Physical-chemical method for desalting organic waste for agricultural cycles

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Abstract. The problem of developing a technology for the removal or drastic reduction of NaCl from organic waste, including human exometabolites and plant waste and intended for disposal in closed agricultural cycles, is very relevant, especially for Northern regions with risky agriculture. Without its solution, it becomes almost impossible to create a long-term functioning ecosystem due to the danger of accumulation of NaCl in irrigation solutions and soil with subsequent poisoning of plants. It is obvious that the development of the technology for extracting NaCl is most rational to perform in combination with the technology for processing human exometabolites, since they are the main source of NaCl.

1. Introduction

For areas with risky agriculture located in the northern regions, a serious obstacle to the disposal of human waste is the presence of high concentrations of NaCl, which have a detrimental effect on the cultivation of plants. The same problem arises when trying to include such waste after accelerated mineralization in the closed cycle of northern eco-houses for fertilizing greenhouse plants. Researchers of the Institute of Biophysics of the Russian Academy of Sciences (IBP SB RAS) are developing a system for physicochemical treatment of plant and animal wastes, including human wastes, in order to involve the elements contained in the wastes in the material cycling within a planetary-type biotechnical life support system (BTLSS), such as BIOS-3 [1-3].

The scientific basis of this technology [4-6] can also be used for closed ecological agricultural cycles in relation to the northern regions, both for field conditions and for northern eco-houses. This technology is based on waste mineralization by the method of wet combustion: oxidation of organic waste in the hydrogen peroxide aqueous solution, using an alternating current electric field [7]. The product of this processing is a mineralized solution that can be used to prepare an irrigation solution for the higher plant compartment [8-10]. The advantages of this method are the rapid recycling and environmental safety of the products (solution and gas) [11]. For instance, mineralization of human wastes takes about two hours.

The liquid prepared in the reactor, however, cannot be directly fed into the irrigation solution for plants if it is intended to be used in a long-term operation of the agricultural cycle. Repeated direct application of mineralized exometabolites to the irrigation nutrient solution will cause its salinization [12] due to the high content of NaCl in human urine.
To establish a reliable closed agricultural cycle, it is necessary that all the processes of the waste processing complex take place within a technologically acceptable time, lasting no more than 1-2 days.

This work is devoted to the development of the scientific basis of the technology for the separation of NaCl by physical-chemical method from a solution of mineralized human exometabolites obtained by "wet" combustion.

2. Methods
The system for physicochemical treatment of organic wastes is schematically shown in figure 1. From the reactor for wet combustion, mineralized wastes are fed into the urea decomposition reactor. In this phase, urea may be decomposed either enzymatically, by urease, or by electrochemical oxidation on the platinum electrode. The method of enzymatic decomposition of urea by urease was described elsewhere [13], and it will not be discussed here.

Physicochemical decomposition of urea involves the release of Cl\(_2\), which enters the reactor for the synthesis of HCl, which is necessary for the production of NaCl in the final phase of the process. Also, this reactor periodically receives Cl\(_2\) released during the electrolysis process from the tank with irrigation solution.

After urea decomposition, the solution is fed into the electrolysis unit, where the alkaline component, which contains the major portion of metals, is separated from the mineralized human wastes. The acidic and neutral components are returned to the irrigation solution.

Then, the alkaline solution is subjected to gas bubbling and preliminary evaporation, which results in precipitation of MgCO\(_3\) and CaCO\(_3\). The precipitated carbonates are returned to the irrigation solution.

After that, the Na\(_2\)CO\(_3\) and K\(_2\)CO\(_3\) solutions are concentrated and cooled to separate the carbonates of these metals. This manipulation produces a precipitate, mainly consisting of Na\(_2\)CO\(_3\), and supernatant fluid, which contains the major portion of K\(_2\)CO\(_3\). The supernatant fluid is returned to the irrigation solution, and the precipitate is used in the final phase of the process. In this phase, Na\(_2\)CO\(_3\) and HCl are mixed to form a NaCl solution. This process can be performed by automated titration.

The most important is the development of the basic technology of the solution electrolysis stage of mineralized human exometabolites, since it is a multicomponent solution. The experimental implementation of this stage was carried out in this paper.

