Possibility of conservation of urine as a source of drinking water in water supply systems of space and ground inhabited objects

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Abstract. Life support systems for long-term closed objects can be created either on the basis of consumed water reserves, or on the basis of regeneration processes. Urine can be used as a regenerated source of drinking water. But urine is a good breeding ground for many microorganisms, therefore, to preserve it in its native form, conservation is necessary in order to prevent microbiological transformation and precipitation. The article discusses the possibility of preserving urine with a composition consisting of a 0.5% solution of plumbagin in trichloroacetic acid and an 11% solution of chromic anhydride in sulfuric acid in a ratio of 1:9 at the rate of 5 ml per 1 liter of urine.

1. Introduction
One of the conditions for the life support and preservation of a person's working capacity, including in space flight, is the availability of a sufficient amount of good-quality drinking water. The impact of accelerations, vibration, weightlessness, and enormous psychological stress cause increased rates of water excretion from the human body. Therefore, the lack of water in the human body in space flight is of particular importance [1].

Building up supplies of consumables, especially water and oxygen, during long space flights can be difficult due to weight constraints. The high weight of inventory-based systems necessitates the use of reclaim systems to recycle waste and recovered components to be returned to use. As a result of human activity, such products as moisture released by a person with sweat and during breathing, urine, feces, as well as sanitary and hygienic and sanitary water can enter the water regeneration system.

One of the sources of water is urine. It is released from one person on average 1.2–1.3 liters. However, in this case, urine, by its chemical composition, is one of the most difficult sources of water supplied for regeneration. Urine is formed at the stage of ultrafiltration of blood plasma. The main purpose of urine formation is the constant removal of urea and other nitrogenous metabolic degradation products from the blood. Another equally important function includes the regulation of water-salt balance to maintain osmotic and acid-base balance in tissue fluids of the body. Urine also contains many other components, such as hormones and end products of hormonal metabolism [2]. Although urine is a very complex metabolite, its main components are water, urea and inorganic ions.

As a rule, fresh urine has a slightly acidic reaction, although fluctuations in pH from 4.5 to 8.4 are noted. Such fluctuations in pH are caused by the composition of the food taken. Under the influence of space flight factors, the amount of salts excreted with urine can also change. A person's stay in orbital
flight conditions leads to increased excretion from the body of elements such as calcium, phosphorus, magnesium, potassium, sodium [3].

Moisture-containing human waste products are a favorable environment for the reproduction of various kinds of microorganisms. When people stay in an air-tight space, there is a pronounced increase in the content of microbes in the air, which correlates with an increase in the duration of isolation [4].

Due to the fact that in zero gravity, the collection of human waste is carried out by transporting them with a high-speed flow of atmospheric air from the manned object, the likelihood of urine contamination by various putrefactive and fermentative microorganisms increases and depends on the design of the regeneration system. When designing regeneration systems, it is necessary to remember that in the process of vital activity of microorganisms, organic and inorganic components decompose with the formation of new classes of compounds. So, during alkaline fermentation, urine acquires a sharply ammonia smell, due to the vital activity of urobacteria, as well as putrefactive bacteria, which cause the process of decomposition of urine urea to ammonia and carbon dioxide. The released ammonia shifts the pH to the alkaline side, which leads to the precipitation of calcium and magnesium salts. Fermentation processes can lead to the formation of various volatile compounds in the urine, for example, acetic, butyric acids [5, 6]. Changes in the chemical and aggregate composition of waste as a result of the vital activity of microorganisms can significantly affect the technological parameters of water regeneration processes.

In world practice, physical, biological and chemical methods of preservation and disinfection of human waste products are known. Physical methods include exposure to high temperatures, ultraviolet radiation, ultrasound treatment, exposure to ionizing radiation, treatment with magnetic and electric fields [7]. The listed physical methods of waste disinfection have a common disadvantage - the absence of an aftereffect. After processing waste by these methods, accidentally trapped microorganisms can develop even more and change the chemical composition of the environment. Apparently, chemical methods are currently the most optimal solution to the problem of disinfection.

Exposure to human waste with antibacterial chemicals has many advantages: processed products do not form harmful gases, they do not need to be stored under antiseptic conditions, the remaining antimicrobial compounds destroy microorganisms that can get into waste products after initial processing.

