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WATER PURIFICATION IN SPACE CONDITIONS

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Abstract. The life support system of the International Space Station must include the provision of drinking water to the crew and the treatment and disposal of wastewater. The cost of water delivery to the ISS is very high, so it is necessary to improve the technological schemes of wastewater treatment in space in order to reuse water in a complete closed cycle. The studies were performed based on the analysis of Ukrainian and foreign scientific sources and reporting data on the specifics of water use at space stations and the treatment methods of the used waters (wastewaters). In addition to international experience, our own research was used to develop a technology for wastewater treatment in space. The authors of the article analyzed the operation of existing wastewater treatment facilities in space and made recommendations for their use at the ISS. The developed technology for the treatment ofwastewater and drinking water in zero-gravity (space) is based on the use of various reactors. They can be made of various materials (metal, plastic, etc.); they do not contain non-standard equipment that requires factory manufacturing. Compactness, complete tightness and small dimensions of bio- and physicochemical reactors allow them to be installed within the ISS. The cleaning process is easy to manage and can be fully automated. Water problems are central to the whole world, including in space. The ISS should have a system for the wastewater treatment and their closed use, since the supply of new water to stations significantly increases the cost of space exploration. Quality water is the health and well-being of people in space. Since there is no gravity in space, centrifugal forces (centrifuges) must be used to separate suspended particles from water. A comprehensive review of the issues related to wastewater treatment in space, allows us to conclude that it is necessary to regenerate water at International space stations (ISS). Indeed, to ensure the life support of the astronauts, a colossal amount of water is required, and its delivery to the ISS from the Earth is expensive.

Keywords: WASTE WATER TREATMENT; SPACE; WASTEWATER TREATMENT FACILITIES; SPACE WATER TREATMENT TECHNOLOGY; SPACE LIFE SUPPORT SYSTEM

ОЧИСТКА ВОД В УСЛОВИЯХ КОСМОСА

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Аннотация. Система жизнеобеспечения Международной космической станции обязательно включает в себя обеспечение экипажа водой питьевого качества, очистку и обезвреживание сточных вод. Стоимость доставки воды в МКС очень высока, поэтому необходимо совершенствовать технологические схемы очистки сточных вод в условиях космоса с целью повторного использования воды в полном замкнутом цикле. Исследования выполнены на основании анализа украинских и зарубежных научных источников и отчетных данных о специфике использования воды на космических станциях и способах очистки сточных вод. Для разработки технологии очистки сточных вод в условиях космоса кроме мирового опыта использованы собственные исследования. Авторы статьи провели анализ работы существующих построек по очистке сточных вод в условиях космоса и представили рекомендации по их использованию на МКС. Разработанная технология для очистки сточных и питьевых вод в условиях невесомости (космоса) основывается на использовании реакторов. Реакторы могут быть выполнены из различных материалов (металл, пластик и др.), они не содержат нестандартного оборудования, требующего заводского

изготовления. Компактность, полная герметичность и небольшие габариты био- и физико-химических реакторов позволяют устанавливать их внутри МКС. Процесс очистки прост в управлении и может быть полностью автоматизирован. Водные проблемы главны во всем мире, в том числе и в условиях космоса. На МКС должна быть предусмотрена система по обработке сточных вод и их замкнутому использованию, поскольку снабжение станций новой водой значительно увеличивает стоимость освоения космического пространства. Качественная вода – это здоровье и благополучная работа людей в условиях космоса. Поскольку в космосе отсутствует гравитация, для отделения взвешенных веществ от воды следует использовать центробежные силы (центрифуги). Комплексное рассмотрение вопросов, связанных с очисткой сточных вод в условиях космоса, позволяет заключить необходимость регенерации воды на Международных космических станциях (МКС). Ведь для обеспечения жизнедеятельности космонавтов нужно колоссальное количество воды, а ее доставка на МКС с Земли очень дорогая.
Ключевые слова: ОЧИСТКА СТОЧНЫХ ВОД; КОСМОС; СООРУЖЕНИЯ ПО ОЧИСТКИ СТОЧНЫХ ВОД; ТЕХНОЛОГИЯ ОЧИСТКИ ВОД В УСЛОВИЯХ КОСМОСА; СИСТЕМА ЖИЗНЕОБЕСПЕЧЕНИЯ В КОСМОСЕ