2.1. Electrolysis of mineralized human wastes
To solve space-related problems, ion-selective membranes were usually used to isolate certain ions from a solution [14-16]. However, in conditions of closed ecological agricultural cycles, high purity of solution treatment is not required, since it is only a question of maintaining the concentration of certain elements in the irrigation solution within acceptable limits. Moreover, the presence of organic compounds leads to a rapid pollution of the membranes [17]. Therefore, we used a simpler process, which can be employed in aggressive media and decrease concentrations of specified elements sufficiently effectively.

Electrolysis was performed in the installation shown in figure 2. The installation was equipped with electrodes with capillary tubes, through which the solution was pumped from the near-electrode layer. We used solutions of NaCl of different concentrations, representing concentrated, normal or diluted to different degrees solutions of mineralized human wastes. In each experiment, the electric current was stabilized and varied between 8 and 1000 mA in different treatments. Based on the results obtained in these experiments, we chose the most suitable parameters and carried out experiments with mineralized human wastes.
3. Results and Discussion

3.1. Electrolysis of mineralized human wastes

Results of experiments on electrolysis of model solutions are given in table 1. The most effective isolation of the alkaline component (i.e. isolation of the greatest percentage of cations) was achieved at concentrations corresponding to the dilution of mineralized human wastes by a factor of 2-10, with the current strength chosen individually for each case. Isolation of a sufficiently high percentage of cations is unlikely at concentrations higher than the two-fold dilution, as at the current strength above 100 mA, the electrodes crumble and the near-electrode layer bubbles considerably, which results in its
destruction. At the same time, this current strength is not sufficient to isolate 50% cations from the solution of mineralized human wastes of initial concentration.

The best treatments in this series of experiments were those with solutions diluted by factors of 5 and 2 and current strength of 50-100 mA, respectively. In both cases, we managed to isolate about 50% sodium in 4 h. Hence, we assume that about 75% sodium can be isolated in 8 h. These options were chosen to test the effectiveness of the method in the experiment with the solution of mineralized human wastes.

The most effective electrolysis was achieved in the experiment with the five-fold dilution of the solution and the 50-mA current (table 2). Under such parameters, up to 80% sodium can be isolated in 8 h of electrolysis. Additionally, a lower amount of acid residue was detected in the alkaline component, and the percentage of sodium was higher relative to other metals.

All this suggests that the effectiveness of this method is enhanced as the solution becomes more dilute and the strength of the current is increased to a certain level.

**Table 1.** The degree of Na release into the alkaline component of model solution, % of the total Na.

| Current, mA | Degree of concentration |
|-------------|-------------------------|
|             | 1/10 | 1/5 | 1/2 | 1   | 4   |
| 8           | 46-49 | -   | -   | -   | -   |
| 80          | 47   | 35-45 | -    | -   | -   |
| 50          | -    | 45-58 | 29-32 | -   | -   |
| 100         | -    | -    | 51-55 | 40-47 | -   |
| 1000        | -    | -    | -    | -   | 29-30 |

**Table 2.** The degree of release of the elements into the alkaline component of the solutions of mineralized human wastes, % of the total amount of each element.

| Degree of dilution | Current, mA | K     | Mg    | Na    | P     | S     |
|--------------------|-------------|-------|-------|-------|-------|-------|
| 2                  | 100         | 66-96 | 29-36 | 53-54 | 28-34 | 29-30 |
| 5                  | 50          | 67-80 | 27-53 | 59-73 | 28-30 | 20-23 |

4. Conclusion
Technologies for organizing high-closed mass exchange cycles for biotechnical life support systems can be applied to closed ecological agricultural cycles due to the high requirements of environmental friendliness and efficiency. The present study shows that the proposed physicochemical system can be used to separate NaCl from mineralized human wastes.

The possibility of extracting more than 70% of Na\(^+\) from a solution of mineralized human exometabolites in an alkaline solution has been demonstrated. A further increase in the proportion of isolated Na\(^+\) and the purity of the alkaline solution can be achieved by reducing the temperature of the dialyzed solution (to prevent mixing of the near-electrode layer and increase the purity of the alkaline solution), reducing the area of the electrodes and increasing the current strength to 100 mA, or increasing the number of electrodes with capillaries.

Thus, the complex arrangement of the system for the isolation of NaCl from liquid human exometabolites makes it possible to supplement and expand the potential for a sharp decrease in the concentration of NaCl for inclusion in closed agricultural cycles, taking into account their purpose, composition and configuration.

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