CHEMICAL ENGINEERING TRANSACTIONS

VOL. 43, 2015

A publication of AIDIC

The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Chief Editors: Sauro Pierucci, Jiří J. Klemeš

ISBN 978-88-95608-34-1; **ISSN** 2283-9216

DOI: 10.3303/CET1543315

Best Operative Practices for the Management of full Scale Biological Reactor for non Hazardous Landfill Leachate Treatment

Anna Laura Eusebi*[a], Pablo Romero[b], Paolo Battistoni[a]

[a]Dipartimento SIMAU, Facoltà di Ingegneria, Università Politecnica delle Marche, Via Brecce Bianche, 12, 60100 Ancona, Italy.
[b]Department of Environmental Technology, Faculty of Marine and Environmental Sciences, Cadiz University, Poligono Rio San Pedro s/n, 11510 Puerto Real, Cadiz, Spain
a.l.eusebi@univpm.it

The landfill is the most common final destination of the municipal solid wastes. Therefore, the landfill leachate is a serious environmental priority. The characteristics of the leachate are mainly related to the high ammonia concentrations, the low bioavailable carbon, the heavy metals and the inorganic salts. Consequently, the biological activated sludge treatment of landfill leachate is considered a low efficiency process in terms of nitrogen removal and of aeration transfer capacity and it is characterized by elevated stripping of ammonia. For these reasons, best operative practices have to be performed for the optimization of the removals and for the energy savings when, as in this case, the biological process is applied. First of all, the increment of the soluble free ammonia (up to NH_3 of 13.9 mg/L) coupled with the dissolved oxygen limiting conditions (<1 mg/L) caused the inhibition effect of the nitrite oxidizing bacteria. Therefore the kinetic of the nitrogen removal is developed via nitrite up to 0.160 kgNH_4-N/kgMLVSS/d. The nitritation process permitted to treat a specific nitrogen load up to 0.8 kgTN/m^3/d. Moreover, the installation of elastomeric polyethylene diffusers determined an increment both of 53 % for the standard oxygen transfer rate (%) and of 40 % for the standard aeration efficiency (kgO_2/kWh). The kinetic improvement together with the optimized aeration permitted to transform from 950±323 mgNH_4-N/l in the influent to 29± 20 mgNH_4-N/l in the effluent. The specific biological energy consumption was 2 kWh/m^3 with a global energy saving of 50 %. In terms of the gases emission, the ammonia stripping phenomenon was quantified. The NH_4-N load in the air resulted negligible and equal to 0.006 % of the total ammonia nitrified load. The increment of the removed nitrogen load in the liquid phase reduced the stripped ammonia amount.

1. Introduction

In the European countries in 2010 the municipal waste generated for capita was 500 kg/person/y almost similar with the data registered in 2001 (520 kg/person/y) (European Environmental Agency, 2013). Moreover, the final destination of these wastes (expressed as percentages discharged in landfill, send to the incineration or recycled) remained almost similar during these ten years (Eurostat, 2012). In this scenario the landfill leachate generated by rainfall permeation and waste degradation from the urban landfill sites is a serious threat to the environment. Even though compositions and concentrations of landfill leachate vary depending on the kind of waste received, landfill age, location and climate, operation technology, there are some common features of municipal landfill leachate. The main similar parameters are the high ammonium concentration, the low bioavailable carbon (for old landfill leachate), the heavy metals and the inorganic salts (Eusebi et al., 2011). All these aspects are considered the primary reasons for causing a low efficiency in the biological treatment of landfill leachate. In fact, the treatment of the high influent level of total nitrogen, mainly composed by ammonia (400-1000 mgNH_4-N/L), defines the necessity of high requesting of oxygen transfer, of minimization of the stripping phenomena and of optimization of the aeration efficiency. Finally, the energy

Please cite this article as: Eusebi A.L., Romero P., Battistoni P., 2015, Best operative practices for the management of full scale biological reactor for the not hazardous landfill leachate treatment, Chemical Engineering Transactions, 43, 1885-1890 DOI: 10.3303/CET1543315

consumption has to be reduced. In these directions, the complete removal of nitrogen could be achieved preventing the complete oxidation of ammonium and retaining the reaction into nitrite formation (Frison et al., 2013). This paper reports the results in the full scale biological reactor for the treatment of landfill leachate where, after the optimization of the aeration system, a continuous process characterized by oxic and anoxic phases via nitrite was applied. Moreover, the ammonia gas was controlled to avoid the stripping phenomena. Finally, the energy savings were presented.

