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ORIGINAL ARTICLE

The recovery of gold from the aqua regia leachate of electronic parts using a core–shell type anion exchange resin

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Abstract A method of processing Wasted Electric and Electronic Equipment (WEEE), and the separation of gold that it contains, is presented within the present work. Due to the fact that the amount of Au in real-life secondary resources covers a broad range of concentrations, the applied solutions were obtained by digesting in aqua regia WEEE characterized by relatively high (Central Processing Units, CPU) and relatively low (Pin Contact Elements, PIN) amounts of gold. The investigated systems were received after processes of enrichment and leaching, ignoring the usually applied WEEE processing reduction and solvent-extraction processes, keeping the amount of generated wastes to a minimum. The obtained CPU and PIN solutions were then directly contacted with core–shell type anion exchange resins functionalized using ethylenediamine and 1-(2-aminoethyl) piperazine. Application of the designed polymers allowed the process of aqua regia-leaching, omitting the application of other, more harmful agents.

The investigated resins revealed great selectivity towards gold. Despite the fact that the obtained solutions contained only 1.5% (CPU) or 0.1% (PIN) of Au, its removal reached 86% and the logarithms of partition coefficients indicate that affinity of the applied resins to gold is almost ten times greater than the very competitive nickel present in the obtained solutions. Finally, the gold-containing core–shell polymers were effectively eluted, recovering 100% of the taken from the solutions gold.

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1. Introduction

Information Technology (IT) dominates different areas of life. As a result, humanity generates great amounts of Wasted Electric and Electronic Equipment (WEEE) each year. Nowadays, almost everyone carries at least one electronic device and moreover, it is difficult to imagine a life without a computer, television or washing machine [1,2]. Producers, being aware of this phenomenon, have mastered the skill of making their products obsolete [2], forcing users to shorten the interval between replacing their devices. According to Germany's Digital Association [3] the replacement frequency of Electric and Electronic Equipment (EEE) has increased almost twice over the last 20 years, which combined with an increasing human population and improving quality of life, results in a serious problem.

Regarding the Environmental Program of the United Nations [4], the worldwide "production" of WEEE reaches 50 million tons each 12 months. The European Union as a society creates 8 million tons of WEEE each year and this number increases annually by 5%. However, globally just 20% of electricity-powered equipment is being recycled, which is not only caused by ecological ignorance, but also by a lack of know-how in developing countries with great costs being a barrier for proper WEEE utilization [5].

Wasted electronic devices carrier a lot of resources, such as copper, iron, tin, nickel, lead, zinc and silver. Some of them, like gold, platinum and palladium are considered as extremely rare, precious and essential for the development of human society [6,7]. Although recovery of these metals may make recycling of WEEE more attractive and economically justified, the methods of their processing must keep-up with new challenges such as diversified composition of these wastes, as well as the fact that the precious resources that they contain occur in ultra-trace amounts (up to 1%) [8].

Because a composition of WEEE is very diversified and complex, a number of methods for their recycling have been already proposed [5,8]. Especially hydrometallurgical technologies for the recycling of the WEEE and recovery of its gold have attracted a great deal of attention in recent years [8]. This phenomenon is dictated by the fact, that an alternative, pyrometallurgical process involves higher operational costs, considerable influence on the environment and smaller efficiency. The recycled electronic elements, after suitable preparation (such as disassembly) must be leached in order to transfer metals, especially precious ones into a solution. Then, Au is usually reduced to its metallic form using zinc or iron powder [8]. Additionally, iron sulphate or sodium metabisulphite can be used [5]. Such an approach is necessary to further concentrate the gold, and thus making it possible to recover. Also, different solvent-extraction methods may be applied here, however, they produce considerable amount of waste and suffer a lack of effectiveness in very diluted media.

Although a number of possible leachates, as cyanide, halide, thiourea and thiosulphate, were investigated, they are reported to make an extremely harmful impact on the environment [9], reveal poor efficiency or are very expensive. For this reason, the effectiveness of extraction of gold from solid electronic elements is still most efficient after appliance of HNO_3/HCl, i.e. aqua regia [5,10]. For this reason, a number of methods for recovery of gold from aqua regia leachates have been reported in recent 20 years. A significant number of techniques involving application of extractants such as diethyl malonate [11] or ionic liquids [12] are described. These methods were considered as of low impact on the environment and effective, however, because release of gold from an extractant can be challenging, the attention of researchers turned to other areas. There are examples of works describing optimization of aqua regia leaching for recovery of gold. Lee et al. [13] indicated, that the recovery of gold by its separation from scrap printed circuit boards using aqua regia reaches 100%. However, the process is still not selective as great amounts of other metallic components are recovered. Other approaches, as application of multiple step leaching of waste material proposed by Sheng and Etsell [10] allow to selectively recover gold but also generate a considerable number of excessive waste solvents. The same phenomenon was observed by Park and Fray [14] who decided to apply a mixed solvent extractant of tetraoctylammonium bromide in toluene in order to selectively recover gold from printed circuit boards. However, because chloride ions originating from concentrated HCl hinder precipitation of gold, the aqua regia leachate must had been significantly diluted, resulting with generation of excessive, organic–contaminated waste [10].

Lack of selectivity is becoming a major disadvantage especially in the processing of WEEE, which often contains ultra-trace amounts of gold [15]. In such circumstances, according to Syed [8], the only economically viable method to concentrate and recover gold from such diluted media requires the use of ion exchange resins.

Ion exchange polymers have reliably established applications [16,17] including the separation of noble metals [18,19]. Low operational costs, reusability and low impact on the environment can be accounted to the main advantages of the ion exchange resins. However there are also drawbacks: their utilization in processes of gold recovery from WEEE should be carefully thought-through as their preparation entails high costs that include the synthesis/purchase of a polymeric matrix and the introduction of functional groups (able to selectively remove gold) into its structure [20]. The economic condition is gaining importance in the face of the fact, that the commercially available polymers, in form of polymeric beads are not fully exploited during adsorption process and often suffer from so-called osmotic shock blocking their structure in concentrated electrolytes [21,22] Moreover, the most popular commercial resins for the recovery of gold, for example Purogold™ products manufactured by Purolite Co. [23], are functionalized by a mixture of weak- and strong-base amines. These functionalities provide on the one hand, great sorption capacity, and on the other, selectivity towards gold [20]. However, they must be used in solutions received after leaching of gold using extremely toxic cyanides. They are not suitable for systems obtained using the obvious and most efficient choice for leaching gold – aqua regia, as strongly basic quaternary amines degenerate in the presence of nitric acid during extremely exothermic reactions [22].

For this reason, for some time our team has been working on the development of new types of anion-exchange resins which would be on the one hand resistant to aqua regia and on the other, due to core–shell nature, their ion exchange capacity would be fully available during the process. For this reason, neither pyrometallurgical nor solvent extraction techniques had to be applied during present studies. The investi-