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Sustainable valorisation of industrial residues as an enabler for achieving the goals of the EU Green Deal: European Training Network SOCRATES

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Abstract

The accomplishment of the goals set in the EU Green Deal and the Agenda 2030 for Sustainable Development requires a metallurgical industry that is even more resource-efficient, environmentally friendly and socially responsible than it is today. The European Training Network SOCRATES has taken this up by developing ground-breaking metallurgical processes for the valorisation of industrial intermediate products. This short article summarizes the results obtained in the four-year project and discusses the outcomes in light of the recently adopted EU Green Deal.

Keywords: circular economy; digital twins; electrochemistry; hydrometallurgy; industrial residues; sustainability; valorisation; zero-waste.

Introduction

Raw materials are crucial for the transition to a climate-neutral economy. Indeed, this transition is highly resource intensive and strongly relies on critical raw materials such as cobalt, lithium, rare earth elements, niobium, tantalum *etc*. Both globally and in Europe it is expected that the demand for raw materials will continue to increase. As recently indicated in *A New Industrial Strategy for Europe*,[1] EU demand for raw materials is projected to double by 2050, making diversified sourcing crucial to increase Europe's security of supply. Although easily accessible ore deposits rich in valuable metals are rare in Europe, the metallurgical industries in European countries have accumulated over the years – and continue to generate – vast quantities of process residues that contain critical metals. In some of these secondary raw materials the metals of high economic value are present, *e.g.* silver and gold in copper flotation tailings, whereas other contain elements that are important from a technological perspective, such as indium and germanium in zinc leaching residues. Despite the fact that the metal concentrations in these materials are relatively low, the involved volumes are so large that they could secure an independent source of critical metals for Europe. The European Training Network SOCRATES [2] targeted technological innovation for the sustainable, nearly zero-waste valorisation of such metal-bearing industrial process residues. By unlocking the potential of secondary raw materials, the SOCRATES project aimed to contribute to a more diversified and sustainable supply chain for metals in Europe.

The project

The SOCRATES consortium brought together relevant stakeholders from along the value chain, going from metal extraction to metal recovery and the subsequent upcycling of the minerals in high-value engineered materials, hence integrating very different sectors. The main objective of the SOCRATES as a European Training Network was to educate 15 early-stage researchers (ESRs) in all aspects of sustainable recycling of low-grade residues, while exploring ground-breaking metallurgical processes (*e.g.*, plasma-, bio-, hydro-, solvo-, electro- and ionometallurgy) that can be integrated into environmentally friendly valorisation flowsheets (Figure 1). Close collaboration between the researchers and consortium partners resulted in three prospective technologies for residues valorisation that differ in technological readiness and industrial applicability.

The most technologically advanced flowsheet combines treatment of fayalite slag in a plasma furnace with subsequent recovery of zinc and valorisation of the metal-depleted slag in construction materials. Currently, SOCRATES partner Metallo is operating the industrial scale plasma fumer to produce sellable zinc oxide product,[3] while the cleaned slag can be marketed as high-quality aggregates or used as a by-product for sand-blasting purpose. Together with Imerys, KU Leuven and other academic partners, Metallo is now looking for high added value applications of clean slag, such as cementitious binders and inorganic polymers.[4] The developed technology is not limited to the specific raw material and can be in theory applied for any type of the fayalite slag produced by the non-ferrous metallurgical industry.

