Efficiency of sorption of metals from electronic waste by microscopic algae

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Abstract. The extraction of metals from e-waste is currently not well understood. In this regard, a promising method for the extraction of metals was chosen, namely the biotechnological method. E-waste includes various categories of waste. This complicates the search and development of a universal method for disposing of electronic waste. In this regard, one category of e-waste was selected, namely mobile phone screens. The article presents the results of experimental studies on assessing the efficiency of metal sorption from mobile phone screens by microscopic algae at various parameters of biosorption.

1. Introduction
During the development of the world of computerization and electronics, there is a need for such natural resources as rare and rare earth metals, the extraction of which from the environment is a difficult and expensive process. For the production of electronic equipment, the following rare earth metals are used (yttrium, gadolinium, lanthanum, cerium, neodymium, europium, dysprosium, erbium), rare metals (indium, titanium and others), as well as more common metals such as aluminum, iron, copper, etc. many others [1]. Rare earth and rare metals do not have their own deposits, they are found in other ores, which complicates their production. The content of these metals in minerals averages 0.02% [2]. Sources of rare and rare earth metals are not only ores, but also some types of waste such as e-waste.

Electronic waste is used household and office equipment, computers, monitors / screens, mobile phones. E-waste includes metals that are currently being lost due to the lack of a separate collection of e-waste and thus end up in the general solid municipal waste (MSW) stream that is disposed of at a landfill. In this regard, not only the pollution of environmental objects with metal oxides occurs, but also the loss of the resource potential of electronic waste.

The actual task of today is the search, development and implementation of methods for the disposal of electronic waste in order to extract the resource potential, which will be further used in the production cycle.

The aim of this study is to assess the efficiency of metal extraction from electronic waste (using the example of mobile phone screens) by microscopic algae.

The classification of electronic waste is quite extensive, from large household appliances to microchips and screens. The composition of each category of e-waste is different, therefore it is necessary to select the most appropriate disposal methods. Based on the literature data, the object of research on the extraction of metals was the screens of mobile phones. This is due to the fact that the
mobile phone screens include rare earth metals - erbium and cerium, and a rare metal - indium, which has a wide range of uses. The extraction of metals from this type of waste is currently unexplored.

The next step in preserving the resource potential of e-waste is to find an effective method for extracting metals from mobile phone screens. There are several methods of disposal of electronic waste: mechanical methods (crushing, separation), chemical methods (pyrolysis), hydrometallurgical method [3]. The application of these methods entails the formation of secondary components, and is also insufficiently effective for the extraction of rare and rare earth elements. Based on the analysis of foreign literature, a promising method for extracting metals from electronic waste using microscopic algae was identified.

The method of metal extraction by microscopic algae is based on the ability of algae to sorb metals. This ability of microscopic algae is characterized by the fact that they include hydroxyl groups, which have the property of sorption [4-8]. There are different types of microscopic algae, but the most effective species for the sorption of metals are Chlorella Vulgaris, Chlorella Sorokiniana, Chlorella Spirulina, Scenedesmus [9]. Based on this, these types of microalgae were selected for the process of biosorption of metals from the screens of mobile phones.

2. Materials and methods

The preparation of the working solution from the screens of the mobile phone was carried out in the following way. Mobile phone screens were ball milled. The size of the crushed particles was up to 1 mm. The resulting powder was dissolved with 1M sulfuric acid in the following ratio of 1:50 (gram: ml). Dissolution parameters were 90 minutes at a temperature of 90 ± 2 ℃ [10]. The solution was then filtered and analyzed with an optical emission spectrometer (ICP-OES) to estimate the initial metal concentration. This solution contained more than 10 metals with different initial concentrations.

The next stage of the study is the biosorption of metals from solution. The biosorption process is carried out under certain parameters. Important parameters of the metal biosorption process are pH-environment, the dose of microscopic algae and temperature.

The parameters of the biosorption of metals from the screens of mobile phones were: solution temperature (22 ± 2 and 36 ± 2 environment), pH medium from 2.5 to 3.5, dose of microscopic algae from 0.5 to 3 grams/liter, types of microscopic algae Chlorella Sorokiniana, Chlorella Spirulina, Scenedesmus, the contact time of the solution with the biosorbent is 90 minutes with constant stirring at 760 rpm.

After the biosorption process, the solution was filtered and analyzed for the content of final metal concentrations using an optical emission spectrometer.

Statistical processing of the data obtained was carried out using a computer program Excel 2007, calculating the arithmetic mean and standard error of the mean. The significance of the differences between the mean values was assessed using the Student's t-test for the significance level α = 0.05 [11].

3. Results

The composition of the test solution included the following metals, with the initial concentration, presented in table 1.

The results of the evaluation experiment on the extraction of metals from the screens of mobile phones are presented in table 2. The table shows only those metals, the concentration of which changed significantly after the biosorption process.

