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Microbially Supported Recovery of Precious Metals and Rare Earth Elements from Urban Household Waste Incineration Slag

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Abstract. The use of precious metals and Rare Earth Elements in electronic, medical, and automobile industries is drastically increasing. To meet this demand and to escape the financial pressure of the global metal market, not only mining activities but recently also the recovery of these elements from industrial and urban household waste is in the focus of research. It has been shown that the application of extracting solutions with pH values lower than 4 lead to an economically feasible recovery of industrially precious metals. It is unclear, however, whether and to which extent this abiotic extraction efficiency can potentially be increased by using microorganisms capable of dissolving more stable minerals at low pH. The goal of this project therefore is to first view urban household waste as a resource for metals and evaluate combined abiotic and biotic extraction procedures for an increase in metal extraction efficiency.

Introduction and Motivation

Currently, the market and price level of metal raw materials are dominated by single states (i.e. China) that own monopole rights on most precious metal and Rare Earth element mining areas worldwide [1]. Thus, to ensure independence from these monopoles, alternative resources for (precious) metals and Rare Earth elements need to be exploited to meet the increasing societal demand for these elements [2].

One of these alternatives are urban household wastes, which originate from a wide range of metal-containing residuals based on plastics, paper and woods, metals, and organics. By incinerating the waste to carbon-poor slags, metals-fractions in the slag are concentrated in the slag and make up several weight percent therein (Table 1). These waste incineration slags are usually buried at waste disposal sites or are used as construction agent (see Fig. 1) [3]; at higher expense of the company as slags are often categorized as metal-containing, and thus, hazardous materials. Such waste deposition not only causes a potential threat to the environment in case of metal leaching [3] but also translates into a direct loss of metals for use in industry and into financial and trade dependences on metal monopole states.

Thus, the effective recovery of (precious) metals and Rare Earth elements from urban household waste should be considered as potential alternative for sustainable, economic, and eco-friendly metal resource.

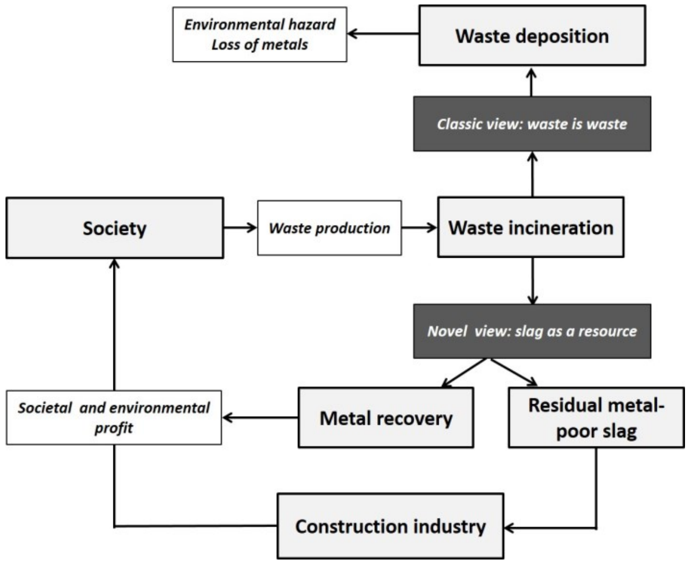

Figure 1. Comparison of the classic approach for waste flow after its production compared to the here proposed novel view of seeing waste as a resource for metals and eco-friendly construction material.

Conceptual Approach

Instead of viewing urban household waste as a final product only suitable for deposition, it should be viewed as a resource for metals and construction material (Fig. 1). A regional waste incineration plant in Southwest Germany produces approximately 170 000 tons of urban household waste incineration slag per year. The amounts of common (Fe, Al, Cr, Ni, Cu…), precious (Ag, Pt, Au…) and Rare Earth (Tm, Nd…) metals in these wastes add up to several thousand tons per year (Table 1). Considering the current market values of these metals shows that 170 000 tons of slag per year contain approximately 48 million Euros worth of metals (Table 1). Assuming a global production of 300 million tons of urban household waste per year (equals approximately 80 million tons of incineration slag), the value of metal present in the slag can be extrapolated to approximately 20 trillion Euros. Thus, the recovery of these metals from household waste incineration slag and their subsequent re-feeding into industries would meet our societal metal requirements with fewer industrial, economic, and financial ties to metal monopoly nations (Fig. 1). Furthermore, the residual slag contains significantly less metal after leaching, thus transforming the residual slag into an eco-friendly resource for construction material used in road and building works. So overall, urban household waste needs to be viewed as a resource that enters the cycle from societal disposal to societal use (Fig. 1). To achieve this, innovative and effective strategies for (precious) metal and Rare Earth element recovery from urban household waste needs to be developed. For materials with a low metal content microbial leaching strategies seem most economically and ecologically feasible for the effective recovery of (precious) and Rare Earth metals [4,5].

