How partial nitrification could improve reclaimed wastewater transport in long pipes

S. Delgado,* M. Álvarez,* L.E. Rodríguez-Gómez,* S. Elmaleh, and E. Aguiar*****

* Department Chemical Engineering. University of La Laguna. Av. Astrof. Fco. Sánchez, S/N. 38200 La Laguna. Spain

** Génie des Procédés-Traitement des Eaux, CC24. Université Montpellier II. 34095 Montpellier Cedex 5. France

*** BALTEN (Tenerife Water and Wastewater Reservoirs Agency). Panama S/N. Pol. Ind. Costa Sur. 38009 Santa Cruz de Tenerife. Spain

Abstract Reclaimed wastewater transport is studied in a concrete-lined cast iron pipe, where a nitrification-denitrification process occurs. The pipe is part of the Reuse System of Reclaimed Wastewater of South Tenerife (Spain), 0.6 m in diameter and 61 km long. In order to improve wastewater quality, at 10 km from the inlet there is injection of fresh water saturated in dissolved oxygen (DO), after which a fast nitrification process usually appears (less than two hours of space time). The amount of oxidized nitrogen compounds produced varies between 0.8 and 4.4 mg/l NO_X^--N. When DO has disappeared, a denitrification process begins. The removal of nitrite is complete at the end of the pipe, whereas the nitrate does not disappear completely, leaving a concentration of about 0.4–0.5 mg/l. For a COD/NO_X^--N ratio higher than 5, a first order nitrification rate in NO_X^--N has resulted, with the constant $k_{20} = 0.079\ h^{-1}$, for a NO_X^--N concentration range of 0.8–4.4 mg/l. Finally the following temperature dependency for the first order denitrification rate constant has been found : $k = k_{20} \cdot 1 \times 15^{T-20}$. Although nitrogen could be used as nutrient in the agricultural reuse, its removal from reclaimed wastewater could be useful in order to diminish the chlorine needs for reclaimed wastewater disinfection.

Keywords Biofilm; denitrification; gravity pipe; nitrification; reclaimed wastewater transportation; reuse

Introduction

The reuse of reclaimed wastewater is usually distant from urban areas where most of it is obtained, as is the case in Tenerife (Spain), so it usually has to be transported through long pipes. When reclaimed wastewater has a high organic load and a space time above 25 hours, chemical and biochemical transformations in reclaimed wastewater may take place, especially in areas with high temperature like the Canary Islands. Under these conditions H_2S build-up is one of the most serious problems which can appear (Delgado *et al.*, 1999).

Sulfide production does not take place if dissolved oxygen (DO) or another more thermodynamically favored electron acceptor, e.g. nitrate are present in water. Hence, the occurrence of a nitrification in the pipe could inhibit the generation of sulfide. Nitrification-denitrification are well known processes, and different types of reactors have been reported in the literature, with suspended and fixed culture. However, denitrification kinetics during reclaimed wastewater transportation has not been studied yet.

Ammonia nitrogen is considered as a pollutant, and normally a reduction in concentration is attempted before its release into the environment. However, when wastewater is destined for agricultural reuse, the nitrogen content can be useful as a nutrient for crops. However, from the point of view of disinfection, the ammonia nitrogen increases the chlorine requirements for disinfection. Hence, the knowledge of nitrogen removal kinetics during wastewater transportation is in this case very important, since nitrification-denitrification processes may produce gas (N_2) which may affects the hydrodynamics of the pipe, the nitrate produced inhibits the sulfide generation (Elmaleh *et al.*, 1998), and the

Water Science and Technology **Vol 43 No10 pp 133–138** © IWA Publishing 2001

removal of ammonia nitrogen could diminish the chlorine needs for reclaimed wastewater disinfection before its agricultural reuse.

The aim of this research is to study the effect of an injection of fresh water saturated in DO in a 61 km long pipe, which transports reclaimed wastewater for agricultural reuse. The study will be focused particularly on the effect that the nitrification-denitrification process has on wastewater transportation, making a study of the denitrification kinetics.

