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Автоматизированная система очистки жидких продуктов переработки отходов для замкнутых экосистем космического назначения

С. В. Трифонов[1, 2*], А. А. Тихомиров[1, 2], А. В. Мурыгин[2]

[1]Институт биофизики ФИЦ КНЦ СО РАН
Российская Федерация, 660036, г. Красноярск, ул. Академгородок, 50/50
[2]Сибирский государственный университет науки и технологий имени академика М. Ф. Решетнева
Российская Федерация, 660037, г. Красноярск, просп. им. газ. «Красноярский Рабочий», 31
[*]E-mail: trifonov_sergei@inbox.ru

Обеспечение жизнедеятельности человека в течение нескольких лет в изолированных условиях будущих марсианских и лунных баз представляется возможным при организации круговоротного процесса преобразования органических отходов, в том числе экзометаболитов человека (кал. урина), в необходимые ему продукты: воду, кислород и пищу. Перспективным способом организации такого круговоротного процесса является создание трехзвенной замкнутой экосистемы (ЗЭС): человек, звено получения удобрений из органических отходов и растения – где растения синтезируют необходимые человеку продукты. В работе рассмотрена оригинальная схема комплексной установки очистки жидких продуктов переработки экзометаболитов человека от поллютантов в процессе получения питательных растворов для выращивания растений в условиях ЗЭС. Переработку экзометаболитов человека осуществляли в устройстве физико-химического окисления в водной среде перекиси водорода под действием переменного электрического тока – в реакторе «мокрого» сжигания. Подобрано периферийное оборудование для организации системы автоматического управления установкой очистки, выявлены проблемы и разработаны подходы в автоматизации тнехнологических процессов и создании программного обеспечения для взаимодействия человека с предлагаемой установкой. Выполнены эксперименты по выращиванию растений салата, подтверждающие эффективность предлагаемых процессов очистки жидких продуктов переработки экзометаболитов человека. Сделан вывод, что созданная комплексная установка очистки, оснащенная предлагаемым программным обеспечением, может быть использована для научных исследований применительно к тематике ЗЭС, в том числе космического назначения.

Ключевые слова: управление технологическим процессом, системы жизнеобеспечения, утилизация органических отходов, обессоливание, растительное звено.

Automated system for cleaning liquid waste products for closed ecosystems for space purposes

S. V. Trifonov[1, 2*], A. A. Tikhomirov[1, 2], A. V. Murygin[2]

[1]Institute of Biophysics SB RAS
50/50, Akademgorodok, Krasnoyarsk, 660036, Russian Federation
[2]Reshetnev Siberian State University of Science and Technology
31, Krasnoyarskii Rabochii prospekt, Krasnoyarsk, 660037, Russian Federation
[*]E-mail: trifonov_sergei@inbox.ru

Ensuring human life activity for several years in isolated conditions of future Martian and lunar bases is possible with the organization of a circular process of converting organic waste, including human exometabolites (feces . urine), into the products he needs: water, oxygen and food. A promising way to organize such a circular process is to create a three–link closed ecosystem (CES): a person, a link for obtaining fertilizers from organic waste and plants - where plants synthesize the products necessary for a person. The paper considers the original scheme of a complex installation for the purification of liquid products of processing of human exometabolites from pollutants in the process of obtaining nutrient solutions for growing plants in a CES. The processing of human exometabolites was carried out in a device for physicochemical oxidation of hydrogen peroxide in an aqueous medium under the action of alternating electric current – in a "wet" combustion reactor. Peripheral equipment was selected for the organization of the automatic control system of the cleaning plant, problems were identified and approaches were developed in the automation of technological processes and the creation of software for human interaction with the proposed installation. Experiments on the cultivation of lettuce plants have been carried out, confirming the effectiveness of the proposed processes of purification of liquid products of processing of human exometabolites. It is concluded that the created integrated cleaning plant, equipped with the proposed software, can be used for scientific research in relation to the subject of CES, including space purposes.

Keywords: process control, life support systems, utilization of organic waste, desalination, plant link.

