Processing of sanitary and household waste in biotechnical life support systems

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Abstract. In order to establish material loops in biotechnical life support systems (BTLSS), various types of organic waste generated within the system need to be effectively processed. A universal method should be developed to produce mineral fertilizers for the higher-plant compartment of the BTLSS regardless of the level of reduction of the organic compounds contained in the waste and the contents of mineral elements in it. A method of producing mineral fertilizers by organic waste oxidation in the hydrogen peroxide aqueous solution under application of an alternating current electric field is proposed as a possible approach. Methods of processing of human wastes and inedible plant biomass were discussed in previous studies. The present study demonstrates the approach to processing cotton waste and kitchen wastewater. The study describes processing of such wastes by using a supplementary oxidizer (nitric acid) and co-oxidation with other types of organic waste typically generated in the BTLSS. Recommendations are offered on using these approaches to process sanitary/household waste in the BTLSS.

1. Introduction
Processing of organic waste within the BTLSS is a serious challenge facing designers of the systems. The method used to process organic waste should be ecofriendly, the mineral elements contained in products of processing should be available to plants, no additional reagents should be brought into the system, and waste processing should occur at an acceptable rate (the daily amount of waste should be processed within 24 h). A number of countries have been developing methods of waste processing for the currently existing BTLSS prototypes such as Bios-3 [1] and Yuegong-1 [2]. Researchers of the Institute of Biophysics SB RAS are developing a method of oxidation of organic waste in the hydrogen peroxide aqueous solution under application of an alternating current electric field – wet combustion [3]. Studies have been carried out to prove that this method can be successfully used to process organic wastes typical for the BTLSS such as human waste and inedible plant biomass [4]. Processing of other types of waste may be necessary too. For instance, in a BTLSS functioning for extended periods of time, H, O, and C losses may occur because of leaks in construction materials. These losses can be reduced by involving such wastes as cotton material and kitchen wastewater into the mass transfer in the system. In our previous study [5], we processed cotton material in the wet combustion reactor using various reagents available in the system in order to find the optimal approach to processing materials with high cellulose content. The purpose of the present study was to
find the optimal approach to processing kitchen wastewater both separately and in combination with cotton waste, using the wet combustion method.

2. Developing the wet combustion method for processing sanitary/household waste
In the development of the wet combustion method for utilization of sanitary waste, issues such as energy consumption and the synthesis of the required amount of hydrogen peroxide inside BTLSS were omitted. This was made from those considerations that the energy consumption during processing, both of the easily oxidized (human metabolites) and the hardly oxidizable (inedible plant biomass and cotton material) organic waste, is much lower than during the cultivation of the plant cenosis. The issue of the synthesis of hydrogen peroxide inside BTLSS from water and oxygen is fundamentally resolved [6].

2.1. Method of mineralization of sanitary/household waste
The oxidation was carried out in a quartz cylindrical reactor (horizontally oriented) with a working volume of 1.25 L (half the cylinder volume). An alternating electric field was provided by applying a predetermined voltage to carbon rod electrodes located vertically at opposite ends of the reactor vessel. The boiling point of the solution at the exit of the process to the operating mode was 98-102 °C, therefore, the emitted gas was removed through a water cooler to condense and return moisture to the reactor. After completion of the process, the solution was decanted and brought to the original volume of 12.5 L. Next, the solution was settled for three days, the solution was separated and the precipitate, the precipitate was dried and ground. As a result, the solution, practically free from suspensions, and a dry ground sediment were analyzed. Analyzed the mineral composition of oxidation products and the total content of organic matter.

The soapy water that had been used to wash dishes (1 L water per 1 set of dishes per 1 human) and dried and ground vegetable peelings that remained after cooking represented kitchen wastewater in this study. Here and in what follows, this water is referred to as “wash”. The daily amount of the wash per person is 3 L. Table 1 shows different ways of wash processing in combination with various reagents available in the system. In the “Wash 100/1000+HNO3” and “Wash 50/1000+HNO3” treatments, processing was done using 100 and 50 ml H2O2 (36%) per 1 L of the wash, respectively, to evaluate the amount of hydrogen peroxide needed for processing, and nitric acid, to enhance electrical conductivity and oxidizing properties of the solution. The amount of the acid for the daily amount of the wash was taken equal to half the amount of acid that can be produced by nitrifying the ammonia resulting from decomposition of the daily amount of urea [7]. In the “Wash + urine” and “Wash + human waste” treatments, processing was done using urine and human waste preliminarily mixed with hydrogen peroxide as described elsewhere [4], at a daily ratio to the wash.