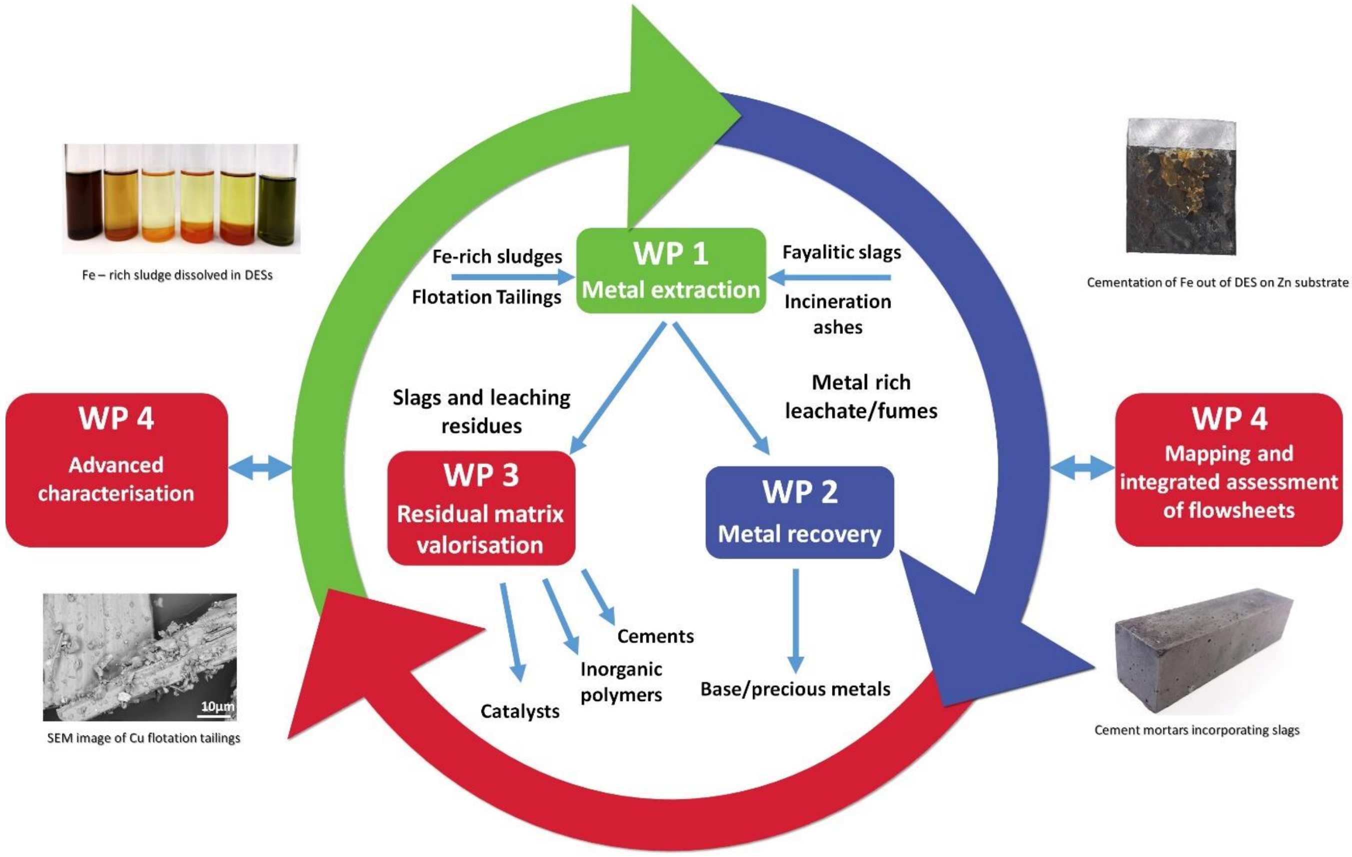

Figure 1. Schematic organization of the SOCRATES project

Another process developed by Metso Outotec and Aalto University is intended for chloride leaching of gold and other metals from copper flotation tailings combined with gold recovery through electrodeposition-redox replacement (EDRR) [5] and further valorisation of the mineral matrix in zeolite production. It has to be stated, that the chloride leaching route has been validated in a continuously operated tests with higher grade materials, *i.e.* primary ores, and is now ready to be upscaled to a pilot scale. For the low-grade tailings studied in the SOCRATES project though, gold recovery can make up for only a fraction of the technology costs. Combination with bioleaching and simultaneous recovery of other valuable metals from flotation tailings, such as cobalt and nickel, was studied together with VTT and was demonstrated to further increase feasibility of the process and potentially bring it closer to an industrial implementation.[6] ESRs from University of Utrecht also indicated that production of zeolites from silica-rich tailings could be an important added value to the business case. This part of technology is, however, considered to be less ready for commercialization as market acceptance of waste-derived zeolites at the moment is rather low.

