Journal of Environmental Management 225 (2018) 112–119

Contents lists available at ScienceDirect

Journal of Environmental Management

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

Research article

Bottom-up approach in the assessment of environmental impacts and costs of an innovative anammox-based process for nitrogen removal

Andrea Arias[a,*], Iana Salim[a], Alba Pedrouso[a], Nicolás Morales[b], Anuska Mosquera-Corral[a], José Ramón Vázquez-Padín[b], Frank Rogalla[b], Gumersindo Feijoo[a], María Teresa Moreira[a]

[a] Department of Chemical Engineering, School of Engineering, Universidade de Santiago de Compostela, E-15782, Santiago de Compostela, Galicia, Spain
[b] Aqualia, Guillarei WWTP, Camino de la Veiga s/n, E-36720, Tui, Spain

ARTICLE INFO

Keywords:
Partial nitritation-anammox
Scale-up analysis
Sustainable wastewater treatment
Life cycle assessment (LCA)
Eco-efficiency
Economic evaluation

ABSTRACT

In recent decades, the wastewater treatment sector has undergone a shift to adapt to increasing discharge limits. In addressing the evaluation of innovative technologies, it is necessary to determine the scale at which reliable and representative values of environmental impacts and costs can be obtained, ensuring that the system under assessment follows the direction of eco-efficiency.

This study has evaluated the environmental and economic indicators of an autotrophic nitrogen removal technology (ELAN®) from laboratory conception (1.5 L) to full scale (2 units of 115 m^3) using the Life Cycle Assessment (LCA) methodology. Indirect emissions related to electricity consumption are the main contributor in all impact categories except eutrophication. Electricity consumption referred to the functional unit (1 m^3 of treated wastewater) decreases as the scale increases. The rationale behind this can be explained, among other reasons, by the low energy efficiency of small-scale equipment (pumps and aerators). Accordingly, a value of approximately 25 kg CO_{2eq} per m^3 of treated water is determined for laboratory scale, compared to only 5 kg CO_{2eq} per m^3 at full-scale. When it comes to assessing the reliability of data, a pilot scale system of 0.2 m^3 allowed to perform a trustworthy estimation of environmental indicators, which were validated at full-scale. In terms of operational costs, the scale of approximately 1 m^3 provided a more accurate estimate of the costs associated with energy consumption.

1. Introduction

In the design of new processes and products, there is a growing demand to label them as sustainable from the earliest stages of their conception and development. Traditionally, the evolution of an innovative technology, from its conception to its implementation in the market, consists in overcoming a series of successive stages of development, where performance and operational conditions vary according to scale, making them comparable to conventional technologies. When introducing the environmental and economic perspectives, it is necessary to evaluate the scale level that allows reliable and representative values of environmental impacts and costs to be obtained, ensuring that the emerging technology is moving in the direction of eco-efficiency. This stage is critical, as it will mean the “abandonment” or “scaling up” of R&D activities to large-scale installation.

In the context of wastewater treatment, reducing the nitrogen load in the treated effluents is one of the main objectives to avoid excessive growth of algae in watercourses (eutrophication), toxicity by ammonia and decrease of dissolved oxygen, negatively affecting aquatic fauna and flora (Li and Brett, 2012). In accordance with the European Water Framework Directive (EC, 2000), a nitrogen discharge limit of 10–15 mg N/L applies for European wastewater treatment plants (WWTPs) in sensitive areas, provided that 70–80% of the total nitrogen in the influent is removed. This increased legislation restriction leads to the development of novel treatment technologies that need to be validated from an environmental and economic point of view (Machado et al., 2009; Wang et al., 2012). Several authors highlighted the balance between nitrogen removal and energy demand, which may lead to an increase in indirect greenhouse gas emissions depending on the complexity of the treatment scheme (Foley et al., 2010a; Lederer and Rechberger, 2010; Rodriguez-Garcia et al., 2011; Vidal et al., 2002).

Conventional nitrogen removal from wastewater is based on the biological nitrification-denitrification processes. Beyond the requirements of aeration and depending on the COD/N ratio of the wastewater, the addition of an external carbon source may be required, which implies operational costs between 2.85 and 3.64 €/kg N removed.

* Corresponding author.
E-mail addresses: andrea16_verin@hotmail.com, andrea.arias.cisterna@rai.usc.es (A. Arias).

https://doi.org/10.1016/j.jenvman.2018.07.070
Received 27 February 2018; Received in revised form 18 July 2018; Accepted 20 July 2018
0301-4797/

Nomenclature

Anammox	Anaerobic Ammonium Oxidation
AOB	Ammonium-Oxidizing Bacteria
CAS	Conventional Activated Sludge System
CC	Climate Change
CML	Centre of Environmental Science of Leiden University
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
ELAN®	Autotrophic Nitrogen Removal, in Spanish (ELiminación Autótrofa de Nitrógeno)
EP	Eutrophication Potential
FD	Fossil Depletion
FET	Freshwater EcoToxicity
FS	Full Scale
FU	Functional Unit
HRT	Hydraulic Retention Time
HT	Human Toxicity
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LS	Laboratory Scale
MET	Marine EcoToxicity
NOB	Nitrite-Oxidizing Bacteria
OD	Ozone Depletion
OLAND	Oxygen Limited Autotrophic Nitrification-Denitrification
PMF	Particulate Matter Formation
PN-AMX	Partial Nitritation-AnaMmoX
POF	Photochemical Oxidation Formation
PP1	Pilot Plant 1
PP2	Pilot Plant 2
SBR	Sequencing Batch Reactor
SCENA	Short Cut Enhanced Nutrient Abatement
TA	Terrestrial Acidification
TET	Terrestrial EcoToxicity
VER	Volume Exchange Ratio
WD	Water Depletion
WWTP	WasteWater Treatment Plant

Furthermore, conventional technologies require extensive land use, increasing capital costs (Renzi et al., 2015).