ОЧИСТКА ВОД В УМОВАХ КОСМОСУ

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Анотація. Система життєзабезпечення Міжнародної космічної станції обов'язково включає забезпечення екіпажу водою питної якості та очистку і знешкодження стічних вод. Вартість доставки води до МКС дуже висока, тому необхідно вдосконалювати технологічні схеми очищення стічних вод в умовах космосу з метою повторного використання води в повному замкненому циклі. Дослідження виконані на підставі аналізу українських і зарубіжних наукових джерел і звітних даних про специфіку використання води на космічних станціях і способах очищення стічних вод. Для розробки технології очищення стічних вод в умовах космосу, окрім світового досвіду, використані власні дослідження. Автори статті провели аналіз роботи існуючих споруд по очищенню стічних вод в умовах космосу і представили рекомендації по їх використанню на МКС. Розроблена технологія для очищення стічних і питних вод в умовах невагомості (космосу) ґрунтується на використанні реакторів. Реактори можуть бути виконані з різних матеріалів (метал, пластик та ін.), вони не містять нестандартного устаткування, яке вимагає заводського виготовлення. Компактність, повна герметичність і невеликі габарити біо- і фізико-хімічних реакторів дозволяють встановлювати їх в межах МКС. Процес очищення простий в управлінні і може бути повністю автоматизований. Водні проблеми є головними у всьому світі, у тому числі і в умовах космосу. На МКС має бути передбачена система по обробці стічних вод та їх замкнутого використання, оскільки постачання станцій новою водою значно збільшує вартість освоєння космічного простору. Якісна вода - це здоров'я і благополучна робота людей в умовах космосу. Оскільки в космосі відсутня гравітація, для відділення зважених речовин від води треба використовувати відцентрові сили (центрифуги). Комплексний розгляд питань, що пов'язані з очищенням стічних вод в умовах космосу, дозволяє зробити висновок про необхідність регенерації води на Міжнародних космічних станціях (МКС). Адже для забезпечення життєдіяльності космонавтів потрібно колосальну кількість води, а її доставка на МКС із Землі є дуже дорогою.
Ключові слова: ОЧИЩЕННЯ СТІЧНИХ ВОД; КОСМОС; СПОРУДИ ПО ОЧИЩЕННЮ СТІЧНИХ ВОД; ТЕХНОЛОГІЯ ОЧИЩЕННЯ ВОД В УМОВАХ КОСМОСУ; СИСТЕМА ЖИТТЄЗАБЕЗПЕЧЕННЯ В КОСМОСІ

Introduction

The International Space Station (ISS) is a permanent research laboratory in space, the fruit of the labor of more than 100,000 people. Most of them work in Canada, Russia and the United States of America, others in Belgium, Brazil, Great Britain, Germany and other countries. After the completion of construction (2004) , the ISS was 88 meters long and 109 meters wide, and in terms of the volume of living and working premises the station was comparable to two Boeing-747 jet liners. The weight of this structure in the end is about 520 tons (Fig. 1) [1].

Figure 1 - The International Space Station

Electrical, computer and hydraulic communications are laid on the surface of the modules, through which electricity is transmitted, drinking water and water of the air cooling system passes.

The state close to zero gravity plays an important role in scientific research carried out on board the ISS. The force of gravity at the station altitude (400 km) is a million times less than what we experience on the surface of the Earth. On Earth, a thrown pencil will fly a distance of 2 m in 0.5 s, and on board the ISS it will take ten minutes. This huge «house», consisting of many modules, can accommodate crews of up to seven or more people.

Formulation of the research problem

All the water available at the space station is delivered by cargo ships. It is spent on food, hygiene procedures, and support of the station's technical systems. The technique calculates literally every gram of excess weight, so it is impossible to take it with a margin. On board with a huge amount of state-of-the-art technology, scientists and engineers work under strict water economy conditions.

