Journal of Cleaner Production 183 (2018) 1021–1033

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Environmental assessment of a landfill leachate treatment plant: Impacts and research for more sustainable chemical alternatives

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ARTICLE INFO

Article history:
Received 29 September 2017
Received in revised form
18 February 2018
Accepted 20 February 2018
Available online 21 February 2018

Keywords:
Life Cycle Assessment
Municipal landfill leachate
Polyaluminum chloride
Ferric chloride
Sodium hydroxide
Calcium hydroxide

ABSTRACT

The aim of this study is to evaluate, from an environmental point of view, the performance of various technologies applied to the treatment of municipal landfill leachate. The study has been led in an Italian wastewater treatment plant and it applies the principles of the Life Cycle Assessment (LCA) technique, using ReCiPe as the assessment method. This study shows how the operating stage of a wastewater treatment plant, that applies chemical and physical treatments, can affect the following four environmental impact categories: "Freshwater Eutrophication", "Freshwater Ecotoxicity", "Marine Ecotoxicity" and "Human Toxicity". Within this operating stage, the study shows the relevant environmental impacts generated by the use of polyaluminum chloride (PAC) as a coagulant chemical agent and sodium hydroxide (caustic soda) as a pH control chemical agent. In order to investigate these results, and to discover more eco-friendly alternatives, two LCA comparisons have been carried out, comparing respectively the above two agents to analogous and common substitutes: ferric chloride as a coagulant agent and calcium hydroxide (lime) as a pH control agent. These comparisons demonstrate the higher environmental impacts of the use of ferric chloride over PAC and of sodium hydroxide over calcium hydroxide. Ferric chloride has shown to have more than double the environmental impact of PAC in 9 environmental categories out of the 10 considered, while calcium hydroxide has been able to cut down the negative environmental impacts of the sodium hydroxide of more than 65% in all the environmental categories. Considering the highly positive environmental results achieved from our study, whenever possible, a substitution of calcium hydroxide to sodium hydroxide and of PAC to ferric chloride is strongly recommended.

1. Introduction

The landfill leachate is a liquid which draws its origin predominantly by the infiltration of water in the mass of waste or from the decomposition of the same. To a lesser extent, the landfill leachate is also produced by the progressive compaction of the waste. The leachate from the landfill, therefore, is a complex and highly polluted wastewater. The pollution of the leachate is the result of biological, chemical and physical processes that take place within the landfill, along with the composition of the waste and the water regime of the landfill. Thus, the leachate can have very different chemical composition as a function of many parameters, including the type of waste which produced it and the age of the landfill (Kulikowska and Klimiuk, 2008; Huo et al., 2008; Müller et al., 2015). The average characteristics of the leachate are evaluated through indicators such as pH, Biochemical Oxygen Demand (BOD5), Chemical Oxygen Demand (COD) and metal content. Among the types of wastewater treatment, the treatment of landfill leachate is certainly one of the most complex (Amor et al., 2015). The difficulty is due not only to the entity of the pollutant load but also to its variability in time. The selection of the process to be applied for the required purification efficiency depends on the regulations on discharges. When landfill leachate is treated in waste water treatment plants (WWTPs), plant managers are increasingly concerned about its impact on a WWTP's ability to meet discharge limits (Brennan et al., 2016).

Life Cycle Assessment (LCA) is a technique that can be used to evaluate the overall environmental impact of a certain human activity, such as wastewater treatment process. LCA is a well-established procedure quantifying inputs and outputs as well as the potential environmental impacts associated with a product, a process, or a service throughout its whole life cycle (ISO, 2006a;

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https://doi.org/10.1016/j.jclepro.2018.02.219

ISO, 2006b). In the field of wastewater treatment (WWT), LCA has been applied since the 1990s. In the pursuit of more environmentally sustainable WWT, Corominas et al. (2013a) stated that LCA is a valuable tool to elucidate the broader environmental impacts of design and operation decisions.

This paper has been organized as follows: after this introduction, section 2 presents a review of the analyzed literature concerning LCA and WWTs; section 3 describes the research objectives and approach; section 4 explains in details the LCA used for this study; section 5 shows the outcomes of the LCA; section 6 reports a discussion regarding the outcomes, together with the final considerations of the study.

2. Literature review

Life Cycle Assessment has been applied to water treatment systems (water treatment plants, sewer systems, and waste water treatment plants) since this technique began to develop. Emmerson et al. (1995) were the first to publish a study about the environmental impact of small-scale sewage treatment works, using LCA. In their analysis of three sewage-treatment works (with different process options), they identified and quantified material use, energy use and environmental releases during construction, operation and demolition stage of the WWTPs.