Material and methods

The pipe under study is part of the Reclaimed Wastewater Reuse System of South Tenerife in the Canary Islands, Spain (Delgado *et al.*, 1998, 1999; Elmaleh *et al.*, 1998). The Santa Cruz Wastewater Treatment Plant treats the domestic wastewater from the metropolitan area of the city (350,000 inhabitants). The wastewater treatment includes a pretreatment, a primary treatment and an activated sludge system. The effluent from the treatment plant is transported by gravity to a pumping station, from where it is pumped to a gravity transportation reservoir. From there, a completely filled gravity pipe transports the Reclaimed Wastewater to the south of the island for agricultural reuse (especially banana plantations). The pipe is cast iron with a concrete inside coating, 0.6 m in diameter and 61 km long. It works permanently with an average wastewater flow of 500 m^3/h.

In order to improve wastewater quality (reduction in salinity and organic matter content), and to determine the influence of DO on wastewater behavior during transportation, an injection of fresh water saturated in DO has been made at a distance of 10 km from the inlet of the pipe, with a constant flow of 122 m^3/h. The point of injection is located where anaerobic conditions usually appear and sulfide generation begins.

Both before and after fresh water injection, reclaimed wastewater, fresh water and mixed wastewater (treated + fresh) were sampled at different sites along the pipe. Temperature, DO, pH and ORP were measured *in situ*, and total suspended solids (TSS), total and soluble chemical oxygen demand (COD_t and COD_s), electrical conductivity (EC), NO_3^--N, NO_2^--N, NH_4^+-N, S^{2-} and SO_4^{2-} were measured at the laboratory, all according to Standard Methods (APHA, 1989).

Results and discussion

General aspects

The inside wall of the pipe is covered by a biofilm with a depth of several mm (2–6), which provides a far higher biomass concentration associated with the biofilm than that associated with the suspended solids, which is very low (5–15 mg/l VSS). Hence, processes such as nitrification and denitrification are assumed to take place in the biofilm rather than in the bulk of wastewater. Reclaimed wastewater from Santa Cruz has a high nitrogen concentration (NH_4^+-N > 35 mg/l). Although the EEC guidelines advise keeping the maximum ammonia nitrogen concentration below 20 mg/l (Lefevre *et al.*, 1993), a high content could be of agricultural benefit, but at the same time it would induce a very high chlorine need for disinfection before agricultural reuse.

Due to the presence of DO at two points of the pipe (at the beginning, and at km = 10, point of fresh water injection) a nitrification-denitrification process may take place during reclaimed wastewater transportation. As a consequence of this process a small nitrogen removal may occur. Figure 1 shows one particular experiment where the changes in ammonia nitrogen and oxidized nitrogen compounds during transport are clearly visible. In the initial section of pipe, with aerobic conditions, a nitrification takes place, followed by denitrification once DO has disappeared. Figure 2 shows how at 10 km down the pipe, the added OD saturated fresh water causes a considerable increase in the OD concentration. Once again, in this case a nitrification process is followed by denitrification. The removal of nitrite is total at the end of the pipe, while the nitrate does not disappear totally, remaining at a residual concentration of 0.4–0.5 mg/l.

In the initial section of the pipe and in the section immediately after fresh water addition the nitrification process which takes place is very fast (less than 2 hours of space time), so the quantity of oxidized nitrogen compounds produced is relatively small (0.8–4.4 mg/l NO_X^--N). This means that, in some cases, a reduction of 10% of ammonia removal can be achieved with the nitrification-denitrification process. The appearance of the oxidized nitrogen compounds has a direct effect on the appearance of anaerobic conditions. Although the concentration in oxidized nitrogen compounds were quite low (<5 mg/l NO_X^--N), they inhibited sulfide production (Figure 3). It can be seen how the sulfide generation begins only after the oxidized nitrogen compounds have disappeared. NO_X^--N concentration above which sulfide generation was inhibited was 1 mg/l.

