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***Lesia Pavliukh***, PhD, Associate Professor
National Aviation University
orcid.org/0000-0002-7715-4601
e-mail: lenyo@ukr.net;

***Sergei Shamanskyi***, Doctor of Engineering. Associate Professor
National Aviation University
orcid.org/0000-0002-6215-3438
e-mail: shamanskiy_s_i@ukr.net;

***Zaiats Olga***, PhD, Associate Professor
National Transport University
orcid.org/0000-0002-6574-4516
e-mail: zaiats.olga.v@gmail.com


# A FLAT-PARALLEL TYPE PHOTOBIOREACTOR DESIGN FOR SEWAGE WATER TREATMENT

## Introduction

Organic and inorganic substances which were released into the environment as a result of domestic, agricultural and industrial water activities lead to organic and inorganic pollution. The normal primary and secondary treatment processes of these wastewaters have been introduced in a growing number of places, in order to eliminate the easily settled materials and to oxidize the organic material present in wastewater. The final result is a clear, apparently clean effluent which is discharged into natural water bodies. This secondary effluent is, however, loaded with inorganic nitrogen and phosphorus and causes eutrophication and more long-term problems because of refractory organics and heavy metals that are discharged. Microalgae culture offers an interesting step for wastewater treatments, because they provide a tertiary biotreatment coupled with the production of potentially valuable biomass, which can be used for several purposes. Microalgae cultures offer an elegant solution to tertiary and quandary treatments due to the ability of microalgae to use inorganic nitrogen and phosphorus for their growth. And also, for their capacity to remove heavy metals, as well as some toxic organic compounds, the refore, it does not lead to secondary pollution. Compared to higher plants, microalgae are simple in structure, being unicellular, filamentous or colonial, and energy is directed via photosynthesis into growth and reproduction; they do not need to establish and maintain complex tissues and organs [1]. More recently these photosynthetic microbes have also become the focus of considerable attention as a potential source of oils for biodiesel production [2–5].

In the current review we will highlight on the role of microalgae in the wastewater treatment processes.

## Problem statement

Microalgae have been proposed as an option for wastewater treatment since the 1960s, but still, this technology has not been expanded to an industrial scale. The main reason for the small-scale use of microalgae in purification processes is their cultivation.

**The purpose of this article** is to develop a photobioreactor design for wastewater treatment in which the application of new elements and connections reduces material consumption for the manufacture of transparent flexible tanks, reducing labor costs for installation and dismantling of tanks, and preventing the mixing of immobilized algae and their removal from the working area of the photobioreactor.

## Analysis of previous research

To design adequate photobioreactors, it is mandatory to understand the major phenomena limiting the performance of microalgae cells such as light availability, nutrients supply including $CO_2$, environmental conditions including temperature and solar radiation, and mixing. To fulfill the requirements of microalgae cells, different technologies has been proposed such as raceway and thin-layer open reactors, in addition to tubular and flat-plate closed reactors. These technologies are still being upgraded and improved to maximize the biomass production capacity and to reduce the production cost. Additionally, the control and modeling of these reactors is a hot topic for the industrial development of microalgae-based processes [6].

The current market of microalgae biomass is estimated to be around 20,000 *t* per year; the price ranges between 30 and 300 € $kg^{-1}$. Mass cultures of microalgae have traditionally been cultivated in open ponds which are much cheaper and easier to operate than photobioreactors (PBRs). Several PBR designs have been proposed in recent years, to grow microalgae as a source of sustainable energy. For the cultivation of most species suitable for biodiesel production and for human consumption, the use of a closed system is advisable. Indeed, most of the species cultivated for oil production require strict control of the temperature between 20 and 30 °C, which is problematical to maintain in open ponds. PBRs are also recommended for the production of high-value compounds for which the strict control of culture variables is necessary in order to satisfy the good manufacturing practice (GMP) requirement for pharmaceutical products. However, it is worth pointing out that although a major advantage of closed PBRs is their ability to prevent contact of the microalgae culture with the atmosphere, the risk of pollution cannot be ruled out. Among the closed systems, tubular PBRs are the most common design developed at an industrial level [7]. The advantages and limitations of tubular PBRs have been discussed in several book chapters [8-10].Because of the high production cost usually reached with this culture system, the main R&D on PBR design is aimed at achieving high light conversion efficiency, i.e. at pushing productivity well beyond the one currently attained, which — it seems — is the main way to develop cost-effective tubular PBRs.

