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Review

Sludge treatment: Current research trends

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HIGHLIGHTS

- Review papers on sludge treatment studies were reviewed.
- Sludge production rate and associated emergent contaminants were studied.
- Thermal processes on sludge with involved heavy metals were research focuses.
- Mesophilic and hyperthermophilic co-digestion of sludge was studied.
- Recovery of phosphorus at low costs was research highlight.

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ABSTRACT

Sludge is produced during wastewater treatment as a residue containing most insoluble and adsorbed soluble impurities in wastewaters. This paper summarized the currently available review papers on sludge treatments and proposed the research trends based on the points raised therein. On partition aspect, sludge production rate and the reduction of production rate and the fate and transformation of involved emergent contaminants including endocrine disrupting chemicals and pharmaceuticals and personal care products are widely studied. On release aspect, development of thermal processes on sludge with migration and transformation of heavy metals in sludge during treatment is a research focus. The use of detailed fluid and biological reaction models and advanced instrumentation and control systems is studied to optimize treatment performances. On recovery part, co-digestion of sludge with co-substrates at mesophilic and hyperthermophilic conditions and the recovery of phosphorus at low costs are research highlights.

Contents

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1. Introduction

Sludge is the residue produced during wastewater treatment (Edwards et al., 2017). The conventional activated sludge process yield primary sludge from settling tank and excess activated sludge from aerated activated sludge tank, totally named sewage sludge (Wu et al., 1998). The coagulation-sedimentation process in drinking water produces alum or ferrous sludge that is principally inorganic matrix with sand particles and coagulants (Chang et al., 1997). The residues from industrial wastewater treatment units are the industrial sludge (Chang et al., 2004), many of which contain priority chemicals or heavy metals hence are regarded as hazardous waste in their handling.

The sludge is composed of aggregates made of constituent components including functional microbes and secreted extracellular polymeric substances (EPS) that are suspended in wastewater, with the bioaggregates in activated sludge basin being named as flocs (Wu and Lee, 1998). The flocs have very complicated interior structure (Chu and Lee, 2004) with water strongly bound with the solid phase that is difficult to be released from solid surface via mechanical means (Lee, 1994; Hung et al., 1996). Therefore, the sludge has non-Newtonian fluid-like behavior in suspension form (Yen et al., 2002) and has visco-elastic characteristics in dewatered cake form (Zhao et al., 2003). Generally, if the bond energy between incorporated moisture and the biomass matrix exceeds 70 kJ/kg, the moisture would remain in the mechanically dewatered sludge cake (Chen et al., 1997). Physical or chemical conditioning can release part of the moisture with high bond energy to free form so the moisture content in dewatered cake can be reduced (Chang et al., 2001).

In the US, the land application, landfill and incineration are the major ways of handling sewage sludge (Gude, 2015). The sewage sludge production in Lithuania was 82,000 tons/year with 60% to storage and landfills, 14% to agriculture, 26% to be composted (Praspaliauskas and Pedisius, 2017). Database ISI search on May 28, 2017 using [(“sludge” or “biosolids”) and (“dewatering” or “conditioning” or “digestion” or “thermal” or “landfill” or “management”)] as “topic” during year period 1967–2007 led to 5638 papers, with top journals being Water Science and Technology (1007), Water Research (374) and Bioresource Technology (197). The top country contributors were USA (1200), Canada (404), UK (344), Spain (322) and Japan (318). These papers received a total of 166,407 citations, giving average citation number of 29.5. The search using the same criterion during year 2008–2016 led to 9731 papers, with top journals being Bioresource Technology (1102), Water Science Technology (461), and Water Research (439) and top countries being China (2179), USA (1104), Spain (820), Canada (488) and Japan (449). These papers received a total of 120,182 citations, giving average citation number of 12.3. Restated, the Bioresource Technology has become the leading platform for sludge management papers, while China takes the lead on publication while UK is out of the shortlist.

To monitor the research and development trend of a specific topic, meta-analysis on all publications including regular papers and review articles can provide a “quantitative” overview on the current efforts for sludge studies. This mini-review however adopted another approach based on the following proposal: review articles are generally composed based on digest of prestigious research groups to summarize contemporary studies with significant impacts on the specific field. Since the references summarized in review articles are highly selective, to summarize the perspectives listed in contemporary reviews can provide a “qualitative” overview on the current research trend. This mini-review reviews the current research trends on sludge management papers based on the contemporary 51 reviews on sludge treatments (Table 1). These reviews cited a total of 5365 relevant sludge treatment papers, so the present mini-review can be regarded as a summary of these relevant cited papers.

Sludge is composed of most residual substances after wastewater treatment plants. To use the sludge as a carrier, the scheme of partition–release–recover (PRR) discussed by Batstone et al. (2015) can be employed as a general platform for discussion. For instance, in partition stage, the microbes move nutrients and carbon to solid phase that ends up in residue sludge, and then the sludge is collected and is subjected to release stages such as thermophilic anaerobic digestion stage. The nutrients in the yielded concentrated digestate are recovered by stages such as chemical precipitation. Mehta et al. (2015) reviewed a similar scheme with accumulation (plants, microbes, precipitation, physical enrichments)-release (digestion, leaching, thermochemical treatments)-extraction (crystallization, gas stripping, membrane separation). The nutrients in concentrated form such as struvular feces are recommended for wide use options. We used the former scheme as the basis for further discussions on the reviewed reviews in this paper. Briefly, more than half of pollutants in wastewater are transformed to the sludge, hence the partition incorporates the production of sludge and the enrichment of contaminants to the sludge biomass. In release section, the pretreatment technologies and the fate and transformation of the pollutants in the pretreated sludge are discussed. In the recovery section, the carbon and other nutrient recovery from sludge biomass is reviewed.

2. Partition

2.1. Sludge production-status

The sludge production quantity is rapidly increased this decade. An emerging sludge market is in China (Jain et al., 2015). There were 3508 wastewater treatment plants in China by the end of 2013 which yielded large quantity of sewage sludge; however, merely 25% of the produced sludge was properly treated (Zhang et al., 2016). The number of wastewater treatment plants in China reached 5300 in 2016, yielding about 30 million tons of wet sludge (80% moisture content) annually (Wang et al., 2017a,b). With the implementation of their “13-5” project to widespread installation of more wastewater treatment plants over the country, the sludge production rate is estimated to reach 60 million tons of wet sludge per year that needs comprehensive sludge treatment facility for proper handling (Lee, 2017b). The current global sewage sludge production rate is about 45 million dry ton sludge per year, equivalent to about 2.0-billion population equivalent (PE) covered by full sanitation at secondary wastewater treatment facility, if taking conversion factor of 70 g dry sludge produced/PE-day (Lee, 2017a).

Sludge handling other than for sewage sludges are also reviewed. Salihoglu and Salihoglu (2016) discussed the treatment