2. Material and Methods

2.1 The full scale platform

The full scale platform for the treatment of industrial liquid wastes has a maximum capacity of 350 m^3/d, manly composed by landfill leachate (81 % in 2012) and liquid wastes from urban origin (8 % in 2012). The wastes, after the discharge, are screened and gritted. Later, the flow is submitted to the chemical coagulation and flocculation unit. The effluent is equalized and fed to the biological process. The biological reactor (1000 m^3) is dimensioned with an high HRT (3 d). The original air diffusers are in rigid polyethylene with average pore size of 0.5 mm (D1). Moreover, the ultrafiltration membranes are coupled with the biological system with the optional use both as membrane biological reactor (MBR) and as tertiary treatment (TT) after the secondary clarifier. The final effluent is discharged in the headworks of the main municipal wastewater treatment plant (WWTP) (80,000 PE). The chemical and physical characterization of the flows is measured with daily averaged samples once a week according to the Standard Methods (APHA, 2005) for 100 days . Specifically, the standard 4500-NH3 C and 4500-NO2 C methods were used respectively for the determination of the ammonia and the nitrites. In the final 20 days external carbon source (Methanol solution 300,000 mgCOD/L) was added in the biological reactor to increase the COD/TN up to 5.

2.2 The aeration system optimization

For 160 days an experimental pilot plant was submerged in the biological reactor at 2 m of depth to analyse two types (D2 and D3) of diffusers in elastomeric polyethylene, with pore size of 1 mm and different pore extremity (biforcuted for D2 and single for D3). The air diffusers performances were studied measuring the pressure trend at different airflows changing in the range from 2.5 to 5 Nm^3/h per diffuser. At the end of the experimental phase, all the original rigid diffusers (D1), after working for two years, were substituted in the main biological reactor with the elastomeric D2 diffusers (n° 500). The general flow scheme of the full scale and of the pilot plant system is reported in Figure 1. The kla (Real Oxygen Transfer Coefficient), SOTE% (Standard Oxygen Transfer Efficiency) and SAE (Standard Aeration Efficiency) were measured in the full scale before and after the change of the air system.

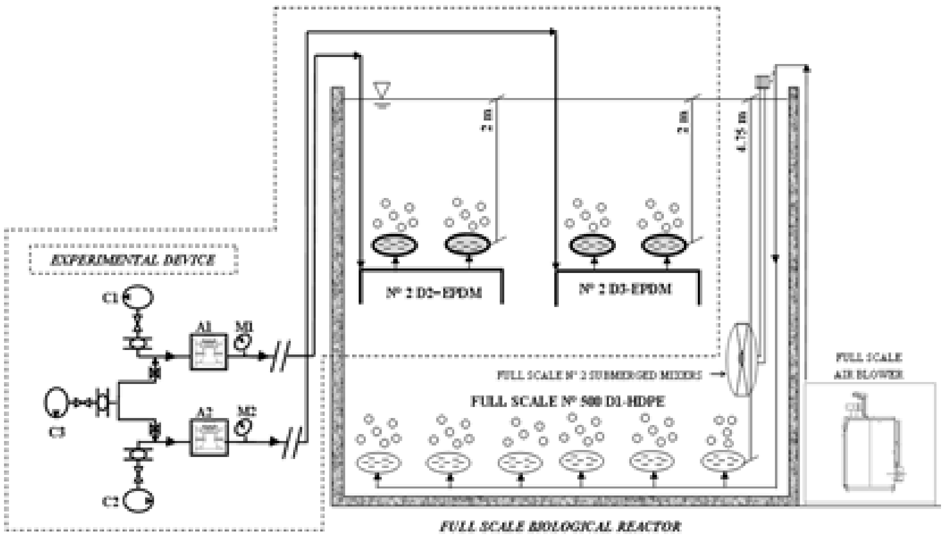

Figure 1. The experimental device applied in the full scale reactor and the full scale configurations. Key: C=experimental air blower, A= experimental air flow meter, M=experimental pressure meter