The combination of partial nitritation-anammox (anaerobic ammonium oxidation) processes (Jetten et al., 2002; Mosquera-Corral et al., 2005) or partial nitrification-denitrification (Renzi et al., 2015) are interesting alternatives to the conventional nitrification-denitrification processes. In recent years, new innovative technologies have been developed to incorporate these processes such as SCENA (Short Cut Enhanced Nutrient Abatement) (Renzi et al., 2015), OLAND (Oxygen Limited Autotrophic Nitrification-Denitrification) (Kuai and Verstraete, 1998) and ELAN® (autotrophic nitrogen removal in Spanish "ELiminación Autótrofa de Nitrógeno") (Vazquez-Padín et al., 2014a). These technologies are applied for the treatment of the supernatant from the anaerobic sludge digesters which are nutrient rich side streams in the WWTP (Vazquez-Padín et al., 2014a; Longo et al., 2017). When ELAN® process is used for nitrogen removal, it can reduce oxygen requirements to 1.83 kg O_2/kg $N_{removed}$, with no consumption of organic matter and an outstandingly low biomass yield of 0.12 kg VSS/kg $N_{removed}$, compared to the remarkably higher values of 3.18 kg O_2/kg $N_{removed}$, 4.9 kg COD/kg $N_{removed}$ and 2.11 kg VSS/kg $N_{removed}$ in the case of nitrification/denitrification process (Vazquez-Padín et al., 2014a).

With the aim of assessing the sustainability of water treatment technologies, the Life Cycle Assessment (LCA) methodology arises as a good alternative because it allows quantifying the potential environmental impacts throughout the entire cycle of a product or process (ISO, 2006). This methodology has been widely used to evaluate the efficiency of WWTPs or to study different treatment alternatives (Foley et al., 2010b; Hospido et al., 2004; Lorenzo-Toja et al., 2016a). Beyond complying with water discharge regulations, it must taken into account that among the different treatment schemes, some might be considered advantages when applied to specific cases, not only considering environmental but also economic perspectives (Longo et al., 2017; Lorenzo-Toja et al., 2016b; Rodriguez-Garcia et al., 2011).

However, the tendency to use LCA to "test" the superiority of one product over another has discredited the concept in some areas (Heijungs et al., 2010; Weidema, 2003). One of these weaknesses is attributed to the collection and validity of data required for the life cycle inventory (LCI). This stage is critical as it will compute the consumption of raw materials, chemicals, water and energy for each stage of the process, as well as emissions to air, water and soil (Finnveden, 2000; Lorenzo-Toja et al., 2016a; Tillman, 2000). When the inventory data are executed from reliable data, it is possible to obtain accurate environmental impacts. This includes the need to make judgements based on the figures collected to assess the likely significance of the various impacts (Reap et al., 2008). However, uncertainty arises regarding the scale of development required. Furthermore, when the aim is to evaluate a technology under development, this drawback is even more important. The definition of the scale of development required, which provides reliable data for LCA, is therefore relevant to ensure the successful implementation of a bottom-up approach.

The main objective of this study is to define the scale for which data collection in the LCA methodology provide a reliable evaluation of a technology under development. In particular, the assessment of an innovative wastewater treatment technology for nitrogen removal (ELAN®) from lab conception to full-scale was conducted.

2. Materials and methods

2.1. Description of the ELAN® technology

The ELAN® technology combines partial nitritation and anammox (PN-AMX) processes in the same unit (Vázquez-Padín et al., 2010). In the partial nitritation process, the ammonium oxidizing bacteria (AOB) oxidize ammonium to nitrite, while the oxidation of nitrite to nitrate by the nitrite oxidizing bacteria (NOB) should be avoided (Vázquez-Padín et al., 2009). The anammox bacteria are capable of oxidizing ammonium to nitrogen gas using nitrite as electron acceptor, without the need of organic matter or oxygen (Dapena-Mora et al., 2004). Thus, in the ELAN® technology, nitrogen is autotrophically removed.

ELAN® technology was developed in a sequencing batch reactor (SBR) with granular sludge (Fig. 1). The establishment of aerobic and anoxic zones within the granule, depending on oxygen depth

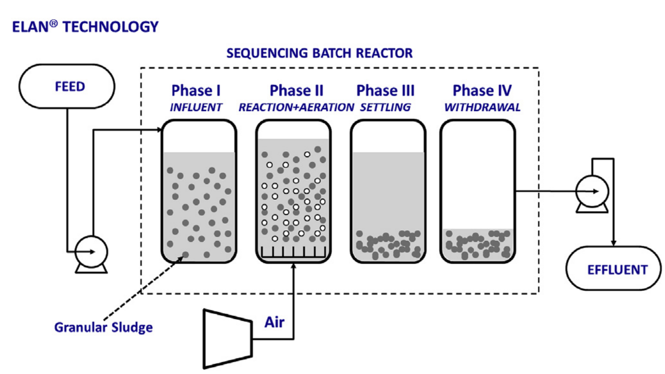

Fig. 1. Scheme of operational cycle in the reactors operated at different scale for the development of the ELAN® process.