During the operation of the system for the regeneration of water from urine, it is inevitable to store it in collectors before the start of the technological process. During this period, urine undergoes decomposition, which necessitates its conservation in order to:

- reducing the general microbial contamination and cessation of the vital activity of microorganisms in the urine;
- binding of some urine components into strong chemical compounds (urea, ammonia);
- maintaining a certain pH of the preserved urine.
- prevention of precipitate formation.

A number of chemical compounds with bactericidal properties have been proposed as preservatives for urine to be used to extract water from it. These include acids, heavy metal ions (copper, iron, silver, cobalt, mercury, etc.) and oxidants (chromium trioxide, hydrogen peroxide, hypochlorite, hypochlorous sodium, etc.) However, many of them have, along with positive and some negative properties. Thus, chlorine-containing preparations are mostly toxic, have a pungent odor, corrode metals, precipitate and lose their bactericidal activity during storage.

For urine preservation, Rogatina L.N. five formulations were studied: copper sulfate and perhydrol, a mixture of chromic anhydride and concentrated sulfuric acid, concentrated sulfuric acid and perhydrol, paranitrophenol, formalin and caustic potassium [8]. All of these preservatives had a bactericidal effect on urine microorganisms in tested amounts. However, the condensate obtained in the evaporation plant using the above substances as preservatives contained increased amounts of ammonia.

In order to preserve urine in the cabin of spaceships, a number of substances have been studied, such as benzylphenol, benzylchlorophenol, phenyltrichloroacetate, hexachlorophene, and resorcinol [9].
these preparations do not corrode metals, do not give precipitation and are low-toxic for warm-blooded animals. But they have a smell, which is extremely undesirable in the conditions of a pressurized object.

The use of hydrogen peroxide and other substances capable of releasing active oxygen in closed systems is limited by their high reactivity in the presence of an excess of organic substances. The formation of gases, which necessitates phase separation, should also be considered a disadvantage of oxidizing agents. The latter complicates the design of the system, increases its weight and reduces the reliability of operation.

In the United States, a mixture of sulfuric acid, chromium trioxide and copper sulfate is recommended for urine preservation. Preference is given to chromium trioxide due to the fact that, in addition to bactericidal properties, in a mixture with sulfuric acid, it prevents precipitation, which can disable the water regeneration system.

Recently, solutions containing 44.3% phosphoric acid and 11% chromium oxide, 37.5% phosphoric acid and 2.5% potassium permanganate have been proposed as urine preservatives [10]. However, the regeneration of urine preserved with these solutions requires a lot of energy.

Thus, the listed methods are not always able to provide a long-term process of urine conservation for its subsequent regeneration.

2. Research methods
The work used standard methods of physicochemical and bacteriological studies of urine and regenerated water.

3. Research results
To optimize the process of urine conservation, a solution of plumbagin in trichloroacetic acid was used. To prevent precipitation an oxidizing agent is introduced into this solution, which converts the uric acid salts into a soluble form. An 11% solution of chromic anhydride in sulfuric acid was used as such an oxidizing agent. The results of the combined use of preservative compositions showed that the best result is achieved with a preserving composition consisting of one part of plumbagin’s solution in trichloroacetic acid (TCA) and nine parts of a solution of chromic anhydride in sulfuric acid (table 1).

| Preserving mixture composition | Precipitate amount in urine, g/l |
|-------------------------------|----------------------------------|
|                               | After 1 day | After 15 days | After 30 days | After 90 days | After 180 days |
| 0.1% sol. plumbagin in TCA    | 0           | 0.15±0.07    | 0.22±0.08    | 0.3±0.01     | 0.52±0.04     |
| 0.5% sol. plumbagin in TCA    | 0           | 0.15±0.06    | 0.24±0.01    | 0.4±0.01     | 0.68±0.05     |
| 1.0% sol. plumbagin in TCA    | 0           | 0.08±0.03    | 0.14±0.07    | 0.2±0.04     | 0.36±0.02     |
| 0.5% sol. plumbagin in TCA + 11% solution of chromic anhydride in sulfuric acid (1:9) | 0 | 0 | 0 | 0 | 0 |

Studies of urine preservation effectiveness with the indicated preservatives have shown that a solution of chromic anhydride in sulfuric acid (SCASA) provides urine preservation in terms of microbiological parameters only for 15 days (table 2). After 15 days of storage, molds are sown from canned urine with SCASA. With longer storage, growth was observed already on urine surface.