2.3 The biological process

The biological reactor is characterized by continuous process performed through the alternation of oxic and anoxic phases into the same stirred reactor. The process is automatically controlled on basis of the dissolved oxygen (DO) and the ation reduction potential (ORP) probes. The software, analysing the DO and ORP signals, defines the time lengths and the end-reason of the phases detecting both the achievement of the set point conditions and of the optimal conditions (OCs) (Eusebi et al., 2012). The identification of the OCs individuates the end of the ammonia (nitritation) and the nitrite (denitritation) forms in the liquid phase. The presence of an influent flow characterized by high level of ammonia increments the biological transformation of the total nitrogen via nitrite. In fact, the free ammonia (FA) (Zeng et al., 2009), present in the reactor is a competitive inhibitor of nitrite oxidoreductase activity of the cell membrane of Nitrite Oxidation Bacteria (NOB).The mechanism is enhanced maintaining the dissolved oxygen concentration in the reactor lower than 1mg/L . The presence of biological transformation via nitrite was controlled by the kinetic tests of Ammonia Uptake Rate (AUR). Finally, the ammonia stripping phenomena was evaluated sampling continuously the airflow on the bottom of the reactor and measuring the NH_3 gas concentration.

3. Results and Discussion

3.1 The influent concentration

The chemical and physical characterization of the influent flow is reported in Table 1 showing a complex scenario for the biological treatment applied in the platform. In fact, the average flow rate was 160±41 m^3/d, on the basis of the seasonal period, and the main contribution was represented by the landfill leachate (130±30 m^3/d equal to 81 % of the total amount of liquid wastes). The influent was characterized by pH of 8.4±0.2 favourable to the stripping mechanism during the aerobic phases in the biological reactor. The flow had high total nitrogen concentrations of 1340±393 mgTN/L mainly constituted by ammonia (950±323 mgNH_4-N/L). Moreover, high and variable concentrations of COD were detected (4637±1168 mg/L) determining a low COD/TN equal to 3.7. This ratio imposed limiting conditions during the anoxic transformation of the NO_x-N in nitrogen gas. Moreover, the chlorides salinity of 1561±433 mgCl^-/L could reduce the nitritation activity.

3.2 The aeration system optimization

Considering that the process applied is characterized by oxic and anoxic phases, a possible crystallization on the surface and inside the pores of the diffusers occurs with a net decrement of the quality and quantity of the diffused bubbles (Rosso et al., 2008). For the type of biological technology applied and for the high concentration of alkalinity in the reactor (between 1,800 and 2,900 mg$CaCO_3$/L) the original rigid diffusers (D1) were subjected to precipitation phenomena and after 2 years of work they were completely blocked. For these reasons D2 and D3 diffusers were experimentally tested and the main results are reported in Figure 2.

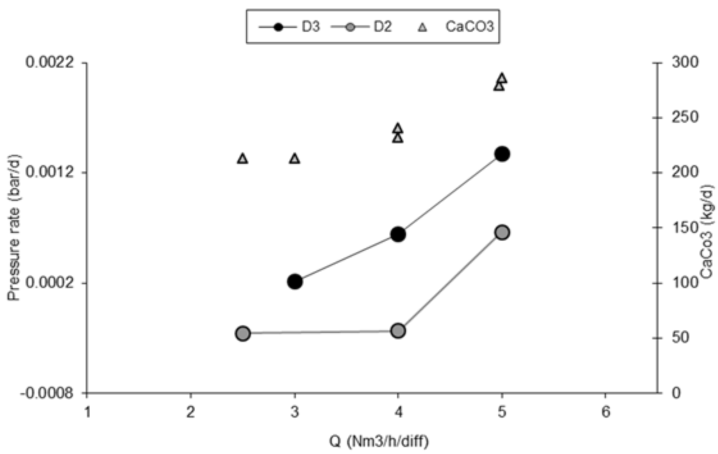

Figure 2. Pressure rate during the tests at different influent air flows and alkalinity influent load

