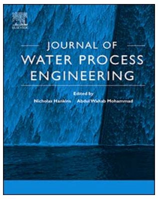
Journal of Water Process Engineering 22 (2018) 59–65

Contents lists available at ScienceDirect

Journal of Water Process Engineering

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



Experiences from an investigation on the potential of packed bed reactors for high rate nitrification of mature landfill leachates

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ARTICLE INFO

Keywords:
Ammonia oxidation
Biofilm
Landfill leachate
Nanofiltration permeate
Reverse osmosis concentrate

ABSTRACT

Due to high specific surface area, high biomass concentration and handling convenience, packed bed reactor technology is a highly competitive option for nitrification of landfill leachates. Nitrification would solve the problem of insufficient ammonia retention faced by the high pressure membrane systems at the Ihlenberg landfill, which aims to achieve clean water recoveries up to 95%. This study investigated the feasibility for ammonia removal using four lab-scale reactors packed with three different packing materials (coke, expanded clay beads and polyethylene carrier) over a period of about 400 days. The research work studied the nitrification of two process streams: reverse osmosis concentrate (RO) of raw leachate (having high dissolved organics content) and nanofiltration permeate of RO retentate (with a low concentration of organics), to identify advantages/disadvantages arising from the differences in their composition. The organics contained in the leachate were observed to cause inhibition. Due to this reason, the maximum nitrification rate obtained in the presence of organics was about 570 g $N\text{-}NH_4^+/(m^3\,d)$, whereas in their absence up to 1.2 kg $N\text{-}NH_4^+/(m^3\,d)$ could be achieved. Although coke packing because of its higher specific surface area and rugged surface favoured faster biofilm development; due to its ability to adsorb organics and thus also promoting the growth of heterotrophs, it was found to be more vulnerable to clogging.

1. Introduction

Landfill leachate, formed predominantly from the percolation of precipitation through landfilled waste, belongs to the class of highly polluted wastewaters. They contain a wide range of hazardous pollutants (both organic and inorganic in nature), the immission of which can be very detrimental to all elements of an ecosystem [1–3]. Ammonium ions are one of the main constituents of landfill leachates, whose release into surface waters can have acute effects – oxygen depletion and ammonia toxicity. Unlike organic compounds content, the ammonium-nitrogen ($N\text{-}NH_4^+$) concentration in leachates does not decrease with the ageing of a landfill [2,4,5]. Therefore, its removal is of high importance in the long run.

Ammonia concentration in the raw leachate (about 600 mg $N\text{-}NH_4^+/L$) from the Ihlenberg landfill (located close to Lübeck, Germany) has not changed much over the last decades [6–8]. Commissioned in 1983 with an area of 113 ha, it is one of Europe's largest hazardous waste landfills and produces about 500 m^3 of methanogenic leachate per day. Since 1990, the leachate is being treated by two-stage reverse osmosis (RO) attaining clean water recoveries of up to 85% [9], following which the concentrate is re-injected into the landfill. Table 1 shows the composition of the raw leachate at Ihlenberg landfill and its RO retentate. At the landfill, sulphuric acid is used during reverse osmosis (to prevent carbonate scaling), due to which sulphate concentration in the RO concentrate is quite high.

However, the German landfill ordinance [10] does not permit the recirculation of retentates, unless it is part of a treatment process or a benefit will result from its practice. Since the leachate at Ihlenberg is mature (low biodegradable organics content), its recirculation cannot do any good. Based on previous research [11], the landfill operator will start treating the RO concentrate further using a nanofiltration (NF) stage (see Fig. 1) in the near future, in order to halve its volume. The retentate of nanofiltration may undergo evaporation followed by solidification and disposal as reported by Peters [9]. Furthermore, it is desired to handle the NF permeate using another RO stage, the permeate of which should be suitable for direct discharge, thereby enhancing the overall clean water recovery up to about 95%.

However, as communicated by the project partner (RTS Rochem Technical Services GmbH, Hamburg, Germany), this final reverse osmosis treatment will not reject ammonia sufficiently. As the $N\text{-}NH_4^+$

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https://doi.org/10.1016/j.jwpe.2018.01.006
Received 13 October 2017; Received in revised form 7 January 2018; Accepted 9 January 2018

Table 1
Composition of raw leachate (RL) from the Ihlenberg landfill and its RO concentrate (adapted from measurements made by the landfill operator).

Cations	in mg/L		Anions	in mg/L	
	RL	RO		RL	RO
Ca^{2+}	230	1200	Cl^-	5800	30000
K^+	1100	5800	$N\text{-}NO_2^-$	< 0.3	1.15
Mg^{2+}	81	350	$N\text{-}NO_3^-$	< 2	< 2
Na^+	3100	15800	$o\text{-}PO_4^{3-}\text{-}P$	4.5	15.6
$N\text{-}NH_4^+$	580	3000	SO_4^{2-}	560	13700
Other parameters					
pH	8.0	7.5	EC[a] (mS/cm)	23.5	92
ORP[b] (mV)	210	190	$Ks_{4.3}$[c] (mmol/L)	56.5	131
COD (mg/L)	1900	11700	BOD_5 (mg/L)	740	960
TOC (mg/L)	840	4060	TN (mg/L)	588	3120

[a] EC – electrical conductivity.
[b] ORP – oxidation reduction potential.
[c] $Ks_{4.3}$ – acid neutralising capacity.