It is known photobioreactor design for wastewater treatment [11], containing: flowing rectangular open-topped container, inside which are transparent tubes, with are interconnected and fixed in a rectangular container by the knees in such a way as to form a continuous zigzag coil into which a mixture of wastewater with microalgae prepared in a mixer and carbon dioxide is fed, the transparent tubes being fixed at an angle to horizon, and placed in a row on one side of the coil elbows are located above the elbows on its opposite side and they are valves for the release of accumulated gases there, while at the outlet of the pipeline is a separator and a guide tray for supplying separated from microalgae wastewater into body capacity.

The disadvantage of this design is that the design occupies a large area due to the horizontal location of the coil tubes, the need to use a long coil due to the impossibility of immobilization of microalgae in the working area, the need to disassemble the coil with significant labor costs and stopping the photobioreactor for a long period to clean the transparent tubes covered with sediment inside.

Also it is known photobioreactor design [12] which is made in the form of a transparent flowing rectangular open-topped tank, inside of which are vertically attached to the bottom of the tank by quick-release fasteners transparent flowing flexible hoses, to which at the bottom by means of non-return valves are connected pipelines for wastewater and microalgae supply and tubes for carbon dioxide supply and are connected by means of shut-off valves pipelines for drainage of a mixture of microalgae with residual wastewater, and in the upper hermetic part, where there are valves for drainage of accumulated gases, while the pipeline for the purified wastewater discharge is connected to a guide tray purified wastewater supply inside of a flowing rectangular open-topped tank, and at the outlet of the pipeline for drainage of a mixture of microalgae with residual wastewater is a microalgae separator to separate return and excess biomass.

The disadvantage of this design is that the design has a cylindrical arrangement, namely transparent flexible hoses are made in the form of a large number of cylinders of small diameter, which leads to overconsumption of material, as well as significant labor costs during installation and dismantling of hoses for cleaning or replacement. gas occurs directly in the working area of the hoses, which promotes mixing and removal of immobilized microalgae from the working area.

It is known airlift and bubble-column bioreactors are simple devices that have been used in bioprocessing, wastewater treatment, and the chemical process industry. These vertical column photobioreactors are compact, low-cost, and easy to operate axenically [13; 14]. Pneumatically agitated bubble columns and airlift devices attain the requisite mass transfer coefficient of $0.006 \cdot s^{-1}$ and liquid circulation velocity at a relatively low power input for practicable culture of microalgae [14; 15]. Camacho et al. reported that the maximum biomass volumetric productivity of *Phaeodactylum tricornutum* obtained in vertically oriented concentric-tube airlift photobioreactors was about half of that obtained by a horizontal-loop tubular photobioreactor [16]. A similar result was obtained in a bubble column, where the volumetric biomass productivity was about 60 % of that in horizontal-loop tubular photobioreactor for *Phaeodactylum tricornutum* grown under identical conditions [17].

Compared to bubble column photobioreactors, air-lift photobioreactors showed superior growth of microalgae. At a low aeration rate of 1 – L $min^{-1}$, cultures of Undaria pinnatifida and Porphyridium Sp. grown in an airlift reactor attained 33–50 % higher growth rates than when grown in a bubble column [18; 19]. Diatom yields were also about double in an airlift device than in a bubble column [20]. It appears that, in contrast to a bubble column where cell flow patterns are more random, the airlift system produces a more homogeneous flow pattern that moves cells from dark (riser) to light (downcomer) zones [21]. Thus, cells in a bubble column may reside in high or in low light intensities for a long time without circulation. Furthermore, cell sedimentation occurred in the bubble column while cells remained more uniformly suspended in the medium of the airlift photobioreactor [18; 21]. When large-scale diatom cultivation was compared in both bubble column and airlift photobioreactors, there was no significant different in the specific growth rate, which was $2.46\times10^{-2}$ $h^{-1}$ and $2.58\times10^{-2}$ $h^{-1}$ for bubble column and airlift reactor, respectively [20]. This may be the result of the non-ideal flow pattern in the airlift system and the internal circulation within the riser itself.

Different photobioreactor designs for microalgae cultivation are presented in the Table.