During the tests an increment of the alkalinity load was detected from 212 to 285 kg$CaCO_3$/d. For the D2 diffuser the velocity of the pressure increment were -0.00025 bar/d (2.5 Nm^3/h/diff), -0.00030 bar/d (4 Nm^3/h/diff) and +0.00066 bar/d (5 Nm^3/h/diff). Instead, for the D3 diffuser the velocity of the pressure increment were +0.00021 bar/d (3 Nm^3/h/diff), +0.00065 bar/d (4 Nm^3/h/diff) and +0.00138 bar/d (5 Nm^3/h/diff). The negative or positive values of slopes (-0.00025 bar/d and -0.00030 bar/d for D2 and +0.00021 bar/d for D3) near zero must be considered as almost null rates of pressure increment and are related to the small fluctuation of the hydrostatic pressure (depth of the liquid) during the load of the main full scale reactor. The higher amount of calcium carbonate during the tests at 4 and 5 Nm^3/h/diff defines the main reason of the starting blocking phenomena. The D2 diffuser is not subject to the alkalinity increment effect during the test at 4 Nm^3/h/diff and starts to be affected only at 5 Nm^3/h/diff. The direct application of the data obtained defines the possibility of a pre evaluation of the diffusers behaviour in the time at the alkalinity up to 2900 mg/L. In fact, for a specific flow of 5 Nm^3/h/diff, the prediction of the pressure growth determines that after 100 days the initial pressure increases of 0.138 bar for D3 (+0.00138 bar/d) and of 0.066 bar for D2 (+0.00066 bar/d). An increment of 138 millibar for D3 has to be considered consistent (39 % of the initial pressure) and double compared with the one of D2. In a hypothetical full scale application this high growth suggests the need of more frequent chemical cleanings for D3 than for D2. The results obtained from the experimental phase were used to define the D2 as the optimal diffuser type to leachate treatment. The maintenance of structural original shape is the principal cause of the better aeration performances. For this motive, all the D1 diffusers (N° 500) are changed in the biological reactor with the D2 type. The real parameters expressing the oxygen transfer capacity were measured in the full scale before and after the diffusers substitution. During the D1 operation the k_{La} evaluated was equal to 9.3 h^{-1} at 20 °C with a Standard Oxygen Transfer of 51 kgO_2/h. The test executed in the platform after the D2 installation determines a k_{La} of 7.6 h^{-1} at 20 °C with a Standard Oxygen Transfer of 40 kgO_2/h. The real comparison between the two configurations is possible considering the amount of oxygen transferred on the total input air flow at standard conditions. The SOTE%, in fact, increases from 7.4 % to 16 % at the same hydraulic depth of 4.75 m with an increment of 53 %. This high improvement of oxygen transfer is showed, also, as Standard Aeration Efficiency defining the amount of oxygen transferred for absorbed power supplied. In fact, the SAE evaluated for D1 was 0.8 kgO_2/kWh and increases up to 5.1 kgO_2/kWh after the D2 installation. This important upgrading defines net energy savings in the full scale working conditions.

3.3 The biological process: kinetic results and effluent performances

Since the influent was characterized by high ammonia concentrations coupled with the low performances of the D1 diffusers, a long period of high free ammonia (FA) amount in the reactor was detected (Figure 3). In fact, the FA changes from 3.9 to 13.9 mg/L. These values create the inhibition effect of NOB bacteria starting theoretically to be limited at free ammonia higher than 0.1 mg/L. In fact, at the augmentation of FA the AUR tests show the increase of the nitritation rates from 0.063 to 0.129 kgNH4-N/kgVSS/d. Moreover, the NO2-N amounts, analyzed during the kinetics, define the average percentage of 99.5 of NO2-N recorded on the NOx-N, certifying the total nitrogen transformation via nitrite.