Table 1. Kitchen wastewater processing.

| Treatment           | Composition                                      |
|---------------------|--------------------------------------------------|
| Wash 100/1000+HNO3 | 1100 ml wash + 150 ml H2O2 (36 %) + 4 g peelings + 2 ml HNO3 (65 %) |
| Wash 50/1000+HNO3  | 1150 ml wash + 78 ml H2O2 (36 %) + 4 g peelings + 2 ml HNO3 (65 %) |
| Wash + urine        | 690 ml wash + 216 ml H2O2 (36 %) + 2.5 g peelings + 340 ml urine |
| Wash + human waste  | 636 ml wash + 486 ml H2O2 (36 %) + 18 g peelings + 300 ml urine + 30 g feces |

The co-processed kitchen wastewater and cotton waste are referred to as “sanitary/household waste”. Table 2 shows different ways of sanitary/household waste processing in combination with various reagents available in the system. In the treatments with human waste, solid and liquid wastes were mixed with hydrogen peroxide as described elsewhere [4], at a daily ratio to the sanitary/household waste.
Table 2. Processing of sanitary/household waste.

| Treatment                      | Composition                                                                 |
|--------------------------------|-----------------------------------------------------------------------------|
| Sanitary/household waste + HNO3 | 636 ml wash + 34 g cotton waste + 637 ml H2O2 (36 %) + 11 g peelings + 2 ml HNO3 (65 %) |
| Sanitary/household waste + urine | 460 ml wash + 25 g cotton waste + 565 ml H2O2 (36 %) + 10.33 g peelings     |
| Sanitary/household waste + human waste | 327 ml wash + 18 g cotton waste + 413.5 ml H2O2 (36 %) + 5 g peelings       |

In all treatments, mineralization was performed until complete decomposition of hydrogen peroxide in the reactor was achieved. The effectiveness of mineralization was assessed based on such parameters as the level of oxidation and amounts of the major mineral elements released to the solution. A comparative assessment of the degree of release of mineral elements in the solution was performed by comparing the indicators of the content of these elements in solution and sediment after mineralization. The depth of oxidation was calculated based on the ratio of the chemical oxygen uptake values of the mixture of waste and hydrogen peroxide before and after mineralization. In this case, hydrogen peroxide was considered as an inert substance occupying a certain volume, indicated in tables 1 and 2.

2.2. Results of mineralization of sanitary/household waste

The same levels of mineralization of the wash were achieved in the “Wash 100/1000+HNO3” and “Wash 50/1000+HNO3” treatments: 63-64%. The mineral composition of the processing products (table 3) suggests that similar amounts of mineral elements were released to the solution in these treatments. Therefore, in all subsequent treatments, 50 ml/L of H2O2 (36%) was used per 1 L wash. In the “Wash + urine” and “Wash + human waste” treatments, the levels of mineralization were 46 and 84%, respectively. In the “Wash + urine” treatment, a lesser level of oxidation is associated with a lower initial content of organic matter in urine. Also, this solution contained the highest concentrations of mineral elements, as all the wastes used in this study, human urine contained the greatest amounts of mineral elements. Co-mineralization of the sanitary/household waste and human waste (the “Sanitary/household waste + human waste” treatment) result in precipitation of mineral elements such as Ca, Mg, P and S. Obviously, this is due to the fact that oxidation products of solid human waste have largely precipitated.