*Table*

**Different Photobioreactor Designs for Microalgae Cultivation [22]**

| Type | Raceway Pond | Flat-Plate | Tubular | Vertical-Column |
|---|---|---|---|---|
| **Conceptual design** | | | | |
| Design characteristics | Consist of closed-loop recirculation channel (oval shape) | Bioreactor with rectangular shape | Consists of an array of straight, coiled, or looped transparent tubes | Bioreactor with vertical arranged cylindrical column |
| | Usually built using concrete or compacted earth-lined pond with white plastic | The flat-plate are usually made of transparent plastic or glass | The tubes are usually made of transparent plastic or glass | The columns are usually made of transparent plastic or glass |
| | Mixing and circulation are provided by paddle wheels | Usually coupled with gas sparer | Usually coupled with a pump or airlift technology | Usually coupled with a pump or airlift technology |
| | The depth of the pond is usually 0.2–0.5 m to ensure microalgae receive adequate exposure to sunlight | The light path (depth) is dependent on microalgae strain; range between 1.3 and 10 cm | Tube diameter is limited (0.1 m) to increase the surface/volume ratio | Optimum column diameter is 0.2 m with 4 m height |
| Advantages | Easy to construct and operate | Large illumination surface area gives maximum utilization of solar energy | Large illumination surface area | High mass transfer rate with good mixing |
| | Low energy input and low-cost | Low concentration of dissolved oxygen | Relatively higher biomass productivity | Compact, easy to operate, and relatively low-cost |
| | Can be position vertically or inclined at an optimum angle facing the sun | Potential of cell damage is minimized if airlift system is used | Lower power consumption | Can be position vertically or inclined at an optimum angle facing the sun |
| | | Lower power consumption | | |

*The End Table*

| Type | Raceway Pond | Flat-Plate | Tubular | Vertical-Column |
|---|---|---|---|---|
| **Conceptual design** | | | | |
| Disadvantages | Water loss due to high evaporation rate | Scale-up require many compartments and support materials | Require large land area because long tubes are used | Small illumination surface area |
| | Difficulty in controlling the temperature and pH | Difficulty in controlling culture temperature | Potential in accumulating high concentration of $O_2$ (poison to microalgae) in culture medium if tubes are too long | Cell sedimentation may occur if airlift system is not used |
| | Susceptible to contamination | | Decreasing $CO_2$ concentration along the tube may cause the microalgae deprived of carbon source | |
| | | | Mixing is problematic in extended tubes | |