The optimization of the kinetic transformation and of the aeration system permits to increase the treated influent load enhancing the removal performances. In fact, as reported in Figure 3, the influent nitrogen specific load (NLR) changes from 0.260 to 0.826 KgTN/m3/d after the new diffusers installation. The average NLR assured with the kinetic approach via nitrite was 0.515 kgTN/m3/d. The value is extremely higher than the usual NLR applicable for the traditional continuous nitrification and denitrification process (maximum usual value of 0.1 kgTN/m3/d). The choices for the process optimization cause an improvement of the final effluent concentrations (Figure 4). In fact, notwithstanding the net increment of the influent treated load, the effluent nitrogen was equal to 148±78 mgTN/L with 68±37 mgNH4-N/L after the new diffusers application. The average performances were 90±10% for the NH4-N removal compared with the 95±4 % obtained with the old diffusers. The effluent ammonia increment during the 45th and 80th day was related with the optimization of the setting conditions of the inverters of the air blowers. The use of external carbon source, to increment the denitritation performances, determines after the 80-th day the achievement of effluent concentrations of 64±41 mgTN/L and of 29±20 mgNH4-N/L. The specific biological energy consumption was 2 kWh/m^3 with a global energy saving of 50 % compared with the traditional and original configuration.

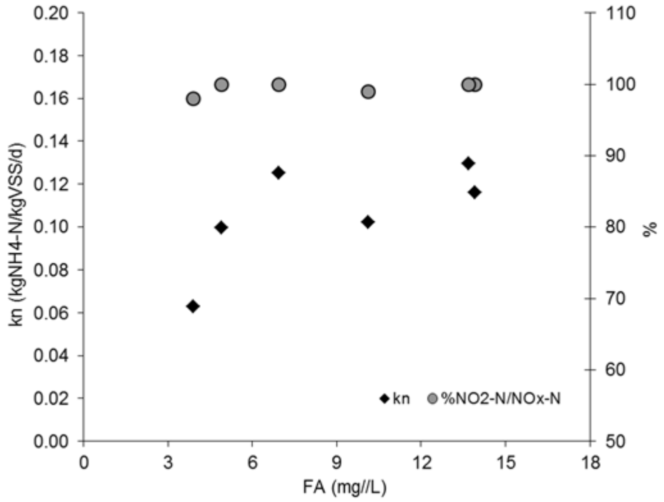

Figure 3 Free ammonia in the reactor and nitritation rates

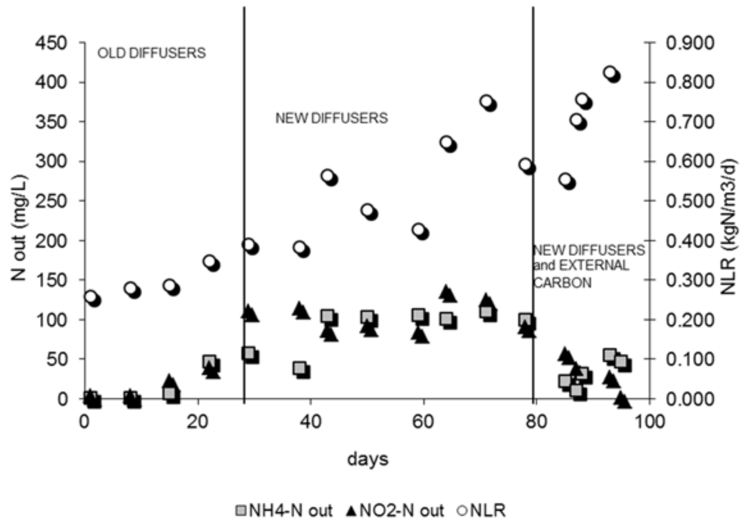

Figure 4. Specific influent nitrogen load and effluent concentrations

Finally, the amount of ammonia stripped in the air was measured to assure that the nitrogen transformation occurs in the liquid phase. The NH_4-N load in the air resulted negligible and equal to 0.0027 % of the total ammonia load (liquid nitrified and gas emitted) (Figure 5). Moreover, decrementing the liquid transformed load from 233 to 160 kg/d the percentages of stripped ammonia increment from 0.0008 to 0.0048%. The increment of the removed nitrogen load in the liquid phase reduced the stripped ammonia amount. Therefore, the control software could predict the ammonia stripping phenomena. In fact, decrementing the percentages of Optimal Conditions automatically detected from 89.7% to 42.3%, the stripped NH_3 on the total liquid nitrified and gas emitted load increments from 0.0008 to 0.0048%. The OCs, automatically measured, can be used to predict the stripping ammonia load.