Introduction

The problem of creating closed ecosystems (CES) to ensure human life during long-term space flight and stay on celestial bodies (Moon, Mars, asteroids, etc.) is currently receiving increasing attention from leading space agencies and other major research centers [1; 2]. In Russia, the Institute of Biophysics SB RAS(Siberian Branch of Russia Academy of Science) is actively engaged in the development of closed ecosystems for space purposes [3]. At the same time, much attention is paid to the creation of models of closed ecosystems. Various patterns of circular processes are worked out on their basis, which can then be the basis for the creation of full-scale closed ecosystems with humans. Future closed ecosystems should include both biological and physico-chemical methods of waste oxidation for their subsequent inclusion in cycling processes [4–17]. To ensure the effective operation of the physical and chemical processes of oxidation of organic and inorganic waste in CES, it is extremely important to create and sustainably operate a set of necessary instruments and equipment. An integral part of such equipment is an installation for the purification of liquid products of human waste processing (feces, urine), since the process of waste oxidation produces pollutants that inhibit plant growth. The Institute of Biophysics of the SB RAS is conducting research on the creation of such cleaning methods in relation to closed ecosystems. In particular, software is being developed to automate cleaning processes [17; 18].

The purpose of this work is biotesting of solutions obtained after purification and the development of a digital automated control system for the installation of physical and chemical purification of mineralized human exometabolites.

Methods and approaches

Long-term daily direct application of mineralized exometabolites into the irrigation solution will cause its salinity due to the high NaCl content in human urine [19; 20]. In addition, the "wet" combustion method is practically unable to utilize urea, which increases the risk of the development of opportunistic urobacteria in the system [21] and reduces the availability of nitrogen for the plant CES link. Therefore, the complex of physical and chemical processing of organic waste includes, in addition to "wet" combustion, several more sequential processes for purifying solutions of mineralized exometabolites, for each of which a reactor has been developed [18]: 1) decomposition of urea; 2) release of Cl_2; 3) synthesis of HCl; 4) release of alkali; 5) release of Na_2CO_3; 6) synthesis of NaCl. Together, these 6 reactors are a plant for the purification of liquid products of physical and chemical processing of human waste products.

To assess the influence of liquid products of the physicochemical oxidation of human exometabolites on plants, we used previously developed methodological approaches for preparing nutrient solutions on this basis for their subsequent use in an experimental model of a closed ecosystem, subject to regular (once every 7 days) replacement of 1/8 of the nutrient solution with water. That is, in 8 weeks there was a complete change of solution [22].

Studying the influence of possible pollutants in a nutrient solution required testing the possibility of long-term use of permanent solutions prepared on the basis of liquid products of the mineralization of human exometabolites for growing plants. The object of research was the "Moscow Greenhouse" variety lettuce. Plants in an experimental model of a closed ecosystem were grown using hydroponics on expanded clay. The technology and growing conditions are similar to those described earlier. [22; 23]. The duration of cultivation from germination to technical maturity is 21 days. In the experimental version, the solution was prepared based on liquid mineralization products. Control options – standard Knop solution: control 1 – permanent solution with correction, control 2 – every 7 days the solution was changed to a freshly prepared one. During plant growth, correction of permanent irrigation solutions was carried out with initial solutions based on the content of available forms of nitrogen.

When creating an automated control system and software for a treatment plant, a uniform approach is desirable, thanks to which the same type of process parameters and reactor programming menus will be displayed in the same way, and the same type of automatic control algorithm for all reactors will be used. This is important, since the reactors are different, and it is more convenient for the operator to control and configure them with a uniform interface display. In addition, the automation system and software being developed should be easily adaptable to connecting possible new reactors to the structure of the treatment plant. Following this logic, the automation and software must be adaptable to connecting the "wet" combustion reactor and other reactors of the physicochemical waste mineralization subsystem [17]. This seems possible, since the program interaction scheme that meets the specified requirements for the automation and software of the treatment plant is the same for the "wet" combustion reactor (Fig. 1) .