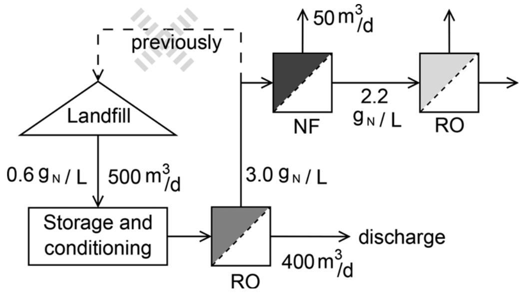

Fig. 1. Proposed scheme for leachate treatment using high pressure membrane systems (typical concentrations of $N\text{-}NH_4^+$ in different streams are depicted).

concentration in the NF permeate (which will be the feed for the final RO stage) will be quite high (see Fig. 1), $N\text{-}NH_4^+$ concentration in the RO permeate will be much larger than the discharge limit of 10 mg $N\text{-}NH_4^+$/L. Therefore, the project partner and the landfill operator desire ammonia removal via nitrification. The authors were informed that the final RO stage would be able to retain nitrate ions sufficiently since they have a higher molecular weight than ammonium ions. Thus, ammonia removal from this mature leachate using nitrification has been the focus of this research project.

The activated sludge process, that we see today in the municipal wastewater treatment plants (WWTP) in industrialised countries, is the result of chronological development of engineered suspended growth microbiological processes, starting from a draw-and-fill reactor in 1913 [12]. From an initial goal of just removing organics and discharging the effluent into rivers; WWTPs have been continually developed to nitrify, denitrify and remove *ortho*-phosphate to prevent eutrophication in the receiving waters. The use of suspended growth processes (conventional activated sludge process and sequencing batch reactor) for organics and ammonia removal from landfill leachates has been widely reported in literature [1,13]. Poor settleability of the sludge resulting in loss of biomass in the effluent is a major problem with suspended growth processes treating landfill leachates. This can be avoided in fixed-film reactors.

Fixed-film processes for nitrification of landfill leachates, although only scarcely reported, have thus been shown to be advantageous (especially for mature leachates) over the suspended growth processes [14–16]. These studies have reported that the influence of temperature on nitrification in biofilms is low and that the effluent from biofilm reactors is nearly free from particulate matter.

Attached growth processes (originally discovered in 1893), which were forgone during the development of the activated sludge process, regained interest in the early 1970s [12] leading to the development of several different reactor configurations or types including the packed bed reactors (PBR). Since then, numerous studies [17–25] on submerged packed bed biofilm reactors aimed at removing nutrients from wastewaters have reported them to be advantageous and highly competitive since they:

- have a high biomass concentration, as a result of which higher $N\text{-}NH_4^+$ loading rates or higher nitrification rates are possible,
- allow immobilization of bacteria, facilitating the enrichment of the slow-growing nitrifiers in the biofilm,
- produce little or practically no residual sludge, thereby obviating large clarifiers and/or associated settling problems met in suspended growth processes,
- can withstand short-term shock loads, inhibitors and/or toxins,
- are less affected by low temperatures than suspended growth processes,
- are “compact, flexible and reliable” offering handling convenience, well-suited especially for treating lower wastewater volumes (e.g. industrial wastewaters).

For these reasons, PBRs were chosen for investigating nitrification of the leachate from the Ihlenberg landfill. To the best of our knowledge, only Jokela et al. [14] have studied PBRs for exclusively nitrification of landfill leachate. The authors of that study investigated nitrification and denitrification of a municipal landfill leachate in up-flow and down-flow PBRs. The study reported the possibility to achieve 90% nitrification efficiencies at 100–130 g $N\text{-}NH_4^+/(m^3\,d)$ in up-flow configuration and stated it to be advantageous over down-flow. However, “the maximum loading potential of the systems” was not investigated in that study. The authors of this study opine that PBRs treating landfill leachates could also offer high nitrification rates, possibly comparable to the values reported in literature for other wastewaters [20,26]. This study investigated the feasibility for ammonia removal via nitrification from various process streams (simulated raw leachate, RO concentrate of raw leachate and NF permeate of the RO retentate) fitting to the scenario depicted in Fig. 1. Nitrification trials were conducted in four lab-scale up-flow PBRs (packed with 3 different media types) for about 400 days. This paper presents the important findings and the experiences gained from the research work.

2. Materials and methods

2.1. Materials

RO concentrate with a composition similar to that in Table 1 was provided from the landfill site. Laboratory grade $NaHCO_3$ or K_2CO_3 were used for controlling the pH during nitrification. Return activated sludge, for inoculating the reactors, was obtained from the WWTP at Seevetal, Germany. Packing materials: activated lignite (HOK – grained), expanded clay beads (Liapor 8 4/8) and PE carrier (Hel-X HXF12KLL) were purchased from Rheinbraun Brennstoff GmbH (Frechen, Germany), Liapor GmbH & Co. KG (Hallerndorf-Pautzfeld, Germany) and Stöhr GmbH & Co.KG (Marktrodach, Germany), respectively.

2.2. Methods

A schematic of the reactor system, consisting of an up-flow PBR, a feed tank, a pump, aeration facility, etc., is shown in Fig. 2. A total of four such systems were used in the study. All trials were conducted as batch experiments in recirculation mode using 25 L wastewater contained in HDPE tanks. Magnetically coupled centrifugal pumps (Model: NDP14/2, Totton Pumps, Cape Coral, Florida, USA), made of chemical-resistant plastics, were used to pump the wastewater through the