Denitrification kinetics

Denitrification process depends fundamentally on these factors: the ratio COD/NO_X^--N, organic matter concentration, oxidized nitrogen compounds concentration, temperature and presence of inhibitors (nitrous acid). According to Abeling and Seyfried (1992), a relationship between denitrification and COD/NO_X^--N exists (Lyngaard and Balmér, 1992). The higher the ratio COD/NO_X^--N, the greater is the denitrification. Indeed, as concluded by Çeçen and Gönenç (1994) a COD/NO_X^--N ratio higher than 5 implies that organic matter is in excess with respect to the oxidized nitrogen compounds, and that denitrification will be practically complete. This ratio in the system under study has been much higher than

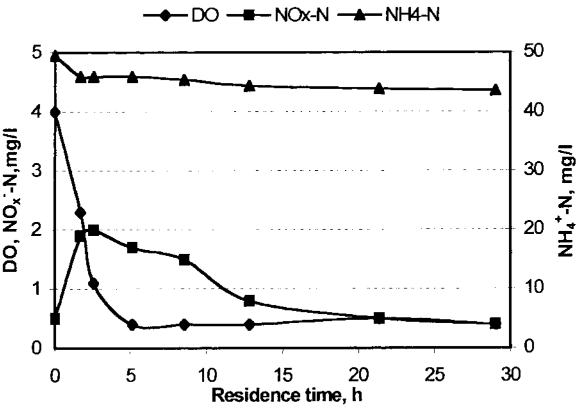

Figure 1 DO, No_X^--N and NH_4^+-N variation along the pipe

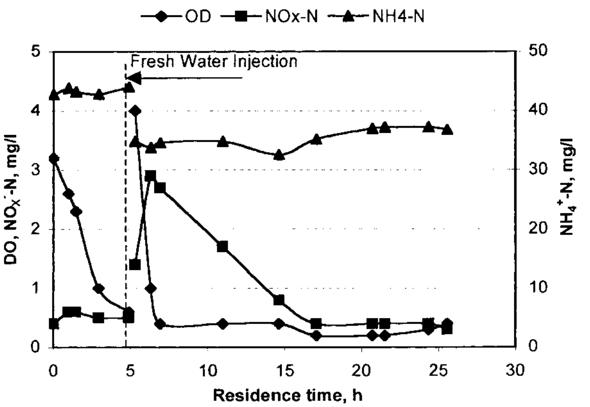

Figure 2 DO, No_X^--N and NH_4^+-N variation along the pipe (injection of fresh water)

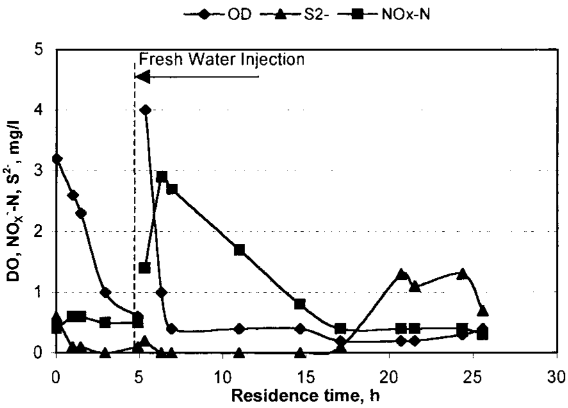

Figure 3 DO, No_X^--N and S^{2-} variation along the pipe (injection of fresh water)

5 in all cases but one. Taking biofilm kinetics into account, the denitrification rate will be first, half and zero order depending on the biofilm characteristics and concentration of limiting reagent (Harremoës, 1975; Henze *et al.*, 1995).

Supposing an first order denitrification rate, $\ln[(NO_X^-\text{-N})/(NO_X^-\text{-N})_i]$ was plotted as a function of the residence time for the different experiments. The points fall in a fairly straight line (Figure 4), with first order rate constants in the range of 0.07–0.34 h^{-1}. According to Çeçen and Gönenç (1994), at NO_X^--N concentrations over 1 mg/l the reaction order is 0.5 and below 1 mg/l it is first order. Given that the range of oxidized nitrogen compounds for which a first order kinetics has resulted is 0.8–4.4 mg/l, it is seen that here a first reaction order has been obtained, where Çeçen and Gönenç (1994) obtained half order.

It must be remembered that the experiments by Çeçen and Gönenç (1994) were done in an upflow submerged filters system, which is very different from the transport pipe studied here, especially in terms of the biofilm (thickness, age, density, etc.). Due to the importance of thickness of biological film in the transition between the reaction orders in denitrification carried out in the biofilm, it is not surprising that a first order of reaction has been obtained at relatively high NO_X^--N concentrations (> 1 mg/l).