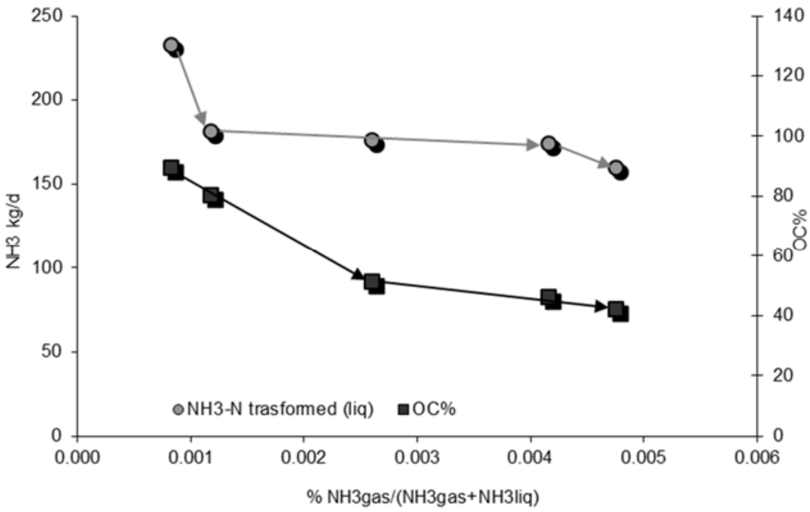

Figure 5. Ammonia transformed in liquid and gas phases and detected Optimal Conditions

4. Conclusions

The treatment of the landfill leachate can be realized using an advanced biological process to minimize the limiting conditions characterizing the influent matrix (nitrogen, alkalinity and salinity concentrations). The application of an alternate oxic and anoxic process can be realized choosing the correct air diffusers type (elastomeric polyethylene) to avoid chemical precipitation and blocking. Moreover, the application of biological transformation via nitrite can be achieved using the high inhibition potentiality of the influent load characterized by high level of free ammonia concentration. The approach permits energy savings with specific biological consumption of 2 kWh/m^3. The high removal performances in the liquid (higher than 90%) minimize the ammonia stripping phenomena with an average percentage of 0.0027% of the total load (gas and liquid phases).

References

APHA, 2005, Standards methods for the examination of water and wastewater, 21th edition, American Public Health Association, Washington D.C., USA.

European Environmental Agency, 2013. Managing municipal solid waste—a review of achievements in 32 European countries, Report No 2/2013, ISSN 1725-9177. – General Report 19 Mar 2013, http://www.eea.europa.eu/publications/managing-municipal-solid-waste

Eurostat, 2012, Guidance on municipal waste data collection – November 2012, WASTE WG 5.2 b(2012), Eurostat – Unit E3 – Environment and forestry http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0CB8QFjAA&url=http%3A%2F%2Fec.europa.eu%2Feurostat%2Fdocuments%2F342366%2F351806%2FMunicipal-waste-statistics-guidance.pdf&ei=YOHIVJ2ALIfxarfkgEg&usg=AFQjCNGuXh3e1ZUfUb50A5SYJg_fsGQOAw&sig2=I0jUA0746AFL_z0nIvjg3A&bvm=bv.84607526,d.d2s

Eusebi, A.L. , Santini, M., De Angelis, A., Battistoni, P., 2011, MBR and alternate cycles processes: Advanced technologies for liquid wastes treatment . Chemical Engineering Transactions, 24, 1057-1062.

Eusebi, A.L., Massi, A., Sablone, E., Santinelli, M., Battistoni, P., 2012. Industrial wastewater platform: upgrading of the biological process and operative configurations for best performances. Water Science Technology, 65(4), 721-727.

Frison, N., Zanetti, L., Katsou, E., Malamis, S., Cecchi, F. and Fatone, F., 2013, Production and use of short chain fatty acids to enhance the via-nitrite biological nutrients removal from anaerobic supernatant, Chemical Engineering Transactions, 32, 157- 162.

Rosso, D., Libra, J.A., Wiehe, W., Stenstrom, M.K., 2008. Membrane properties change in fine pore aeration diffusers: Full-scale variations of transfer efficiency and headloss. Water Research 42, 2640– 2648.

Zeng, Zhang, Li, Peng, Wang, 2009, Control and optimization of nitrifying communities for nitritation from domestic wastewater at room temperatures. Enzyme and Microbial Technology 45, 226–232.