CHEMICAL ENGINEERING TRANSACTIONS
VOL. 34, 2013
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at: www.aidic.it/cet
Guest Editors: Neven Duić, Petar Sabev Varbanov

ISBN 978-88-95608-25-9; **ISSN** 1974-9791
DOI: 10.3303/CET1334012

Improvement of Nitrogen Removal in a Large Municipal Wastewater Plant

Deborah Panepinto*, Giuseppe Genon, Andrea Borsarelli

Politecnico di Torino, DIATI, Corso Duca degli Abruzzi, 24 – 10129 Torino (Italy)
deborah.panepinto@polito.it

The wastewater treatment plant utilized in the metropolitan area of Turin is connected to the Po river near the town, in an area that has been considered very critical for potential eutrophication phenomena. This fact led to the requirement of very high nitrogen removal performances for the plant; with this purpose an examination of water treatment line and sludge system has been performed, in order to identify potential interventions suitable to obtain the required improvement. First of all an analytical screening of the nitrogen concentrations in different flows interesting the plant was performed. The experimental results have been used to construct a nitrogen mass balance in the plant and to identify the removal capacities that the treatments operating in the system are able to realize.
On the basis of the performed observations, two fundamental technological solutions in order to improve the nitrogen removal have been identified. The first one, to be realized on the waste water treatment system, doesn't require plant innovations, but only interventions on the biological treatment tanks. The second technological solution, necessarily connected with a plant innovation, consists in the realization of a system of autotrophic anoxic removal of nitrogen operating on the internal recycle, with the adoption of a fixed specialized biomass bioreactor operating on the recycle flux that is very rich in ammonia nitrogen, and poor in organic carbon. The two solutions are discussed and compared, with reference to operations and performances.

1. Introduction

In the actual regulation that is fixed from the Framework Directive of 2000 (Directive 2000/60/EC) for the surface river waters in Europe, it is required for them to arrive to the definition of good by the year 2016; in particulate to this aim it is established the need of intervention on the water bodies that are present in the areas where an eutrophication risk is operating or in the basins that are feeding these areas, by limiting the immission of phosphorus and nitrogen able to contribute to an eutrophication condition. As a consequence of this fact, the national law (D.Lgs. 152/2006) fixed for the treated wastewaters coming from urban sewers some limits for nitrogen and phosphorus concentrations (N ≤10 mg/L, P ≤1 mg/L), and minimum removal capacities (N = 70 – 80 %, P = 80 %). If we analyze these limits in comparison with the actual quality levels of discharges from municipal wastewater treatment plants and the technology that for this operation can be implemented, it is possible to conclude that different difficulty levels can be ascertained. For the nitrogen removal, that may be obtained by biological solutions in consideration of cost and feasibility bounds, the technological difficulty to obtain the required treatment efficiency is very high (Czerwionka et al., 2012); a large experimentation on this subject has been performed, with the aim to improve the conventional performances of the nitro – denitro traditional systems in order to obtain the required results (Ahn, 2006); these experimentations concerned the realisation of more convenient process control conditions in the nitro - denitro scheme (Kim et al., 2004), the implementation of alternate sequential phases of nitrification and de-nitrification in the aerated and anoxic tanks (Bilanovic et al., 1999), the adoption of process for autotrophic removal of nitrogen that is present in the concentrated flux that from the sludge treatment is recycled to the biological oxidation wastewater line (Jetten et al., 2002) and also MBR solutions (Eusebi et al., 2011). A particular case of a meaningful applicative interest in this

Please cite this article as: Panepinto D., Genon G., Borsarelli A., 2013, Improvement of nitrogen removal in a large municipal wastewater plant, Chemical Engineering Transactions, 34, 67-72 DOI:10.3303/CET1334012

sense is connected with the wastewater treatment plant of the metropolitan Turin area (Panepinto and Genon, 2010), and for this case it is considered convenient to verify in the detail the actual situation, to establish the origin of the present critical aspects, to evaluate the intervention possibilities that can be proposed, and to draw from this some perspective indications as concerns the future possibilities. The so presented approach can be by sure considered important as is concerns a very large practical situation in the Italian and European context, but at the same time it is able to represent a methodological verification of development that can be applied also in other similar situations. It is important to consider the innovative and original aspect of this paper, in the framework of the large research development concerning the systems for improvement of nitrogen removal in wastewater treatment plants, as previously indicated.