Table 1: Selected metals and Rare Earth elements (content and their value in Euros) present in urban household waste incineration slag produced in a waste incineration plant in Southwest Germany. Approximately 170 000 tons of slag are produced annually.

Element	Content %	Content in tons	Value in € per kg	Total value
Fe	5.08	8 636	0.10	**863 600**
Al	2.42	4 114	1.70	**6 993 800**
Cu	0.22	374	5.20	**1 944 800**
Cr	0.06	97	6.00	**583 440**
Ag	0.001	2	498.00	**944 806**
Rb	0.01	9	1 000.00	**9 010 000**
Cs	0.0001	0.2	22 000.00	**4 114 000**
Nd	0.003	5	47.00	**246 891**
Tm	0.0000	0	12 000.00	**204 000**
				......
			Total value in slag [€]	48 460 962

Experimental Approach

Bioleaching of different mineral ores and mine materials was shown to be effective with different types of autotrophic and heterotrophic microorganisms oxidizing Fe(II) and/or sulfur compounds [5]. However, incineration slags are geochemically very different to highly defined mineral ores and mine materials. Incinerations slags are high in pH (pH of approximately 12) and very diverse in their mineralogy, bearing all kinds of metals in very low concentrations. Efficient chemical leaching (defined as leaching of at least 20% of the total amount of an element) of urban household waste incineration slag was achieved in our laboratory when the pH of the slag was adapted to below 4. For example, Cr was leached up to 40% of its total content from household waste incineration slag after 24 hours by applying analytical-grade sulfuric acid to the slag setting the pH to 2.5 (data not shown). Similar efficiency could for example be obtained for Al (~50%), Mn (~70%), Co (~45%), Tm (~30%) (data not shown). To further increase the leaching efficiency of the slag material, microorganisms are considered for bioleaching. A number of different cultivated and in the literature well-described *Bacteria* (including *Acidithiobacillus ferrooxidans* [6,7] and *Acidiphilium* sp. SJH [8]) were investigated for high leaching efficiency of urban household waste incineration slag adapted to a pH of 3 to 4. In order to maximize the bioleaching efficiency of the slag, microbial consortia were also enriched from sediments of the highly acidic and metal-contaminated river Rio Tinto in Spain [9]. These enrichments were performed in the presence of the incineration slag with the purpose to only enrich microorganisms able to thrive under the geochemical properties of the slag. Microbial enrichment cultures were successfully cultivated in the presence and absence of electron donors such as $Fe^{II}SO_4$ and elemental sulfur (Fig. 2A). Microscopic localization of enriched microbial consortium using a DNA stain showed that the cells are associated with the slag material (Fig. 2B).

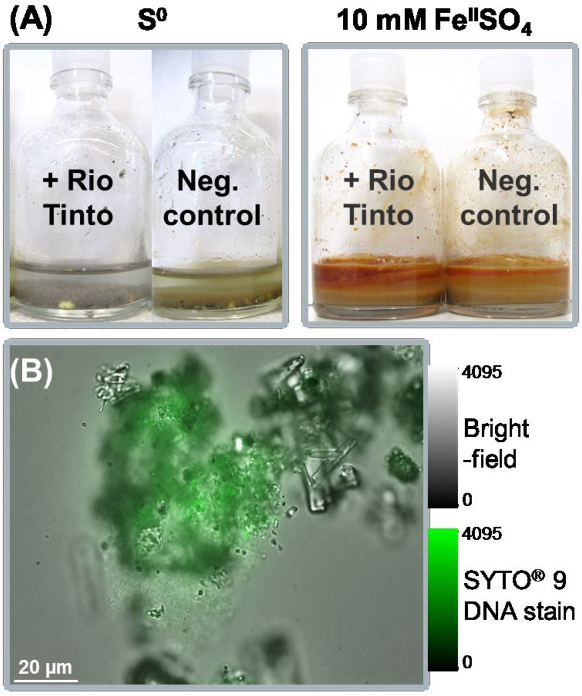

Figure 2: Microbial enrichments from sediments of the Rio Tinto, Spain, in the presence of urban household incineration slag. (A) Enrichment bottles with elemental sulfur and 10 mM ferrous sulfate. (B) Syto®9 DNA stain of cells of an enrichment (seen in green) associated with the slag (seen in bright-field grey).

Summary

Urban household waste holds a lot of potential for recovering precious metals and Rare Earth elements. Since the incineration product slag is mineralogically very diverse and contains low quantities of metals, microbially supported leaching is the strategy of choice to recover these elements. Once the metals are removed from the slag, the slag becomes also a valuable resource for urban construction. Thus, a smart, sustainable and economically valuable concept is here developed to convert urban waste – via effective recycling – into a precious resource contributing to zero waste management.

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