The key point in its recovery is water purification. The purification system collects all sorts of water: leftovers from cooking, dirty water from washing, and even the sweat of astronauts. Water recovery means getting it again. But it is impossible to regenerate water unless it is first brought in from Earth. The regeneration process itself reduces the cost of space flights and makes the ISS system less dependent on terrestrial services [2]. Consequently, the water supplied from Earth is used many times on the ISS.

Solution of the problem

The research was carried out on the basis of an analysis of Ukrainian and foreign scientific sources and data reports on the specifics of water use at space stations and methods of wastewater purification. To develop a technology for wastewater purification in space, in addition to the general world experience, own research was used.

Water issues are on rise all over the world, and the same is about space. The ISS should be provided with a system of wastewater purification and it's multiple looped use, since the supply of new water to the stations significantly increases the cost of space exploration. High-quality water is the health and well-being of people in space. Since there is no gravity in space, centrifugal forces (centrifuges) should be used to separate suspended solids from water.

Now the ISS implements several methods of water regeneration:

- condensation of moisture from the air;
- waste water purification;
- processing of urine and solid waste.

The ISS is equipped with special equipment that condenses moisture from the air. Moisture in the air is natural, it exists both in space and on Earth. In the process of vital activity, astronauts can release up to 2.5 liters of liquid per day. In addition, the ISS has special filters for the purification of used water. But considering how astronauts wash, household water consumption is significantly different from that of the earth. Urine and solid waste recycling is a new development that has only been used on the ISS since 2010.

Currently, the ISS requires about 9000 liters of water per year to operate. This is a generalized figure that reflects all costs. Water on the ISS is recovered by about 93%, so the supply volumes are significantly lower. But do not forget that with each complete cycle of water use, its total volume decreases by 7%, this makes the ISS dependent on supplies from Earth.

Modern Russian water regeneration systems SRV-K2M and Electron-VM make it possible to provide astronauts on the ISS with water by 63% [3]. Biochemical analysis showed that the regenerated water does not lose its original properties and is completely drinkable. Scientists are currently working to create a more closed system that will provide astronauts with 95% water. There are prospects for the development of purification systems that will provide a 100% closed cycle.

The new integrated life support system for the International Space Station is based on a water recycling system using specially designed filters and chemical processes that purify waste fluids, especially astronaut's urine and sweat, so that they are converted into fresh drinking water (Fig. 2) [4].

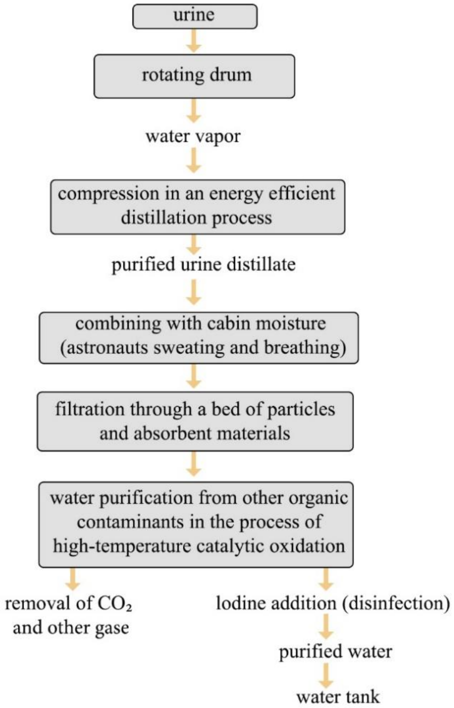

Figure 2 - Technological scheme of how astronaut's urine if purified into drinking water, developed at Marshall Space Flight Center of NASA (USA) and installed in the laboratory of the ISS

The system, which can produce 2,800 liters of water per year, is fundamentally important because it allows the ISS to accommodate six crew members, not three, and reduces the requirement to the amount of fresh water, which is very expensive to bring into the spacecraft from Earth. To send 1 kg of cargo into space, you need to spend 40,000 dollars, and 1 liter of water in space costs 70,000 dollars. These purification facilities are very important for the life at the station and such systems are the key to the upcoming human missions to the Moon and Mars.