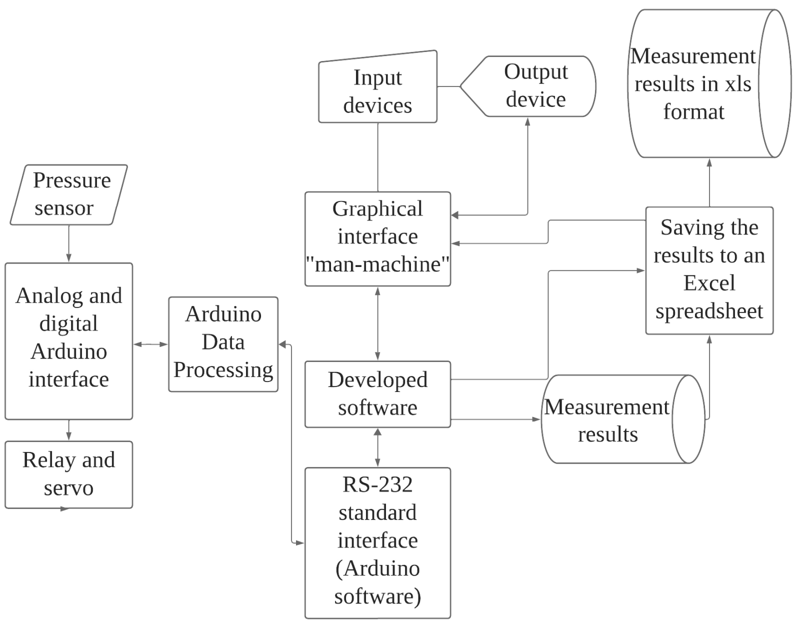


Рис. 1. Схема взаимодействия программ

Fig. 1. Scheme of program interaction

In order to ensure interaction with peripheral devices, including sensors, relays, servos and others, it was decided to use the Arduino platform due to its ease of programming, wide support for hardware modules and sensors. The Arduino IDE development environment is chosen for Arduino programming. For software development, with a focus on creating a convenient interface for the end user, an additional development environment was added – Visual Studio using a programming language C#.

Methods and approaches

A study of the influence of pollutants in a nutrient solution showed that the biomass of lettuce plants grown in non-replaceable solutions of the experimental and control variants did not differ significantly, just as there were no significant differences from the biomass of plants grown in control solutions that were regularly replaced (see table).

Dry weight (g) per plant of lettuce variety "Moscow Greenhouse", grown on solutions prepared on the basis of liquid products mineralization of human exometabolites

Тип питательного раствора	Общая биомасса	Биомасса листьев
Несменяемый раствор экзометаболитов	3.3±0.4	2.9±0.3
Несменяемый раствор Кнопа (контроль 1)	2.8±0.5	2.4±0.5
Сменяемый раствор Кнопа (контроль 2)	2.7±0.9	2.1±0.4

Type of nutrient solution	Total biomass	Leaf biomass
Permanent solution of exometabolites	3.3±0.4	2.9±0.3
Non-replaceable Knop solution (control 1)	2.8±0.5	2.4±0.5
Replaceable Knop solution (control 2)	2.7±0.9	2.1±0.4

Thus, the fundamental possibility of long-term use of nutrient solutions prepared on the basis of liquid products of the mineralization of human exometabolites for growing plants of the phototrophic link of a closed ecosystem has been experimentally demonstrated .

Based on the analysis of the processes of the physico-chemical unit for processing human waste, the automatic reactor control algorithm was taken as the basis for logical control [18, Fig. 2, B)], the logic of which is to maintain the parameters of the technological process conditions in the specified ranges and stop the process when the target parameter reaches the specified value. The work [18] does not disclose the operating principle of the unit for adjusting the conditions parameters, which is a problematic point when trying to create a unified structure of the automatic control algorithm for the treatment plant. This is due to the fact that the processes in the reactors of the installation are varied: they occur in the liquid and gaseous phase, have one or several stages, and may require partial operator intervention. Therefore, maintaining certain condition parameter values ultimately requires different hardware and logic solutions. As a result, despite the possibility of uniformly displaying the parameters of technological processes, the software settings for the operation of different reactors and control algorithms will differ from each other.

The need for an individual approach to settings for each reactor of a treatment plant indicates the possibility of using common software for all reactors of the physico-chemical mineralization subsystem of waste [17], including a "wet" combustion reactor, the operating algorithm of which differs from the operating algorithm of the treatment plant (Fig. 2)

