motor Fuel Production [Text] / S. Shamanskyi, S. Boichenko // Systemy i Srodki Transportu Samochodnego. – Rzeszow: Politechnika Rzeszowska., 2016. – P. 181–188.
30. Shamanskyi, S. Energy efficient and environmentally friendly technology of stabilizing airline enterprises' wastewater sludges [Text] / S. Shamanskyi, S. Boichenko // Eastern-European Journal of Enterprise Technologies. – 2015. – Vol. 5, Issue 8 (77). – P. 39–45. doi: 10.15587/1729-4061.2015.52264
31. Pruvost, J. Systematic Investigation of Biomass and Lipid Productivity by Microalgae in Photobioreactors for Biodiesel Application [Text] / J. Pruvost, G. Van Vooren, B. Le Gouic, A. Couzinet-Mossion, J. Legrand // Bioresource Technology. – 2011. – Vol. 102, Issue 1. – P. 150–158. doi: 10.1016/j.biortech.2010.06.153

32. Kulyk N. S. Aviation chemmotology: fuels for aviation engines. Theoretical and engineering basis of applying [Text] / N. S. Kulyk, A. F. Aksenov, S. V. Boichenko, A. I. Zaporozhets. – Kyiv: NAU, 2015. – 560 p.
33. Karaeva, U. V. Review of biogas technologies and methods of intensification of anaerobic fermentation processes [Text] / U. V. Karaeva, I. A. Trakhunova // Proceedings of Academenerg. – 2010. – Issue 3. – P. 109–127.

UDC 57.013; 576.52
DOI: 10.15587/1729-4061.2016.86077

EXAMINING THE PROPERTIES OF DRY MAGNETICALLY CONTROLLED BIOSORBENT, OBTAINED BY THE METHOD OF MECHANICAL AND MAGNETOHYDRODYNAMIC AGITATION

S. Gorobets
Doctor of technical sciences,
Professor, Head of Department*
E-mail: pitbm@ukr.net
O. Gorobets
Doctor of Physical and
Mathematical Sciences, Professor*
O. Kovalyov
Postgraduate Student*
E-mail: alexej.covalew@yandex.ua
K. Hetmanenko*
E-mail: getmanenko.ka@ukr.net
S. Kovalyova
Kollegium № 11
Miry ave., 137, Chernigiv, Ukraine, 14033
E-mail: Svitlayak@gmail.com
*Department of bioinformatics
National Technical University of Ukraine
"Igor Sikorsky Kyiv Polytechnic Institute"
Peremohy ave., 37, Kyiv, Ukraine, 03056

Досліджено ефективність вилучення іонів Cu^{2+} сухим магнітокерованим біосорбентом (МКБС), виготовленим методом магнітогідродинамічного перемішування (МГДП) у схрещених електричному та магнітному полях. Визначено сорбційну ємність, стабільність магнітних властивостей сухого МКБС у схрещених електричному та магнітному полях, з різною концентрацією магнітних наноміток. Показано, що ступінь вилучення іонів міді сухого МКБС, виготовленого методом МГДП у схрещених електричному та магнітному полях, на 22 % вище, ніж сухого МКБС, виготовленого методом механічного перемішування

Ключові слова: сухий МКБС, біосорбція, наночастинки магнетиту, механічне перемішування, МГДП у схрещених електричному та магнітному полях

Исследована эффективность удаления ионов Cu^{2+} сухим магнитоуправляемым биосорбентом (МКБС), изготовленного методом магнитогидродинамического перемешивания (МГДП) в скрещенных электрическом и магнитном полях. Определена сорбционная емкость, стабильность магнитных свойств сухого МКБС в скрещенных электрическом и магнитном полях, с разной концентрацией магнитных нанометок. Показано, что степень удаления ионов меди сухим МКБС, изготовленного методом МГДП в скрещенном электрическом и магнитном полях, на 22 % выше, чем сухого МКБС, изготовленного методом механического перемешивания

Ключевые слова: сухой МКБС, биосорбция, наночастицы магнетита, механическое перемешивание, МГДП в скрещенном электрическом и магнитном полях

1. Introduction

In recent years, methods for the removal of ions of heavy metals and radionuclides from the waste water and the concentration of precious and rare metals from ores by microorganisms have been widely used. The accumulation of cations of heavy metals from aqueous solutions by microorganisms is attained by biosorption. It is known that microbial biomass may retain a significant amount of ions of metals, more than needed for their metabolism, which defines the prospect of wide use of microorganisms in the biotechnological methods of water purification from heavy metals, toxins, radionuclides, and the use of microorganisms in biometallurgy [1]. Yeast *Sacharomyces cerevisiae* has significant potential to accumulate a wide range of cations of metals, in particular, ions of Cd^{2+}, Cr^{3+}, Cr^{6+}, Cu^{2+}, Pb^{2+} and Zn^{2+} [1, 2].

The use of the magnetically tagged cells of yeast for the biosorption of heavy metals ions on the model solutions has been studied for over twenty years [2, 3]. The problems of creation of magnetically-controlled biosorbent are related to a decrease in its sorption capacity due to the competition