The system was developed at Marshall Space Flight Center, in Huntsville, Alabama. It entered orbit in November 2008 aboard Space Shuttle Endeavor.

In this system, urine is directed into a drum that rotates at high speed, which releases water vapor. This vapor is compressed in an «energy efficient distillation process» and produces a «refined urine distillate» that is not yet pure enough for astronauts to drink.

This distillate is then combined with other wastewater sources (cabin water, which was produced by the sweating and breathing of astronauts). The pooled wastewater is passed through a granular filter and absorbent bed of materials used in commercial honeycomb water purification systems.

At the last stage, to purify the water from the remaining organic contaminants, the water goes through a high-temperature oxidation process. The water heats up and oxygen is injected to oxidize contaminants into carbon dioxide and other gases that are easier to remove. Water disinfection is carried out by adding iodine.

To evaluate the system's performance, drinking water samples are continually collected and sent back to Earth for testing.

The new system is part of a plan to increase the number of crew members who can adequately live on the ISS without relying heavily on supplies from Earth.

The water purification system is a small but fundamental part of NASA's ISS modernization. NASA has also sent in new crew housing and simulators.

Providing astronauts with enough drinking water is one of the tricky parts of defining long-term space travel. Water is heavy, quickly consumed, and the path to orbit is expensive. By comparison, a spacecraft launch costs $ 10,000 a pound, and a gallon of water weighs 8.33 pounds (a gallon is 3.785 liters) [5].

Astronauts are limited to three gallons of water a day when in space, but even such restrictions do not greatly reduce the cost of their stay in orbit, which costs $ 249,000 a day. Astronauts have been drinking purified urine since 2009, but the system they are using now is heavy, slow, and prone to breakage.

Therefore, astronauts on the ISS are testing a new method proposed by the Danish biotechnology company Aquaporin A/S [6]. This system uses a filter that contains aquaporin proteins that only remove pure water from urine, sweat, sewage and other sources of fluid in space. Aquaporin molecules are proteins that live inside cell membranes that are very efficient at allowing water to pass through and trapping other impurities. These proteins are used as building blocks in the manufacture of membranes.

The filter works basically the same way as our kidney (Fig. 3). The system consists of two tubes connected to an energy source. It draws a liter of urine from one container through a filter and discharges it into another container in less than a minute. The device is small, lightweight and less prone to clogging than the filters currently in use.

Aquaporin A/S has been working with NASA since 2011 and is being tested on the ISS in space.

The purpose of our article is to develop a technology for purifying waste (used) water in space. The first steps are being taken in this direction, that will require more detailed study and research in the future.

The research was carried out on the basis of an analysis of Ukrainian and foreign scientific sources and data reports on the specifics of water use at space stations and methods of wastewater treatment. To develop a technology for wastewater purification in space, in addition to world experience, we used our own research [6].

It is quite obvious that in the conditions of long-term space flights, the use of water supply systems based on reserves is impossible. In this regard, one of the most priority tasks is the development of a technological scheme for water regeneration [7].

In space, the following data are used in calculating water used by a single person per day [8]:

- 2.2 liters - drinking and cooking costs;
- 0.2 liters - hygiene;
- 0.3 liters - flushed the toilet.

