Chemical Engineering Journal 255 (2014) 274–281

Contents lists available at ScienceDirect

Chemical Engineering Journal

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

Behaviour of air diffusers and oxygen transfer efficiencies in the biological treatment of matrices at high alkalinity concentrations: Experimental and full scale application

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HIGHLIGHTS

- Slow pressure growth is evaluated for the elastomeric diffusers in the treatment of high alkalinity matrices.
- These diffusers maintain the original pore shape ensuring oxygen transfer in aerobic phases.
- The preservation of pore shape minimizes the blocking effect and the need for chemical cleanings.
- The precipitate on and inside the pores is mainly composed of calcium and iron deposits.
- The full scale application of elastomeric diffusers increases NH_4-N removal and energy saving.

ARTICLE INFO

Article history:
Received 20 November 2013
Received in revised form 20 June 2014
Accepted 21 June 2014
Available online 27 June 2014

Keywords:
Air diffuser
Biological treatment
Landfill leachate
Oxygen transfer rate
Precipitated compounds

ABSTRACT

An evaluation of different types of air diffusers applied to the biological landfill leachate treatment was executed. The optimization of performances in the experimental scale was determined evaluating the pressure evolution at different inlet air flows for two types of elastomeric polyethylene diffusers. The microscope analysis permitted the definition of the chemical compounds precipitated on surface of the diffusers and inside the pores. The compounds were mainly composed of calcium and iron deposits. Formic acid solution was identified as the most efficient for the removal of the insoluble salts. During the experimental phase, the elastomeric polyethylene diffuser was found to be the best suited to the biological treatment of matrices at a level of high alkalinity (2900 $mgCaCO_3l^{-1}$). This result determined the replacement of 500 rigid diffusers in the full scale biological reactor. The substitution incremented the standard oxygen transfer efficiency to 16% and the standard aeration efficiency to 5.1 kgO_2kWh^{-1} with an improvement of the ammonia performances and of energy saving.

1. Introduction

The main factors determining aerobic conditions in biological reactors with suspended activated sludge are related to the air flow rate, the submergence depth and the specific type of installed diffusers [7]. Aeration is the main energetic request in wastewater treatment plants therefore a correct configuration of system of the air diffusers allows an optimization of costs [10]. Fine pore diffusers improve aeration performances determining higher oxygenation conditions, an increase of the adaptability to different oxygen requirements and a reduction in the production of aerosol [4]. The standard procedure for the determination of performances is the measurement of the initial efficiency of diffusers in clean water [3]. Despite this predictive approach, the behaviour of real diffusers in the full scale wastewater treatment plant is mainly linked with other important parameters: the geometry of the tank, the layout of the aeration system and the operating conditions of the biological process [8]. Therefore, the effective inlet air flow, the pressure of diffusers and the real oxygen transfer coefficient (k_La) must be measured in the real applications to take into consideration all the variables which influence the aeration system efficiency [11]. Moreover, the chemical physical characteristics of the influent flow could be an important variable in the performances of diffusers whereas the high load of ammonia defines an elevated demand of oxygen to be supplied. For this reason, the biological treatment of landfill leachate is complicated by the elevated influent level both of total nitrogen, mainly composed of NH_4-N (400–1000 $mg\,l^{-1}$) and of alkalinity (1500–4000 $mgCaCO_3\,l^{-1}$) [1]. In fact, while the process applied is characterized by oxic and

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http://dx.doi.org/10.1016/j.cej.2014.06.083
1385-8947/

Nomenclature

C^*_∞	DO concentration in saturation conditions in the k_La test(mg/l)
$C^*_{\infty 20}$	DO concentration in saturation conditions in the k_La test at 20 °C(mg/l)
C_0	initial DO concentration in the k_La test(mg/l)
C_t	DO concentration at different times in the k_La test(mg/l)
DO	dissolved oxygen(mg/l)
EPDM	elastomeric polyethylene
HDPE	rigid polyethylene
k_La	real oxygen transfer coefficient(h^{-1})
k_La_{20}	real oxygen transfer coefficient at 20 °C(h^{-1})
MLVSS	mixed liquor volatile suspended solids concentration (kg/m^3)
NLR	nitrogen loading rate($kgTN/m^3/d$)
ORP	oxidation reduction potential(mV)
S1	formic acid solution
S2	peracetic with hydrogen peroxide and acetic acid solution
SAE	standard aeration efficiency(kgO_2kWh^{-1})
SEM	scanning electron microscope
SOTE	specific oxygen transfer efficiency(%)
SOTR	standard oxygen transfer rate(kgO_2/h)
SOUR	specific oxygen uptake rate($gO_2kgMLVSS^{-1}h^{-1}$)
V	reactor volume(L)

anoxic phases [5,6], a possible crystallization on the surface and inside the pores of diffusers occurs with a resulting net decrement of the quality and quantity of the diffused bubbles. The precipitation phenomena and the related blocking of pores increase the pressure of the aeration distribution pipes and of the diffusers. In this situation, the augmentation of the air flow rate could not determine an improvement of the oxygen transfer efficiency but, instead, could cause the membrane to stretch under the higher gas pressure and a resulting deformation of the size of pores [13].