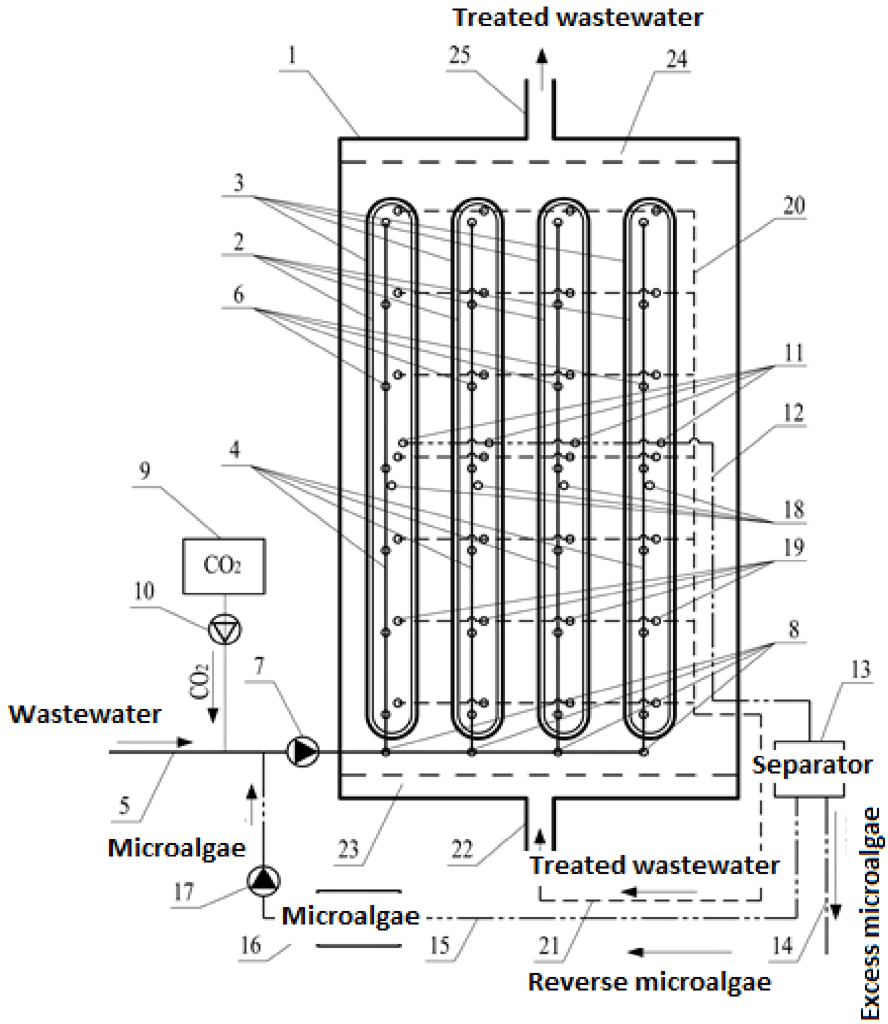
**Research methodology**

Methods were based on a systematic analysis of theoretical research, synthesis, anology and comparison of various photobioreactor designs.

**Research Results**

The problem is solved by the fact that the photobioreactor is made in the form of a transparent flowing rectangular open-topped tank. The flowing flat transparent containers, made with flexible material, are vertically, parallel to each other attached to the bottom of the tank with quick-release fasteners inside. Pipelines for supply saturated by carbon dioxide wastewater and microalgae are connected through non-return valves. Pipelines for drainage of a mixture of microalgae with residual wastewater are connected through non-return valves. Pipelines for drainage of treated wastewater and valves for release of accumulated gases are connected in the upper airtight part. The pipeline for the treatment of treated wastewater is connected to the guide tray for supplying treated wastewater in the middle of a flowing rectangular open-topped tank. A carbon dioxide supply pipeline is connected to the inlet part of the wastewater supply pipeline. At the outlet of the pipeline for the removal of a mixture of microalgae with residual wastewater is a separator of microalgae to separate the return and excess biomass to supply separated from microalgae wastewater in a flowing rectangular tank.

The Figure shows a General diagram of a flat-parallel type photobioreactor design for wastewater treatment, which consists of a housing *1* made in the form of a transparent flowing rectangular open-topped container, through which wastewater treated with microalgae flows. Inside the housing *1*, flowing flat transparent containers *2* made of flexible material are vertically attached to the bottom in parallel with quick-release fasteners, in such a way that they are completely immersed in the flowing treated wastewater. Floats *3* are fixed in the upper parts of flowing flat transparent tanks for their maintenance in water in a vertical state. In the lower parts of flat transparent tanks along their long parts anoffshoot*4* from the sewage supply pipeline *5* is laid, on which non-return valves *6* are installed. At the inlet of the wastewater supply pipe *5* to the housing *1* a pump for pumping wastewater *7* is installed, and inside the housing *1*, at the junction of the offshoots *4* a nipple 8 for the release of excess carbon dioxide is installed. At the inlet of the wastewater supply pipe *5* is a carbon dioxide tank *9* with a carbon dioxide injection compressor *10*. In the bottom of the housing shut-off valves *11*are mounted, to which offshoots from the microalgae discharge pipe *12*are connected. A microalgae separator *13* is installed at the outlet of the microalgae discharge pipeline. The separator is connected to the excess biomass drainage pipe *14* and the return biomass drainage pipe *15*, which is connected to the tank with microalgae *16* and the pump for injection of microalgae *17*.In the upper parts of the flat transparent tanks nipples *18* to discharge the accumulated gases are mounted. Also to the upper parts of the flat transparent tanks through the valves *19*offshoot from the treated wastewater pipeline *20* is connected, to which the treated wastewater return pipe *21* is connected. In the inlet part of the housing is the inlet tray *22* and the distribution tray *23*. In the outlet part of the housing prefabricated tray *24* to which the discharge tray *25* is connected.




A flat-parallel type photobioreactor design

**Discussion**

The photobioreactor-wastewater treatment plant of flat-parallel layout works as follows.

Housing *1* is located in an open area with natural light. The work cycle is divided into three stages: the start operation; wastewater treatment cycle; cycle completion.

At the start stage, the housing *1* is filled with clear water so that the flat transparent containers *2*are attached to the bottom of the housing with the floats *3* attached to their upper parts are in a vertical position. The pre-clarified wastewater to be treated is saturated with carbon dioxide from the tank *9* by means of a carbon dioxide injection compressor *10*. The carbon dioxide-saturated wastewater is mixed with microalgae from the tank *16* pumped by the microalgae injection pump *17*.

Then the mixture by means of wastewater injection pump *7* is fed to the offshoot of the wastewater supply pipeline*4*, by meansof which through non-return valves *6* is distributed over the volume of flat transparent containers *2* until they are filled. After that, the supply of microalgae is stopped.