When urine was preserved with a composition of a 05% solution of plumbagin in trichloroacetic acid (SPTA) and SCASA, microorganisms were not plated from urine.
Table 2. Microbiological indicators of canned urine (CFU / ml).

| Research object | Shelf life, days | SCASA 5 ml/l | SCASA 10 ml/l | SPTA+ SCASA 5 ml/l | SPTA+ SCASA 10 ml/l |
|-----------------|-----------------|--------------|---------------|--------------------|---------------------|
| Original urine  | -               | 2800±310     | 11100±270     | 2800±310           | 11100±270           |
| Canned urine    | 1               | 0            | 0             | 0                  | 0                   |
|                 | 15              | 0            | 0             | 0                  | 0                   |
|                 | 30              | 0            | 0             | 0                  | 0                   |
|                 | 90              | 5            | 2             | 0                  | 0                   |
|                 | 180             | 52           | 10            | 0                  | 0                   |
|                 | 360             | 99           | 32            | 0                  | 0                   |
| Mold on the surface of urine |      |              |               |                    |                     |

In terms of its chemical and bacteriological parameters, urine, preserved with an antimicrobial composition (SPTA+ SCASA in a ratio of 1: 9), corresponded to the requirements for the entire period of its storage (table 3).

Table 3. Bacteriological and chemical indicators of urine, canned for long-term storage with an antimicrobial composition (SPTA+ SCASA in a ratio of 1: 9).

| Controlled indicators | Urine shelf life, (days) | Preservative amount per 1 liter of urine |
|-----------------------|--------------------------|-----------------------------------------|
|                       |                          | 5 ml/l                                  | 10 ml/l                                  |
| Total number of microorganisms CFU / ml | Original urine | 2800 ± 115 | 11000 ± 310 |
|                       | 1                        | 0                                      | 0                                         |
|                       | 15                       | 0                                      | 0                                         |
|                       | 30                       | 0                                      | 0                                         |
|                       | 90                       | 0                                      | 0                                         |
|                       | 180                      | 0                                      | 0                                         |
|                       | 360                      | 0                                      | 0                                         |
|                       | Original urine           | 5.65 ± 0.05                            | 5.67 ± 0.03                              |
|                       | 1                        | 2.24 ± 0.01                            | 2.22 ± 0.01                              |
|                       | 30                       | 2.35 ± 0.01                            | 1.97 ± 0.02                              |
|                       | 90                       | 2.52 ± 0.02                            | 2.08 ± 0.03                              |
|                       | 180                      | 2.48 ± 0.04                            | 2.05 ± 0.03                              |
|                       | 360                      | 2.4 ± 0.03                             | 2.00 ± 0.02                              |
|                       | Original urine           | 509.9 ± 12.1                           | 503.7 ± 11.8                             |
|                       | 1                        | 520.1 ± 14.3                           | 521 ± 15.7                               |
|                       | 15                       | 524.3 ± 12.4                           | 521.8 ± 17.1                             |
|                       | 30                       | 524 ± 21.7                             | 524.8 ± 16.9                             |
|                       | 90                       | 525.1 ± 28.3                           | 525.3 ± 15.5                             |
|                       | 180                      | 528.2 ± 22.4                           | 528.0 ± 23.6                             |
|                       | 360                      | 526.7 ± 21.1                           | 526.4 ± 21.3                             |
|                       | Original urine           | 21.0 ± 0.5                             | 27.7 ± 0.4                               |
|                       | 1                        | 17.5 ± 0.3                             | 26.0 ± 1.1                               |
|                       | 15                       | 19.1 ± 0.9                             | 23.0 ± 1.3                               |
|                       | 30                       | 19.4 ± 0.7                             | 23.0 ± 1.0                               |
Studies have shown that during the entire storage period of canned urine, precipitation was not observed in it. Water regenerated from urine (condensate) at various periods of its storage also had stable satisfactory bacteriological and chemical parameters (table 4).