Having different first order rate constants in the range of 20–26ºC, a temperature dependency for the denitrification rate constant was assumed:

$$k = k_{20} \cdot F^{T-20}$$

where: k = denitrification rate constant at any temperature
k_{20} = denitrification rate at 20ºC
F = temperature factor.

In Figure 5, $\ln(k)$ versus T-20 has been plotted. The denitrification constant at 20ºC, k_{20}, obtained was 0.079 h^{-1}. The temperature factor obtained was 1.15, which is slightly higher than those proposed in the bibliography, which are in the range 1.03–1.1 (Harremoës and Reimer, 1977; Henze *et al.*, 1995). However, since the system is full scale, and thus it is difficult to control the operation variables, and also the temperature range is short (6ºC), the temperature dependence obtained may be considered acceptable for a treated wastewater transport system. The expression for the temperature dependency is:

$$k = 0.079 \times 1.15^{T-20}$$

The injection of fresh water saturated in DO in the reclaimed wastewater transport pipe

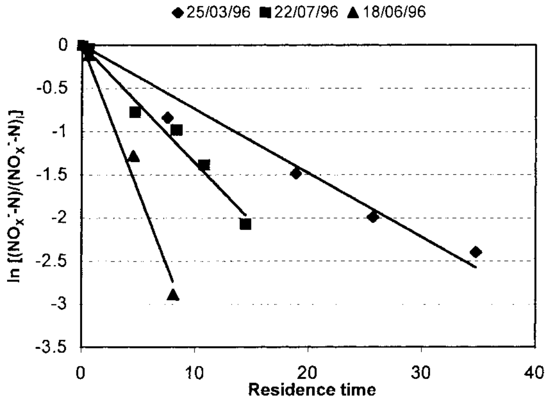

Figure 4 Ln [$(No_X^{-}$-N)/$(No_X^{-}$-N)$_i$]vs residence time in three different experiments

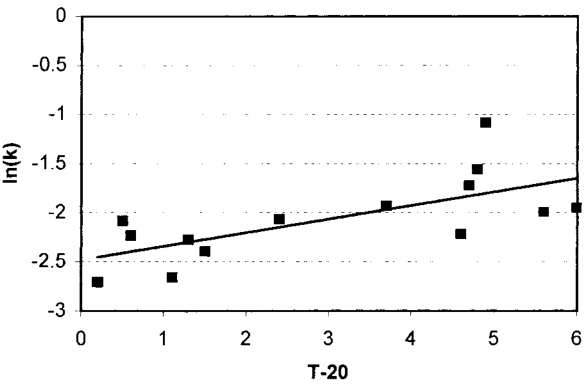

Figure 5 Ln(k) vs T-20

has been succesful in order to inhibit sulfide generation, and in general, in order to improve the quality of wastewater during transportation and before its reuse. When reclaimed wastewater must be transported through long pipes, the ideal form for nitrogen to exist is as oxidized nitrogen compounds (NO_X^{-}-N), in order to inhibit the appearance of anaerobic conditions, and the subsequent sulfide generation. According to this, a nitrification process in the wastewater treatment plant of Santa Cruz could result in a benefit for the maintenance of the transportation pipe, inhibiting the sulfide generation, and diminishing the chlorine requirement for the disinfection of the reclaimed wastewater before its agricultural reuse.

Conclusions

- The injection of fresh water saturated in DO improves reclaimed wastewater quality during transportation (reduction in salinity and organic matter content). The DO injected with the fresh water provokes a nitrification-denitrification process. The appearance of oxidized nitrogen compounds inhibits the generation of sulfide, and the reduction in ammonia nitrogen content results in a lesser chlorine requirement for disinfection.
- The nitrification process occurs very fast (less than two hours of space time), and the amount of oxidized nitrogen compounds produced varies between 0.8 and 4.4 mg/l NO_X^{-}-N The removal of nitrite is complete at the end of the pipe, whereas the nitrate does not disappear completely, remaining a concentration of about 0.4–0.5 mg/l.
- For a COD_t/NO_X^{-}-N ratio > 5, which implies that denitrification is limited by the oxidized nitrogen compounds, a first order nitrification rate in NO_X^{-}-N has resulted, with the constant $k_{20} = 0.079\ h^{-1}$ for a NO_X^{-}-N concentration range of 0.8–4.4 mg/l.

