Special issue on “advanced technology of waste treatment” [Editorial]

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Editorial

Special Issue on "Advanced Technology of Waste Treatment"

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The protection of human health and the environment (representing the main reason for waste management), as well as the sustainable use of natural resources, requires chemical, biological, physical and thermal treatment of wastes. This refers to the conditioning (e.g., drying, washing, comminution, rotting, stabilization, neutralization, agglomeration, homogenization), conversion (e.g., incineration, pyrolysis, gasification, dissolution, evaporation), and separation (classification, direct and indirect (i.e., sensor-based) sorting) of all types of wastes to follow the principles of the waste hierarchy (i.e., prevention (not addressed by this issue), preparation for re-use, recycling, other recovery, and disposal). Longstanding challenges include the increase of yield and purity of recyclable fractions and the sustainable removal or destruction of contaminants from the circular economy.

This Special Issue on "Advanced Technology of Waste Treatment" of *Processes* collects high-quality research studies addressing challenges on the broad area of chemical, biological, physical and thermal treatment of wastes.

The mechanical treatment of municipal solid wastes (MSW, including separately collected fractions (i.e., paper, glass, plastics) and mixed municipal (i.e., residual) wastes, as well as wastes from landfill mining projects) is a key step in the circular economy as it produces "concentrates" of specific secondary raw materials from heterogeneous wastes. Digitalization and intelligent interconnection of mechanical waste processing plants become increasingly important to optimize the process, and especially to improve yield and purity of the produced concentrates which are subsequently utilized as recyclates, when substituting for primary raw materials, and as energy carriers. For this purpose, approaches such as sensor-based material flow characterization (SBMC) [1], sensor-based sorting (SBS) [2], and intelligent robotics [3] are applied more and more in mechanical waste treatment plants. Sarc et al. [4] developed the vision of a "Smart Waste Factory" in which these approaches are combined using digital communication and interconnection. For the realization of this vision, a fundamental understanding of waste properties and their evolution along the waste treatment chain is required. Therefore, Khodier and Sarc [5] developed a distribution-independent model of particle size distributions and applied it successfully to the shredding of mixed commercial waste.

Besides the production of concentrates, the removal of contaminants from the circular economy is the second task of mechanical waste treatment. Currently, the recyclability of MSW is limited by presence and leachability of contaminants, especially when source separation did not occur and/or material interactions and alterations have taken place, e.g., during use, treatment and—in the case of landfill mining [6]—disposal. Schwabl et al. [7] developed a wet-mechanical process to purge polyolefin concentrates from different waste streams, simultaneously removing surface contaminations.

Lithium-ion batteries (LIBs) represent a valuable secondary raw material when collected separately, but are a contaminant when disposed of in the residual MSW. Nigl et al. [8] conducted a risk assessment of LIB-caused fires in waste treatment processes, highlighting their role as ignition sources.

Industrial and mining wastes differ from MSW, as it is not so much the level of the particle but the level of the mineralogical phase which determines their recyclability—both

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with respect to separability and contaminant immobilization capacity [9]. Consequently, comminution along phase boundaries is a prerequisite to obtain high-value concentrates of individual mineral phases for subsequent recycling. Seifert et al. [10] demonstrated the feasibility of an innovative comminution technology, electrodynamic fragmentation, to disintegrate spent refractory ceramics along phase boundaries which were subsequently separated using SBS technology.

Since mechanical waste treatment does not change the phase composition of the material, it is a necessary but not a sufficient step in the circular economy. Therefore, the concentrates produced in mechanical waste treatment have to undergo (thermo-/hydro-)chemical waste treatment for conversion into new products or for safe disposal.

Chemical recycling of plastic waste is an emerging technology which allows closing the loop for plastic waste fractions which cannot be recycled at the material level via the established "mechanical" route which, however, also includes the thermal process of melting and regranulation. Lechleitner et al. [11] used lumped kinetic modelling for the development of a pyrolysis process for the chemical recycling of polyolefins, i.e., polypropylene (PP) and polyethylene (PE). In a complementary study, Rieger et al. [12] focused on plastics from waste electrical and electronic equipment (WEEE) and the comprehensive chemical characterization of the pyrolysis products. Finally, Hee et al. [13] used marine litter waste as feedstock for chemical recycling (pyrolysis, gasification) and energy recovery (incineration) with special emphasis on the potential of the pyrolysis condensate for subsequent upcycling.

Chemical recycling of other types of waste is already more established when considering that, e.g., metal recycling involves chemical reactions and is therefore a thermochemical, not a thermal process. In this field, Windisch-Kern et al. [14] demonstrated how slagging of lithium can be reduced in pyrometallurgical battery recycling when using the InduCarb reactor concept.

Waste treatment and wastewater treatment leave behind secondary wastes, such as MSW incineration ashes and sewage sludge, respectively. The recovery of resources from these secondary wastes is a key challenge in the circular economy, as these materials are often also a sink for contaminants from primary wastes. Sewage sludge incineration is a process which allows energy recovery, but also ensures destruction of organic contaminants. However, the moisture content of sewage sludge hinders the thermal valorization. Therefore, Ekanthalu et al. [15] applied hydrothermal carbonization (HTC) to produce energy-rich hydrochar products and to enable phosphorous recovery. Based on an inventory of MSW incineration fly ash in Switzerland by Zucha et al. [16], Weibel et al. [17] studied metal recovery from these materials by acid leaching, whereas Wolffers et al. [18] investigated co-leaching of MSW incineration fly ash and waste wood fly ash. These leaching processes yield aqueous solutions which are used by Hettenkofer et al. [19] for copper recovery using polymer-assisted ultrafiltration.

In summary, this Special Issue presents an overview on recent international developments in the treatment of primary municipal and industrial, as well as secondary, wastes, covering both mechanical and (hydro-/thermo-)chemical processes. We thank all the contributors, as well as the editorial staff of *Processes*, for their efforts.

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