In the purification step, the carbon dioxide-saturated wastewater is continuously supplied to the offshoot of the wastewater supply pipeline *4* by means of a wastewater injection pump *7* and enters the lower parts of flat transparent tanks *2* through non-return valves *6*.

An excess of carbon dioxide that can enter the wastewater during saturation, are discharged into the environment by means of nipples *8* mounted on offshoots *4*.

Inside the flat transparent tanks *2* wastewater moves from the bottom up and in their upper parts through the valves *19* is discharged by means of the treated wastewater pipeline *20*. The vertical velocity of wastewater is selected so that the microalgae inside the tanks are in a suspended state and are not carried away with water.

Part of the carbon dioxide that can be released from the saturated wastewater inside the flat transparent tanks *2* is discharged into the environment through the nipple *18*.

The treated wastewater is collected by pipe *20* and through the treated wastewater return pipe *21* and the guide tray *22* is fed into the distribution tray *23* of the housing *1*.

The distribution tray *23* evenly distributes the flow of treated wastewater over the internal volume of the housing. At the opposite end of the housing *1*, the wastewater is collected by the collecting tray *24* and removed from the photobioreactor using the drain tray *25*. At the stage of cycle completion, the wastewater supply by the pump *7* is stopped.

The mixture of microalgae with wastewater through the elements of the check valve *11* is discharged from flat transparent containers *2* and through the microalgae drainage pipe*12* is fed into the microalgae separator *13*.

The recirculated biomass is piped to the microalgae tank *16*, and the excess biomass is discharged through the excess biomass pipe *14*.

After the loss of transparency of the walls of the flat transparent tanks *2* at the end of the cycle, the inner tank of the housing *1* is emptied, attached to the bottom of the housing with quick-release fasteners the flat transparent containers *2* are disconnected and replaced with new or previously cleaned.

**Conclusions**

During the past decades, great progress has been made in bioengineering and biotechnology for efficient microalgae mass production. Thus, several types of closed culture systems, such as tubular or flat plate photobioreactors show promise for application in large scale microalgae culture for bioenergy, aqua- and agricultural uses.

The proposed construction of photobioreactor can have good perspectives to be use in communal services for sewage water purification from biogenic elements.

Improved photobioreactor design also can be used in sewage systems of enterprises of different branches of industry, when it is necessary to purify sewage water.

The proposed flat-parallel type photobioreactor design for sewage water treatment differs by changing the geometric shape of the tanks, which serves a mixture of water and microalgae, resulting in a reduction in material costs for the manufacture of tanks and labor costs for their maintenance.

The future of microalgae biotechnology appears promising, and innovative processes and products are expected to emerge over the next few years.

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**Павлюх Л., Шаманський С., Заяц О.**

## ФОТОБІОРЕАКТОР ПЛОСКО-ПАРАЛЕЛЬНОГО КОМПОНУВАННЯ ДЛЯ ОЧИЩЕННЯ СТІЧНИХ ВОД

***Вступ***

*Органічні та неорганічні речовини, які потрапили в навколишнє середовище в результаті побутової, сільськогосподарської та промислової діяльності з води, призводять до органічного та неорганічного забруднення. Стоки завантажуються неорганічним азотом і фосфором і викликають евтрофікацію. Культура мікроводоростей пропонує цікавий крок для очищення стічних вод, оскільки вони забезпечують третинне біоочищення у поєднанні з виробництвом потенційно цінної біомаси, яку можна використовувати для кількох цілей.*

***Постановка завдання***

*Метою цієї статті є розробка конструкції фотобіореактора для очищення стічних вод, в якій застосування нових елементів та з'єднань зменшує витрату матеріалу для виготовлення прозорих гнучких резервуарів, скорочуючи витрати праці на встановлення та демонтаж резервуарів та запобігаючи змішуванню іммобілізованих ємностей водорості та їх видалення з робочої зони фотобіореактора.*

***Методологія дослідження***

*Методи ґрунтувалися на систематичному аналізі теоретичних досліджень, синтезі, аналогії та порівнянні різних конструкцій фотобіореакторів.*