Table 3. Mineral composition of the processed kitchen wastewater.

| Treatment                      | Fraction         | K  | Ca  | Mg  | P   | S   |
|--------------------------------|------------------|----|-----|-----|-----|-----|
| Wash 100/1000+HNO3 solution    | mg/L             | 159| 38.5| 12.2| 24.4| 12.3|
| Wash 100/1000+HNO3 solids (0.9 g/L) | %                | 1  | 0.36| 0.19| 0.17| 0.07|
| Wash 50/1000+HNO3 solution     | mg/L             | 156| 47.1| 17.2| 27.3| 13.2|
| Wash 50/1000+HNO3 solids (1.2 g/L) | %                | 1.18| 6.01| 1.8 | 4.53| 0.28|
| Wash + urine solution          | mg/L             | 970| 3.19| 0.95| 209 | 282 |
| Wash + urine solids (1.3 g/L) | %                 | 0.95| 1.36| 0.43| 0.75| 0.08|
| Wash + human waste solution    | mg/L             | 230| 5.51| 1.33| 63.7| 126 |
| Wash + human waste solids (2.6 g/L) | %            | 1.17| 5.99| 2.99| 4.65| 0.16|

The levels of mineralization of sanitary/household waste in the “Sanitary/household waste + HNO3”, “Sanitary/household waste + urine”, and “Sanitary/household waste + human waste” treatments were 67.6, 61.5, and 56%, respectively. The mineral composition of the processing products (table 4) shows that the use of HNO3 (the “Sanitary/household waste + HNO3” treatment) caused considerable release of Ca, Mg, and P to the solution. The use of urine (the “Sanitary/household waste + urine” treatment) enriched the solution with mineral elements, whereas co-mineralization of the sanitary/household waste and human waste (the “Sanitary/household waste +
human waste treatment) increased precipitation of all mineral elements. The amount of sediment indicates that in all variants it was represented mainly by the substance of cotton material.

### Table 4. Mineral composition of the processed sanitary/household waste.

| Fraction | Fraction | K   | Ca   | Mg   | P    | S     |
|----------|----------|-----|------|------|------|-------|
| Sanitary/household waste + HNO3 | solution, mg/L | 219 | 91.1 | 29.8 | 57   | 14.4  |
|        | solids (13.9 g/L), % 0.22 | 0.1 | 0.03 | 0.04 | 0.01 |
| Sanitary/household waste + urine | solution, mg/L | 424 | 33.6 | 26.8 | 88.8 | 77.9  |
|        | solids (13.6 g/L), % 0.59 | 0.5 | 0.1  | 0.31 | 0.09 |
| Sanitary/household waste + human waste | solution, mg/L | 711 | 8.12 | 2.5  | 103  | 150   |
|        | solids (10.5 g/L), % 1.6 | 1.81 | 0.91 | 1.63 | 0.28 |

All obtained results were estimated as the average of two repetitions of oxidation of waste in the mode that provides the maximum oxidation depth of this option for a reasonable time (no more than 1 day). The error in estimating the mineral composition and the chemical oxygen absorption values of the samples does not exceed 10%.

### 3. Conclusion

As can be seen from the results, the use of sanitary and household waste as a source of mineral nutrition of plants in BTLSS makes sense only with the joint processing of these solutions with human waste, as sanitary waste is in itself contain a small amount of mineral elements. In this regard, we can once again mention that the need to process this type of waste is more associated with the involvement in the mass exchange process of BTLSS elements such as C, H and O necessary to maintain the required amount of water, oxygen and carbon dioxide in the artificial environment of the system.

Thus, in the systems that do not need to involve cotton waste into the mass transfer but do require recycling of kitchen wastewater, the best approach is to co-mineralize kitchen wastewater and human waste. For the systems that are supposed to recycle all sanitary/household wastestes, the best option is the following sequence of processes: 1) human waste mineralization; 2) hydrolysis of urea; 3) synthesis of HNO3 using half of the ammonia resulting from hydrolysis; and 4) mineralization of sanitary/household waste with HNO3.

The principles of development of the wet incineration method for the oxidation of sanitary waste presented in this work can be applied to adapt this method for recycling other types of organic waste in BTLSS produced as a result of functioning of individual units, or in the process of involving substances environment. In this case, the fundamental chemical and physical bases of the electroinduced oxidation processes of various types of organic compounds in an aqueous solution of hydrogen peroxide may be of interest. In the future, the results of basic research can be used in terrestrial applications.

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