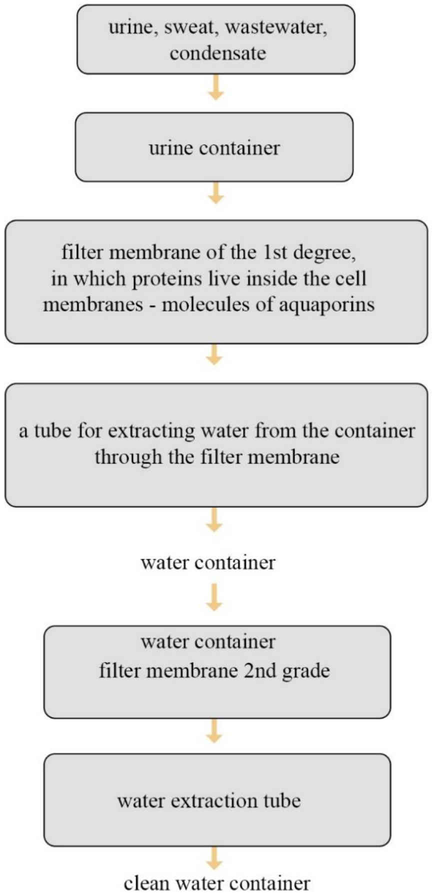

Figure 3 - Technological scheme of wastewater treatment at the ISS, developed by the Danish biotechnology company «Aquaporin A/S»

The first time water regeneration in space was carried out at the Salyut-4 space station in January 1975. In the system for the recovery of water from condensate (SRV-K), water was regenerated from atmospheric moisture to the condition of drinkable water. Subsequently, similar systems operated at the Salyut-6, Salyut-7, and Mir stations. At the Mir station, a system for the regeneration of water from urine was in use, and the system for the regeneration of sanitary and hygienic water was tested [9].

It is important to note that due to the influence of space conditions, calcium in the urine of astronauts is greatly increased. Filters for urine processing, designed on Earth, are not designed for such biochemical composition of urine and therefore quickly deteriorate.

The sedimentation of used water does not work in space, since there is no gravity, but it can be successfully replaced with nettling centrifuges of a special design.

Structures for the purification of waste and drinking water in zero gravity (space) conditions can be different reactors. Such reactors can be made of various materials (metal, plastic, etc.) they do not contain non-standard equipment that requires factory production [10]. The compactness, complete tightness and small dimensions of the bio- and physicochemical reactors allow them to be installed inside the ISS. The cleaning process is easy to operate and can be fully automated. The number of necessary controlled parameters is minimal, for example, for aerobic bioreactors, these are temperature, pH, and chemical oxygen demand (COD) of the treated effluent. The process is resistant to both peak loads and changes in the quality of the incoming water.

According to the wastewater purification method, reactors are divided into [10]:

1. Biological, which in turn are classified:

- air supply;

- for the immobilization of microorganisms in the apparatus;

- by design features;

- by design and technological characteristics.

2. Physicochemical (chemical, electrochemical, physical, etc.).

3. Bio- physical and chemical (membrane bioreactors).

On the ISS, the use of gases (chlorine, ozone, etc.) for disinfecting water poses a danger to astronauts in case of a leak.

These days, an expensive water disinfection unit based on special ultraviolet lamps is used in passenger aircraft to disinfect drinking water [11]. Such system need to have its lamps replaced every 3000 operating hours, which is costly.

The new water disinfection system developed by the Canadian company International Water Guards uses ultraviolet light-emitting diodes [12]. Thus, it was possible to reduce the cost of the system compared to the system using UV lamps. Therefore, we recommend this system for the disinfection of waste and drinking water on the ISS.

The above emphasizes the thesis of both the necessity and the possibility of water regeneration at the International Space Stations. The technological scheme developed by the authors (Fig. 4) implies the treatment of wastewater at the ISS and their closed use.

As noted above, in conditions of space and the absence of gravity, the use of sedimentation tanks is useless. Therefore, we propose to install settling centrifuges of special designs for wastewater sedimentation and sand removal [13, 14]. For the purification of water from dissolved substances, we offer reactors, or rather membrane bioreactors of a new generation [15].