***Результати та обговорення***

*Поставлене завдання вирішується так, що фотобіореактор виконаний у вигляді прозорої проточної прямокутної ємності з відкритим верхом, усередині якої вертикально, паралельно один одному розташовані прикріплені до днища ємності швидкороз'ємними кріпленнями проточні плоскі прозорі ємності з гнучкого матеріалу, до яких у нижній частині через зворотні клапани під'єднані трубопроводи подавання насиченої вуглекислим газом стічної води і мікроводоростей, під'єднані через запірну арматуру трубопроводи для відведення суміші мікроводоростей з залишковою стічною водою, а у верхній герметичній частині під'єднані трубопроводи для відведення очищеної стічної води і клапани для випускання накопичуваних газів, трубопровід для відведення очищеної стічної води приєднано до направляючого лотка для подавання очищеної стічної води у середину проточної прямокутної ємності з відкритим верхом, при цьому до вхідної частини трубопроводу подавання стічної води приєднано трубопровід подавання вуглекислого газу, а на вихідній частині трубопроводу для відведення суміші мікроводоростей з залишковою стічною водою розташований сепаратор мікроводоростей для розділення зворотної та надлишкової біомаси для подавання сепарованої від мікроводоростей стічної води у проточну прямокутну ємність.*

***Висновки***

*Запропонована конструкція фотобіореактора може мати хороші перспективи для використання в комунальних службах для очищення стічних вод від біогенних елементів. Запропонована конструкція фотобіореактора-очищувача стічних вод плоско-паралельного компонування відрізняється зміною геометричної форми ємностей, куди подається суміш води та мікроводоростей, у результаті чого досягається зменшення витрат матеріалу на виготовлення ємностей та трудозатрат на їх обслуговування.*

*Покращена конструкція фотобіореактора також може бути використана в каналізаційних системах підприємств різних галузей промисловості, коли необхідно очистити стічні води. Майбутнє біотехнології мікроводоростей виглядає багатообіцяючим, а впродовж наступних кількох років очікується поява інноваційних процесів та продуктів.*

**Ключові слова**: фотобіореактор, евтрофікація, очищення стічних вод, мікроводорості.

**Pavliukh L., Shamanskyi S., Zaiats O.**

## A FLAT-PARALLEL TYPE PHOTOBIOREACTOR DESIGN FOR SEWAGE WATER TREATMENT

***Introduction***

*Organic and inorganic substances which were released into the environment as a result of domestic, agricultural and industrial water activities lead to organic and inorganic pollution. Effluent is loaded with inorganic nitrogen and phosphorus and causes eutrophication. Microalgae culture offers an interesting step for wastewater treatments, because they provide a tertiary biotreatment coupled with the production of potentially valuable biomass, which can be used for several purposes.*

***Problem statement***

*The purpose of this article is to develop a photobioreactor design for wastewater treatment in which the application of new elements and connections reduces material consumption for the manufacture of transparent flexible tanks, reducing labor costs for installation and dismantling of tanks, and preventing the mixing of immobilized algae and their removal from the working area of the photobioreactor.*

***Research methodology***

*Methods were based on a systematic analysis of theoretical research, synthesis, anology and comparison of various photobioreactor designs.*

***Results and discussion***

*The problem is solved by the fact that the photobioreactor is made in the form of a transparent flowing rectangular open-topped tank. The flowing flat transparent containers, made with flexible material, are vertically, parallel to each other attached to the bottom of the tank with quick-release fasteners inside. Pipelines for supply saturated by carbon dioxide wastewater and microalgae are connected through non-return valves. Pipelines for drainage of a mixture of microalgae with residual wastewater are connected through non-return valves. Pipelines for drainage of treated wastewater and valves for release of accumulated gases are connected in the upper airtight part. The pipeline for the treatment of treated wastewater is connected to the guide tray for supplying treated wastewater in the middle of a flowing rectangular open-topped tank.A carbon dioxide supply pipeline is connected to the inlet part of the wastewater supply pipeline. At the outlet of the pipeline for the removal of a mixture of microalgae with residual wastewater is a separator of microalgae to separate the return and excess biomass to supply separated from microalgae wastewater in a flowing rectangular tank.*

***Conclusions***

*The proposed construction of photobioreactor can have good perspectives to be use in communal services for sewage water purification from biogenic elements. Improved photobioreactor design also can be used in sewage systems of enterprises of different branches of industry, when it is necessary to purify sewage water. The proposed flat-parallel type photobioreactor design for sewage water treatment differs by changing the geometric shape of the tanks, which serves a mixture of water and microalgae, resulting in a reduction in material costs for the manufacture of tanks and labor costs for their maintenance.*

*The future of microalgae biotechnology appears promising, and innovative processes and products are expected to emerge over the next few years.*

**Keywords:** photobioreactor, eutrophication, wastewater treatment, microalgae.

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