Non-aqueous metal extraction processes based on solvo- and ionometallurgical treatment were found to be too costly for the low-grade metal containing residues even in combination with the valorisation of the mineral matrix. On the other hand, the project researchers at University of Leicester demonstrated that deep-eutectic solvents might be used for recovery of critical metals from secondary raw materials with elevated metal content, such as fluorescent lamp phosphors.[7] In addition, the ESRs from KU Leuven and University of Bonn collaborated on the design and the synthesis of potential selective extractants for solvometallurgical separations of metal ions with aim to meet the requirements of stability, low cost, and recyclability.[8] Further studies will assess the actual suitability of newly synthesized ionic liquids as metal extractants.

The impact of the developed metallurgical processes on the sustainability of metal supply chain was quantified by SOCRATES researchers at Helmholtz Institute Freiberg for Resource Technology through the creation of large simulation-based digital twins of the metallurgical systems.[9] "*Digital twin*" is a virtual platform that represents a complete metallurgical system in terms of raw materials, water, energy and exergy flows, and any information accessible from inspecting a physical process can be obtained from its digital twin. In the SOCRATES case, the developed digital twin tracks all possible inputs, intermediate flows and products on a chemical element level of detail and is capable of predicting the behaviour of the actual metallurgical processes on an industrial scale.

Furthermore, the mass, energy and exergy balances provided by the simulation tool were used to obtain indicators for material recovery and losses, residue and emissions generation, resource consumption and environmental impacts. This information provides a good starting point for the conversation about resource efficiency and sustainability of conventional metallurgical processes and proposed alternatives aimed at more circular economy. The digital twins and the information contained within can be used to engage society in the dialogue and decision-making process to attain the social license to operate (SLO). It can also quantify the impacts of new legislation, policies and technologies, enabling a fact-based discussion between stakeholders. Therefore, it is expected that this methodology will apply more extensively in future to evaluate the feasibility of different processes and projects.

The SOCRATES ESRs also actively contributed to the growth of the network on zero-waste valorisation of secondary raw materials by active participation in conferences and events in the field, organization of symposia and summer schools. For instance, the 3rd International Process Metallurgy Symposium held in Aalto University on November 5-6, 2019 (Figure 2) provided young researchers with a valuable opportunity to meet professionals from industry and academia and share latest results and developments in the area of raw materials and process metallurgy. All ESRs of the SOCRATES team delivered presentations of high quality during the symposium that attracted attention of the audience and lead to many discussions about the future of the field. The events like this highlight the important role that metallurgy and metallurgists will play in accelerating the transformational change required by the European Green Deal. The fourth edition of the International Process Metallurgy Symposium with a topic "*Metallurgy as a tool for challenges in circular economy*" will be organized in Aalto University on November 9-10, 2021 (preliminary program and more details are available on the symposium's website: http://ipms2021.aalto.fi).

Figure 2. Members of the SOCRATES consortium at the IPMS 2019 in Aalto University, November 2019.

The SOCRATES project has been officially concluded on August 31st, 2020, and it has largely succeeded in advancing the scientific knowledge of zero-waste valorisation of industrial process residues. Project results have been widely communicated and disseminated – apart from participation in many conferences and over 30 publications in peer-reviewed journals, a special attention is also paid to ESRs' blogs published on the project website and further promoted on social media. Moreover, the project achieved its goal of training 15 young, enthusiastic professionals for the raw materials industry in the fields of sustainable metallurgy, resource recovery and green chemistry with ESRs graduating from their doctoral programs throughout 2020 and 2021.

Conclusion

Four years of the SOCRATES project have shown that agile metallurgical industry is an essential component of the sustainable development roadmaps. It enables the transition to a more circular society through the recycling of products, materials, and metals. But even in a fully implemented circular economy some residues will always be generated during metal processing, material production and recycling causing inevitable losses of valuable elements due to underlying principles of thermodynamics.[10] Industrial ecosystems and alliances, which include relevant stakeholders, are required to develop sustainable solutions for transforming industrial residues into high-quality secondary resources and further to low-carbon engineered materials. This underlines the importance of fundamental metallurgical research, knowledge and education, as stepping stones on the way to a sustainable growth and climate-neutral, competitive economy as outlined in European Green Deal.

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