- The temperature dependency for the first order denitrification rate constant has been found to be: $k = k_{20} \times 1.15^{T-20}$

Acknowledgements

This work was funded by an agreement between BALTEN and the Dpt. of Chemical Engineering of the University of La Laguna. Financial support has also been provided by the Water Council of Tenerife and the Finance and Taxation Department of the Autonomous Government of the Canary Islands, along with a grant from the Education Department of the same body. As well, we would like to express our gratitude to the Canarian Water Center Foundation (CCA) for its help.

Nomenclature

COD_s = soluble chemical oxygen demand, mg/l

COD_t = total chemical oxygen demand, mg/l

DO = dissolved oxygen, mg/l

EC = electrical conductivity, μS/cm

F = temperature factor

k = denitrification rate constant

NH_4^+-N= ammonia nitrogen, mg/l

NO_2^--N = nitrite nitrogen, mg/l

NO_3^--N = nitrate nitrogen, mg/l

NO_X^--N= oxidized nitrogen compounds (nitrite and nitrate nitrogen), mg/l

ORP = oxidation-reduction potential, mV

TOC = total organic carbon, mg/l

TSS = total suspended solids, mg/l

VSS = volatile suspended solids, mg/l

References

Abeling, U. and Seyfried, C.F. (1992). Anaerobic-aerobic Treatment of High-Strength Ammonium Wastewater – Nitrogen Removal Via Nitrite. *Wat. Sci. Tech.*, **26**(5–6), 1007–1015.

APHA (1989). *Standard Methods for the Examination of Water and Wastewater*, 17th edition. American Public Health Association, Washington, D.C.

Çeçen, F. and Gönenç, I.E. (1994). Nitrogen Removal Characteristics of Nitrification and Denitrification Filters. *Wat. Sci. Tech.*, **29**(10–11), 409–416.

Delgado, S., Alvarez, M, Aguiar, E. and Rodríguez-Gómez, L.E. (1998). Effect of Dissolved Oxygen in Reclaimed Wastewater Transformation during Transportation. Case Study: Tenerife, Spain. *Wat. Sci. Tech.*, **37**(1), 123–130.

Delgado, S., Alvarez, M., Rodríguez-Gómez, L.E and Aguiar, E. H_2S Generation in a Reclaimed Urban Wastewater Pipe. Case Study: Tenerife (Spain). *Wat. Res.* **33**, 539–547, 1999.

Elmaleh, S., Delgado, S., Alvarez, M., Rodríguez-Gómez, L.E and Aguiar, E. (1998) Septicity and H_2S Build-up in a Reclaimed Wastewater Pipe. *AWT98, 2nd IAWQ International Conference on Advanced Wastewater Treatment, Recycling and Reuse*, Milan.

Elmaleh, S., Delgado, S., Alvarez, M., Rodríguez-Gómez, L.E. and Aguiar, E. Forecasting of H_2S Build-up in a Reclaimed Wastewater Pipe. *Wat. Sci. Tech*. **38**, 241–248, 1998.

Harremoës, P. and Riemer, M. (1975). Report on Pilot Scale Experiments on Down-Flow Filter Denitrification. Rep. 75–1, Department of Sanitary Engineering, Technical University of Denmark.

Harremoës, P. and Reimer, M. (1977). Pilot-Scale Experiments on Down-Flow Filter Denitrification. *Prog. Wat. Tech.*, **8**(4/5), 557–576.

Henze, M., Harremoës, P., la Cour Jansen, J. and Arvin, E. (1995). *Wastewater Treatment. Biological and Chemical Processes*. Springer-Verlag.

Janning, K.F., Harremoës, P. and Nielsen, M. (1995). Evaluating and Modelling the Kinetics in a Full Scale Submerged Denitrification Filter. *Wat. Sci. Tech.*, **32**(8), 115–123.

Lefevre, F., Audic, J.M. and Bujon, B. (1993). Automatic Regulation of Activated Sludge Aeration – Single – Tank Nitrification – Denitrification. *Wat. Sci. Tech.*, **28**(10), 289–298.

Lyngaard, A. and Balmér, P. (1992). Denitrification in a non-Nitrifying Activated Sludge System. *Wat. Sci. Tech.*, **26**(5–6), 1097–1104.