Most of the LCA studies in WWT have been aimed to compare the different wastewater treatment methods and their different performance characteristics. Vlasopoulos et al. (2006) described the implementation of LCA, to investigate the environmental impact of 20 technologies suitable for treating wastewater produced during the oil and gas extraction processes. Their results were then incorporated into a decision support system which allowed identification and prioritization technology combinations, capable of producing water for different designated industrial and agricultural end uses. In 2011, a study of Rodriguez-Garcia et al. (2011) evaluated the performance of 24 WWTPs using a streamlined LCA, with eutrophication potential (EP) and global warming potential (GWP) as environmental indicators and operational costs as economic indicators. They found out that, for organic matter removal, WWTPs were less costly, both in environmental and economic terms, if the volume was used as the functional unit. On the other hand, more demanding typologies, such as reuse plants, showed a trade-off between lower EP and higher cost and GWP. However, this was overcome if a second functional unit (based on EP reduction) was used instead, proving the sustainability of these options and that this functional unit better reflected the objectives of a WWTP. In 2016, Postacchini et al. (2016) used LCA to conduct a comparative assessment of the environmental impacts of three different methods of treating primary clarifier effluent in a WWTP. They compared two conventional treatment systems, which are activated sludge (AS) and trickling filter (TF) system, with a new experimental one named, high rate anaerobic-aerobic digestion (HRAAD). Their results showed TF having the smallest environmental impacts and AS the largest, while HRAAD set itself in between the two but with much reduced impacts compared to AS.

LCA has also been used in WWT field to study the impact of tertiary treatments, sludge treatment and disposal and nutrient removal. Muñoz et al. (2009) assessed the life-cycle environmental impact of urban wastewater reuse for agricultural purposes, putting special emphasis on the potential toxicity of priority and emerging pollutants, present in the effluents to be reused. The study was based on benchscale experiments, applying ozone and ozone in combination with hydrogen peroxide to a wastewater effluent from a sewage treatment plant. The results highlighted that wastewater reuse, after applying any of the tertiary treatments considered, appeared as the best choice from an ecotoxicity perspective.

Hospido et al. (2010) used LCA to evaluate the reuse of anaerobically digested sewage sludge in agricultural land, focusing on the possible impacts caused by emerging micropollutants. They also analyzed the influence of different operational conditions applied during the anaerobic digestion process on the digested sludge quality. They showed that, from an environmental point of view, the disposal of undigested sludge is the less suitable alternative. Only the results on GWP contradict this fact, due to the dominance of the indirect emissions associated with the electricity used by the digesters. The digestion of sewage sludge before application to agricultural soil is a meaningful activity, not only because it is a requirement, according to the actual legislation, but also because it reduces the environmental impact associated with the pollutants present in the sludge. Corominas et al. (2013b) presented a methodology to evaluate the environmental impacts of enhanced process performance strategies, applied to wastewater nutrient removal systems. They used LCA to assess three different scenarios depending on the limitation of nitrogen (N), phosphorus (P), or both when evaluating the nutrient enrichment impact in water bodies. According to them, decision-making in controlling wastewater nutrient removal systems can be assessed using a combination of mechanistic process models together with Life Cycle Impact Assessment (LCIA) models. They found out that the use of site-specific conditions, for the nutrient enrichment impact category, is essential to define best environmental performance strategies.

Recently, LCA has been adopted to compare WWTP control strategies and management scenarios or the effectiveness and applicability of a particular WWT in a specific location. Meneses et al. (2015) showed the potential additional insight that results from adding indicators based on LCA to the evaluation criteria of plant performance, in the control strategies of wastewater treatment plants. The authors combined plant-performance evaluation criteria, as effluent quality and operational cost, jointly with a detailed environmental evaluation for impact category provided by LCA. In their comparison of the different control strategies, they highlighted the importance of the environmental analysis as an additional source of information for decision makers. A more recent study of Lutterbeck et al. (2017) used LCA to investigate the effectiveness, applicability, and environmental sustainability of a wastewater treatment system located on a rural property. They studied an integrated treatment system, consisting of anaerobic reactors and constructed wetlands, in a rural area in Brazil. Their study showed that the application of LCA can give valuable insights for setting the best configurations for a WWT system in rural areas, by identifying the most critical parameters and by the evaluation of actions to reduce the environmental impacts.

Some studies have discussed the limits and the discrepancies of the various impact assessment methods applied to WWT field. This is the case of Renou et al. (2008), who discussed how LCA could be applied to wastewater treatment projects, through a case study on a full-scale plant, evaluating the influence of the selected impact assessment method on the LCA outcome. They compared five LCIA methods: CML 2000, Eco Indicator 99, EDIP 96, EPS and Ecopoints 97. They obtained consistent assessment between these methods regarding greenhouse effect, resource depletion, eutrophication and acidification. They pointed out that work was needed