Different answers to the described conditions are obtainable using fine bubble diffusers diverse in pore shape and constructing material. In fact, at present, polymeric membranes for wastewater treatment are typically composed of ethylene–propylene-diene-monomer, polyurethane, or polyvinylchloride. In general, the membranes are not pure in their major components and contain additives that are blended to enhance mechanical and chemical properties and to increase polymer ability [9]. During the real working process applications, all these different physical and chemical characteristics influence the change of the specific oxygen transfer efficiency SOTE (%) and the standard aeration efficiency SAE (kgO_2kWh^{-1}).

This paper deals with the evaluation of different types of air diffusers applied to biological landfill leachate treatment both in experimental and full scale applications. The optimization of performances, using elastomeric polyethylene diffusers, are determined by evaluating the differential pressure evolution during 65 days of research; the chemical compounds precipitated on surface and inside the pores of the diffusers and the modification of k_La, SOTE% and energy saving in the full scale plant before and after the air system change.

2. Materials and methods

2.1. Experimental device

The experimental study was performed in the biological reactor (1000 m^3) of a full scale platform treating industrial liquid wastes (maximum influent capacity of 350 m^3 d^{-1}) mainly composed (95% of total wastes treated) of leachate from non-dangerous urban solid waste landfills. The platform layout is structured with a pre-treatment unit (sand removal and degritting), a coagulation and flocculation reactor, a biological unit and a final ultrafiltration membrane section. The biological process is fed continually and is characterized by alternating oxic and anoxic phases [12]. The full scale air system is composed of two lobed air blowers regulated with inverters with an installed power of 55 kW each. There are 500 original full scale diffusers which have been working for 3 years at depth of 4.75 m (hydrostatic pressure). They are made of rigid polyethylene (HDPE) with an average pore size of 0.5 mm (D1) (Table 1a).

For 65 days a pilot experimental system (Fig. 1) was submerged in the biological reactor at a depth of 2 m (hydrostatic pressure) to analyse the performances of two types of diffusers (D2 and D3). The tested diffusers are both in elastomeric polyethylene (EPDM) with a similar pore size of 1 mm but with a different shape of the pore edges (Table 1b and c). The Nm^3/h for cm^2 of area of pores is not possible to be estimated. In fact, this evaluation results incorrect considering the not uniform porosity configuration of D1 (average size of pore 0.5 mm). For The pore size of D2 and D3 was calculated as length of the pore. The free opening of the pore should change between D2 and D3 but the measure is not possible when the diffuser is not working. Moreover, the openings of D2 and D3 are variable on the basis of the flow imposed for the elasticity of the material. Therefore only the general porosity (n° pores/cm^2 of total diffuser area) was reported. The three types of diffusers (Table 1) are characterized by similar range of specific flow for total area of each diffuser (0.008–0.020 $Nm^3/h/cm^2$ for D1; 0.002–0.013 $Nm^3/h/cm^2$ for D2; 0.003–0.019 $Nm^3/h/cm^2$ for D3).

Each air pipe is equipped with two diffusers of each single type (D2 and D3) with one air flow meter Prowirl 72F Endress + Hauser (A1–A2 – Fig. 1), with one pressure measurement device Deltabar M PMD55 Endress + Hauser (M1-M2 – Fig. 1) and with one air blower with a nominal flow of 6 Nm^3 h^{-1} MINICOMP 6 Mapro (C1-C2 – Fig. 1). An additional air blower with a nominal flow of 10 Nm^3 h^{-1} MINICOMP 10 Mapro (C3 – Fig. 1) was installed in the experimental system to increase the air supply either for line 1 or for line 2. All the pressure and airflow signals were stored every 1 min using an Ecograph T RSG30 Endress + Hauser.

2.2. Blocking evaluation: macroparameters

According to the alternating oxic and anoxic process applied in the full scale biological reactor, the duration of the phases was automatically determined by a device which operates an on-line data processing of DO and ORP probes signals. The full scale air blower guarantees aeration in the oxidation period and the two submerged mixers maintain in suspension the biomass during the anoxic phases. The air blowers (C1–C2–C3), installed in the experimental pilot, fed air to the D2 and D3 pipe lines on the time basis of 1 h and for 1 h they are switched off to reproduce the full scale cycles.

The registered flow (Q) and pressure (P) for each experimental pipe line are used as immediate indicators of the blocking phenomena in the tested diffusers. Different air flows specific for one diffuser (Nm^3 h^{-1} $diff^{-1}$), both for D2 (2.5–4–5 Nm^3 h^{-1} $diff^{-1}$) and for D3 (3–4–5 Nm^3 h^{-1} $diff^{-1}$), were studied. The flows were