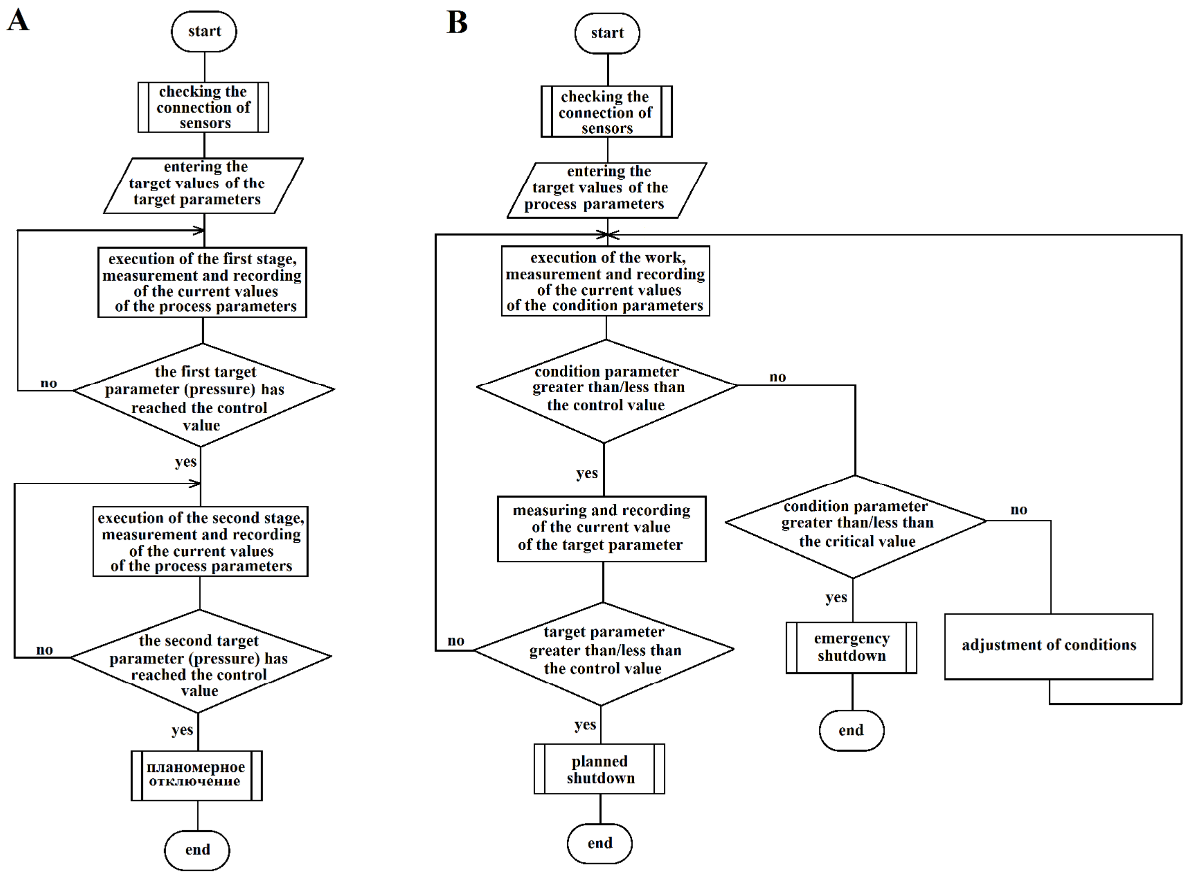


Рис. 2. Алгоритмы работы реакторов:
А – без контроля параметров условий процесса; Б – с контролем параметров условий процесса

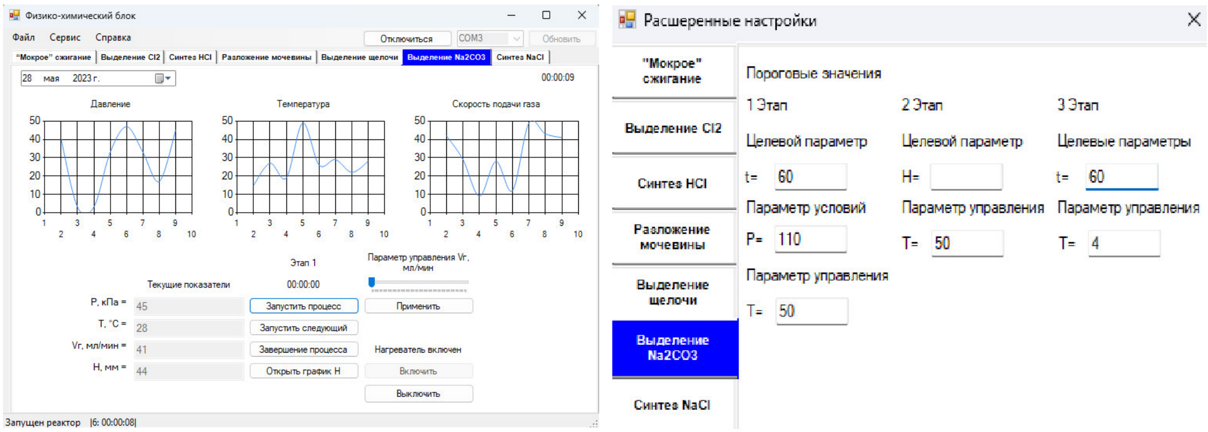
Fig. 2. Reactor operation algorithms:
A – without control of the parameters of the process conditions; Б – with control of the parameters of the process conditions

