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Metal recovery by microbial electro-metallurgy

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ABSTRACT

Raw metals are fundamental to the global economy as they are essential to maintain the quality of our life as well as industrial performance. A number of metal-bearing aqueous matrices are appealing as alternative supplies to conventional mining, like solid industrial and urban waste leachates, wastewaters and even some natural extreme environments (e.g. deep marine sediments, geothermal brines). Some of these sources are already managed for recovery, while others are not suitable either because they are too low in content of recoverable metals or they contain too many impurities that would interfere with classical recovery processes or would be cost-prohibitive. Microbial electro-metallurgy, which results from the interactions between microorganisms, metals and electrodes, in which the electron transfer chain associated with microbial respiration plays a key role, can contribute to overcome these challenges. This review provides the state of the art on this subject, and summarizes the general routes through which microbes can catalyse or support metal recovery, leading to nano- and macro-scale materials. Competing sorption and electrochemical technologies are briefly revisited. The relevant sources of metals are highlighted as well as the challenges and opportunities to turn microbial electro-metallurgy into a sustainable industrial technology in the near future. Finally, an outlook to pursue functional materials through microbial electrometallurgy is provided.

Contents

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1. Introduction

Metals are crucial in the global economy as they are key constituents of a vast number of products, crafts, and industrial processes. From conductors in mobile phones to alloys for strong but light cars, they enable core societal and industrial activities.

Each metal and its alloys have unique properties that make them interesting for particular applications. For instance, carbon-iron alloys produce high-strength steels, whereas aluminium is alloyed to manufacture airplane frames, beverage cans, engines and electrical cables due to the formation of highly stable passive films. A mobile phone can contain functional components with more than 40 elements including base metals such as copper and tin, special metals such as cobalt, indium and antimony, precious and platinum-group metals, silver, gold, tungsten as well as rare earth elements (REEs), including yttrium [1]. Fluorescent lamps also contain various materials and elements which include a range of REE and other non-critical metal resources like iron [2]. Strength, corrosion resistance, wear resistance, machinability and colour are examples of distinctive properties provided by metals and their alloys [3].

The manufacturing of these and other modern technologies depends today on the availability of freshly extracted metals. Typically, these are mined from their ores. Some countries have a monopoly on the beneficiation of some metals which may signify vulnerability for nations who are not primary suppliers [4,5], e.g., currently China produces 97% of the REEs whereas South Africa generates 79% of platinum [6,7] both of which have been highlighted as critical raw metals for application in low carbon technologies [8,9]. This provides impetus by nations who are not primary producers for alternative sources [10] and for developing technologies to scavenge these metals from end-of-life consumer products or solid waste [11], labelled as waste of electric–electronic equipment (WEEE) [12].

The art and science of metal beneficiation and recovery come under the field of extractive metallurgy [13], further branched into the sub-fields of: (1) pyrometallurgy, which uses dry thermal methods, (2) hydrometallurgy, which chemically extracts metals from their ores, and (3) electrometallurgy, which uses electrolytic or galvanic methods typically at late steps in the recovery chain [13]. In general, hydro/electrometallurgy involves two distinct steps: (a) selective dissolution (leaching) of the metal from the ore/WEEE and (b) selective recovery of the metal from solution.

Pyrometallurgical processing is the traditional method to recover non-ferrous metals as well as precious metals from electronic waste [12]. In the past two decades, the most active research areas on the recovery of highlighted critical metals from electronic scraps concern the hydro and electrometallurgical methods [12]. Compared to pyrometallurgical processing, hydro/electrometallurgical methods are more exact, more predictable, and more easily controlled [12]. Moreover, from the environmental and economic perspectives, hydrometallurgical methods are preferred to pyrometallurgical methods, as the latter usually require high temperatures (≈1200 °C), produce harmful gases (such as SO_2) and dust, and require high capital costs [13].

Spent leachates and industrial wastewaters here represent an additional source [14,15]. Recovery from these aqueous sources, as opposed to recovery from solid waste, provides the advantage that the metals are already in solution. However, the grand challenges to extract metals from these matrices are: (1) their typically low concentration, (2) the presence of other metals, inorganics and organics, (3) high ionic strength of some matrices complicating extraction, (4) existing removal techniques are available but geared to meeting discharge limits, and (5) unavailability of technology targeting recovery, that can be integrated within existing processing chains. To meet these challenges, microbial technologies are up and growing [16].