4. Discussion

Microscopic algae carried out the sorption of all metals that were in the leached solution, which indicated the possibility of carrying out the biosorption process in order to extract metals from the screens of mobile phones. The temperature of the solution did not affect the sorption of metals by microscopic algae; therefore, this process can be carried out without additional heating of working
solutions, which is economically beneficial. The sorption efficiency of each of the metals is different, as evidenced by the results obtained. The search for this pattern requires further study.

### Table 1. Initial concentration of metals in the test solution.

| No. | Metal       | Initial concentration, mg/kg |
|-----|-------------|------------------------------|
| 1   | Aluminum    | 1357.74                      |
| 2   | Boron       | 891.2266                     |
| 3   | Barium      | 126.5068                     |
| 4   | Calcium     | 4543.084                     |
| 5   | Iron        | 135.2242                     |
| 6   | Potassium   | 773.7383                     |
| 7   | Magnesium   | 956.12                       |
| 8   | Antimony    | 193.58                       |
| 9   | Tungsten    | 87.92                        |
| 10  | Zinc        | 316.62                       |
| 11  | Indium      | 206.67                       |

### Table 2. The results of biosorption of metals from mobile phone screens.

| Metal   | Microscopic algae | Temperature, ℃ | Recovered metal concentration, mg/kg | Recovery percentage, % |
|---------|--------------------|----------------|--------------------------------------|------------------------|
| Aluminum| Chlorella Spirulina| 22 ± 2         | 272.18                               | 20.05                  |
|         | Chlorella Sorokiniana| 36 ±2         | 283.81                               | 20.90                  |
|         | Scenedesmus        |                | 307.91                               | 22.39                  |
|         | Chlorella Spirulina|                | 251.70                               | 18.54                  |
|         | Scenedesmus        |                | 286.65                               | 21.11                  |
|         | Chlorella Spirulina|                | 239.51                               | 26.87                  |
|         | Chlorella Sorokiniana| 22 ±2       | 320.02                               | 35.91                  |
|         | Scenedesmus        |                | 179.24                               | 20.11                  |
|         | Chlorella Spirulina|                | 232.57                               | 26.1                   |
|         | Chlorella Sorokiniana| 36 ±2       | 168.97                               | 18.96                  |
|         | Scenedesmus        |                | 123.27                               | 13.83                  |
|         | Chlorella Spirulina|                | 20.63                                | 16.31                  |
|         | Chlorella Sorokiniana| 22 ±2       | 28.85                                | 22.81                  |
|         | Scenedesmus        |                | 15.97                                | 12.62                  |
|         | Chlorella Spirulina|                | 21.44                                | 16.95                  |
|         | Chlorella Sorokiniana| 36 ±2       | 19.81                                | 15.66                  |
|         | Scenedesmus        |                | 17.60                                | 13.91                  |
|         | Chlorella Spirulina|                | 410.74                               | 42.96                  |
|         | Chlorella Sorokiniana| 22 ±2       | 478.23                               | 50.02                  |
|         | Scenedesmus        |                | 396.93                               | 41.51                  |
|         | Chlorella Spirulina|                | 435.13                               | 45.51                  |
|         | Chlorella Sorokiniana| 36 ±2       | 384.25                               | 40.19                  |
|         | Scenedesmus        |                | 429.46                               | 44.92                  |
|         | Chlorella Spirulina|                | 33.24                                | 37.81                  |
|         | Chlorella Sorokiniana| 22 ±2       | 31.76                                | 36.12                  |
|         | Scenedesmus        |                | 37.83                                | 43.03                  |
|         | Chlorella Spirulina|                | 40.42                                | 45.97                  |
|         | Chlorella Sorokiniana| 36 ±2       | 34.51                                | 39.25                  |
|         | Scenedesmus        |                | 41.07                                | 46.71                  |
On the basis of literature sources, the process of metal sorption depends not only on the parameters of biosorption, but also on the chemical properties of metals in solution. The efficiency of sorption depends on the attraction of positively charged ions and negatively charged sites (sites) of biomass binding [12].

The use of a biotechnological method of extracting all metals from mobile phone screens is not rational from an economic point of view. In this regard, it is necessary to concentrate only on rarer and more expensive metals, the production of which from other sources is a laborious or poorly studied process.

The most interesting and important metal to be extracted from mobile phone screens was indium. Indium is a rare and promising metal that has a wide range of applications, so extracting indium from mobile phone screens is urgent.

5. Findings
The obtained results of this experiment made it possible to assess the possibility of using microscopic algae to extract metals from electronic waste.

It was found that out of all the flow of metals, the most interesting and important metal in mobile phone screens is indium, the concentration of which is sufficient for the biosorption process. The indium concentration in the test solution was 200 mg / kg. This metal belongs to rare and expensive metals, which indicates the economic feasibility of its extraction.

Based on the experimental data obtained, the indium extraction efficiency was more than 70%. The recovery efficiency of other metals varies from 13 to 80%.

Further research on the extraction of metals from electronic waste by microscopic algae is aimed at analyzing the biosorption mechanism and bringing the biosorption process to the selective extraction of indium from the metal stream.

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