As a result, software was developed in which, for user convenience, the operator's workspace is divided into tabs, where each tab has its own reactor (Fig. 3). Each tab has fields for displaying indicators in text format, buttons for reactor control, fields for plotting graphs based on measurement results, as well as operating time and current date.

By pressing the "Start" button, a signal is sent to the connection port, then the Arduino begins to transmit readings of the running process. The data is displayed in the appropriate fields, and based on this data, the construction of the graphs presented in Fig. begins. 3, where each tab corresponds to a reactor/process of physical and chemical processing of human waste products. Four-color tab marking is proposed to indicate the state of processes:

state 1 – the process is not running, not the current tab;
state 2 – process not running, current tab;
state 3 – the process is running, not the current tab;
state 4 – process running, current tab.

Reactor operation settings allow you to enter parameter values for each purification process to automatically maintain and adjust the conditions for its occurrence.



А **Б**

Рис. 3. Окно ПО во время работы:
А – отображение параметров текущего процесса (выделение Na2CO3);
Б – отображение настроек реактора выделения Na2CO3

Fig. 3. The software window during operation:
A – displaying the parameters of the current process (Na2CO3 extraction);
Б – displaying the settings of the Na2CO3 extraction reactor

When the process is started, in addition to outputting data in the current time, the data is written to a text document. All measurement results are saved in separate folders in the software directory. The file names contain the exact launch date. And the documents themselves describe the number of the launched reactor and the results of measurements over time.

Conclusion

Peripheral equipment for organizing an automatic control system was selected, problems were identified and approaches were developed to automate these processes and create software for human interaction with the proposed installation. Experiments on growing lettuce plants were carried out, confirming the effectiveness of the proposed purification processes for liquid products of the processing of human exometabolites. Thus, the created complex purification installation, equipped with the proposed software, can be used for scientific research in relation to CES topics, including space applications.

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Тихомиров Александр Аполлинариевич – доктор биологических наук, профессор, заведующий лабораторией управления биосинтезом фототрофов, Институт биофизики Сибирского отделения Российской академии наук; заведующий кафедрой замкнутых экосистем, Сибирский государственный университет науки и технологий имени академика М. Ф. Решетнева. E-mail: alex-tikhomirov@yandex.ru.

Трифонов Сергей Викторович – кандидат биологических наук, заведующий лабораторией проблем создания круговоротных процессов искусственных экосистем, Институт биофизики Сибирского отделения Российской Академии наук; доцент кафедры замкнутых экосистем, Сибирский государственный университет науки и технологий имени академика М. Ф. Решетнева. E-mail: trifonov_sergei@inbox.ru.

Мурыгин Александр Владимирович – доктор технических наук, профессор, заведующий кафедрой информационно-управляющих систем; Сибирский государственный университет науки и технологий имени академика М. Ф. Решетнева. E-mail: avm514@mail.ru.

Tikhomirov Alexander Apollinarievich – Dr. Sc., professor, Head of laboratory of Phototrophic Biosynthesis Control, Institute of Biophysics Siberian Branch of Russian Academy of Sciences; Head of chair of Closed EcoSystems, Reshetnev Siberian State University of Science and Technology. E-mail: alex-tikhomirov@yandex.ru.

Trifonov Sergei Viktorovich – Ph. D., head of Laboratory for Problems of Establishing Cycling Processes of Artificial Ecosystems, Institute of Biophysics Siberian Branch of Russian Academy of Sciences; Associate Professor, Department of Closed Ecosystems, Reshetnev Siberian State University of Science and Technology. E-mail: trifonov_sergei@inbox.ru.

Murygin Alexander Vladimirovich – Dr. Sc., professor, Head of chair of Information and Management Systems; Reshetnev Siberian State University of Science and Technology. E-mail: avm514@mail.ru.