Table 4. Bacteriological and chemical parameters of water recovered from canned urine.

| Controlled indicators | Urine shelf life, (days) | Preservative amount per 1 liter of urine |
|-----------------------|--------------------------|------------------------------------------|
|                       |                          | 5 ml | 10 ml |
| Total number of microorganisms CFU / ml | 1 | 0 | 0 |
|                        | 15 | 0 | 0 |
|                        | 30 | 0 | 0 |
|                        | 90 | 0 | 0 |
|                        | 180 | 0 | 0 |
|                        | 360 | 0 | 0 |
| PH                    | 1 | 3.89 ± 0.03 | 3.89 ± 0.04 |
|                        | 15 | 3.97 ± 0.03 | 3.65 ± 0.05 |
|                        | 30 | 3.95 ± 0.02 | 3.77 ± 0.05 |
|                        | 90 | 4.04 ± 0.04 | 3.60 ± 0.03 |
|                        | 180 | 4.02 ± 0.02 | 3.61 ± 0.03 |
|                        | 360 | 3.89 ± 0.03 | 3.89 ± 0.04 |
| Ammonia, mg/l          | 1 | 4.4 ± 0.07 | 2.8 ± 0.03 |
|                        | 15 | 3.5 ± 0.05 | 2.8 ± 0.03 |
|                        | 30 | 2.8 ± 0.03 | 2.8 ± 0.03 |
|                        | 90 | 2.75 ± 0.044 | 2.5 ± 0.05 |
|                        | 180 | 2.0 ± 0.06 | 2.1 ± 0.04 |
|                        | 360 | 2.0 ± 0.06 | 1.3 ± 0.01 |
|                        | 1 | Less than 0.1 | Less than 0.1 |
|                        | 15 | Less than 0.1 | Less than 0.1 |
|                        | 30 | Less than 0.1 | Less than 0.1 |
|                        | 90 | Less than 0.1 | Less than 0.1 |
|                        | 180 | Less than 0.1 | Less than 0.1 |
|                        | 360 | Less than 0.1 | Less than 0.1 |

4. Conclusion
Antimicrobial composition, including a solution of plumbagin in trichloroacetic acid and a solution of chromic anhydride in sulfuric acid in a ratio of 1: 9, provides effective preservation of urine for 360 days of storage without precipitation at a preservative amount of 5 ml per liter of urine.
References

[1] Chizhov S V and Sinyak Yu E 1973 *Water supply for spacecraft crews. Problems of space biology* (Moscow, Russia: Science)

[2] Taylor E N, Stampfer M J, Mount D B and Curhan G C 2010 DASH-style diet and 24-hour urine composition *Clinical Journal of the American Society of Nephrology* 5 2315-22

[3] Samsonov N M, Bobe L S, Farafonov N S, Soloukhin V A, Sinyak Yu E and Skuratov V M 2004 Status Aboard the International Space Station and Water Recovery Future Prospects *Proc. 34th Int. Conf. On Environmental Systems (ICES) (Colorado Springs, US: SAE)* p 11

[4] Lykov I N 2003 The problem of microbial contamination of air in autonomous ecosystems *Proc. XXXVIII scientific readings dedicated to the development of scientific heritage and the development of ideas of K.E. Tsiolkovsky* (Kaluga, Russia) pp 107-8

[5] Gazenko O G, Grigoriev A I, Meleshko G I and Shepelev EYa 1990 Habitability and biological life support systems *Space biology and aerospace medicine* 2 12-7

[6] Sychev V N, Shepelev E Ya, Meleshko G I, Gurieva T S, Levinshkh M A, Podolskiy I G, Dadasheva O A and Popov V V 1999 Biological life support systems - research on board of Mir orbital complex *Aviation and Space and Environmental Medicine* 33(1) 10-6

[7] Lykov I N and Shestakova G A 2014 *Microorganisms: Biology and Ecology* (Kaluga, Russia: Publishing house "SerNa")

[8] Rogatina L N 1971 Conservation of urine in the system of water regeneration from it *Problems of space biology* 16 173-7

[9] Borshchenko V V 1971 Study of the urine conservation method as applied to space flight conditions *Problems of space biology* 16 249-53

[10] Nazarov N M, Voronina M A and Korotkova T P 2019 Method of urine conservation to obtain regenerated water as applied to the conditions of long-term space flight *Aviation and Space Medicine* 53(4) 101-9 DOI: 10.21687 / 0233-528X-2019-53-4-101-109