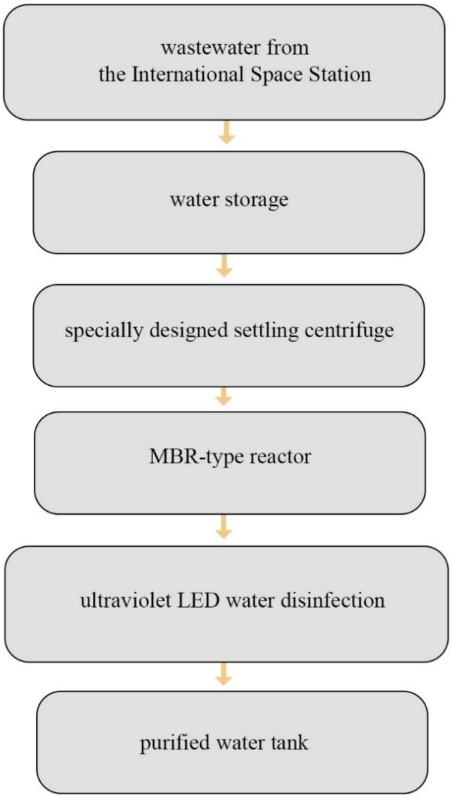

Figure 4 - Technological scheme of wastewater treatment at the International Space Station

Membrane bioreactors (MBR) are modern high-intensity biological wastewater purification facilities [16]. In contrast to the classical biological treatment scheme with separation of the sludge mixture in secondary sedimentation tanks, in membrane bioreactors, the separation of activated sludge flakes from treated wastewater is achieved by filtering the sludge mixture through an ultrafiltration or microfiltration membrane with a pore size in the range from 0.04 to 0.04 micron.

The main component of an MBR is a cartridge consisting of membrane modules. Membranes can be in the form of a hollow fiber or two flat sheets with a polymer backing [10, 17]. The cartridges are put directly in the sludge mixture. A self-priming pump creates a negative pressure on the inner surface of the diaphragms. Thus, due to the pressure difference between the outer and inner surfaces of the membrane, the wastewater is filtered through the membrane layer. The resulting clean water (permeate) is removed by a filtrate pump.

Individual microorganisms (bacteria) of activated sludge have a size that is significantly larger than the pore size of the membranes. Therefore, the membrane retains flakes of activated sludge, microorganisms and suspended inert substances floating freely during the filtration process, and are removed from the membrane surface using an aeration system.

Advantages of using MBR:

1) fewer structures - MBR replaces secondary sedimentation tanks, aeration tanks and sand filters;

2) compactness - the concentration of activated sludge in MBR is several times higher than in traditional structures, respectively, the volume of structures is the same number of times less;

3) the possibility of year-round nitrification even in cold climates - in traditional structures, with a decrease in temperature, the growth rate of nitrifiers decreases, and they are washed out of the reactor;

4) selection of microorganisms capable of oxidizing bioresistant substances - slowly growing microorganisms with such ability thanks to the membrane are not washed out of the reactor. Consequently, the cleaning efficiency for heavily oxidizing substances in the MBR is much higher than in the aeration tank-settler system;

5) automatic process convenience - the process is fully automated;

6) safe operation - the operation of the facilities does not depend on the settling capacity of the sludge (sludge index), its swelling, etc .;

7) waste water disinfection - the pores of the membranes are smaller than the size of a bacteria.

And, in conclusion, we suggest using UV-LED lamps for water disinfection. In conditions of space and the absence of gravity for the movement of water, we propose to use pumps of a new generation.

Scientific novelty

An analysis of the operation of existing wastewater purification facilities in space conditions is carried out, recommendations for their use on the ISS are presented. The developed technology for the purification of waste and drinking water in zero gravity (space) conditions is based on the use of reactors. Reactors can be made of various materials (metal, plastic, etc.) they do not contain non-standard equipment that requires factory production. The compactness, complete tightness and small dimensions of the bio- and physicochemical reactors allow them to be installed inside the ISS. The purification process is easy to operate and can be fully automated.

Conclusions

On board the ISS, water is used not only for drinking, but also for the life of the crew and the functioning of the station’s systems. Water is an essential component for the recovery of freeze-dried foods.

We have developed a technology and proposed a scheme for the purification of wastewater in space. The work of existing wastewater purification facilities in space was also analyzed and recommendations for their use on the ISS were developed.

The ISS should be provided with a system for wastewater treatment and their closed use, since supplying stations with new water significantly increases the cost of space exploration, and high-quality water means health and prosperous work of people in space.

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