2. Actual condition of the Turin wastewater treatment plant

The wastewater treatment plant of the city of Turin is operating on the wastes of a metropolitan area of approximately 1,500,000 inhabitants, and to these discharges the pre-treated discharges of a large number of industrial activities are joined; this additional contribution leads more or less to the increase of 100 % of the load that must be treated in comparison with the values of civil wastewaters only. The plant (SMAT, 2012) is operating with the quite traditional scheme and it is formed from the following operations:

- Pre-treatment (seeving, de-silting);
- Primary sedimentation;
- De-nitrification phase (anoxic environment);
- Oxidation and nitrification phase;
- Secondary sedimentation;
- Final sand filtration and eventually disinfection.

For the process control, a sufficient number of meters is used (nitrates and redox potential in anoxic tanks, dissolved oxygen and ammonia in aerated tanks), final sedimentation (control of total suspended solids in the outlet channel). The main point of interest of the present work can be fixed in the actual nitrogen balance, and in the possibility to increase the removal levels; on this point a detailed analysis will be presented in the following chapter. As concerns the inlet nitrogen, it can be characterised from different components as it is indicated in Table 1, and it presents values as it is indicated in Table 2, where the values of total inlet nitrogen of the last three years are reported. From these data, and from the flow-rate values, it can be estimated the total yearly value of the inlet load; a value of approximately 6,500 t/y can be established.

Table 1. Inlet nitrogen

N tot in [mg/L]	NH_4^+ %	NO_2^- %	NO_3^- %
29	82	1	3

Table 2. Values of total inlet nitrogen (t/month)

2009	t	2010	t	2011	t
Jen	679	Jen	560	Jen	619
Feb	577	Feb	612	Feb	551
Mar	619	Mar	658	Mar	574
Apr	492	Apr	560	Apr	555
May	626	May	618	May	566
Jun	551	Jun	475	Jun	494
Jul	466	Jul	494		
Aug	390	Aug	411		
Sep	491	Sep	519		
Oct	487	Oct	557		
Nov	511	Nov	512		
Dec	609	Dec	614		

3. Nitrogen mass balance

In order to perform a correct nitrogen balance, it is required to take into account the fact that at the wastewater treatment plant other concentrated fluxes are fed together with the sewer liquor, and they correspond to:

- Concentrated wastes that are received with trucks, with a potentiality of approximately 50 t/y of nitrogen;

- Concentrated pharmaceutical sludges, with a potentiality of 330 t/y considered in terms of nitrogen;
- An internal nitrogen recycle coming from the sludge treatment and from mechanical de-watering, with a nitrogen value of approximately 460 t/y.

As a whole it can be observed that the indicated concentrated fluxes contribute to an increase in the load of nitrogen that is fed to the biological treatment section, that can be evaluated as 5 – 7 % more or less. As concerns the removal efficiency that is obtained, in Table 3 the results concerning the final discharge are reported, as it was evaluated in the years 2009, 2010, 2011. From these data it can be established that, if we compare the total outlet load with the inlet one, it is possible to arrive to removal efficiencies that are comprised between 70 and 75 %, with values that can be slightly increased if we consider for the efficiency estimation the total entering load, but the level of 80 % that for the plant is required cannot be obtained.

Table 3 Values of total outlet nitrogen (t/month)

2009	t	% removal	2010	t	% removal	2011	t	% removal
Jen	259	62	Jen	158	72	Jen	231	63
Feb	220	62	Feb	172	72	Feb	219	60
Mar	174	72	Mar	193	71	Mar	232	60
Apr	206	58	Apr	169	70	Apr	134	76
May	226	64	May	172	72	May	141	75
Jun	190	65	Jun	174	63	Jun	134	73
Jul	160	66	Jul	115	77			
Aug	149	62	Aug	122	70			
Sep	139	72	Sep	112	78			
Oct	150	69	Oct	158	72			
Nov	144	72	Nov	194	62			
Dec	193	68	Dec	217	65			

As it will be better illustrated in the following, in order to improve the total efficiency two alternatives are possible: they consist in an increase of the removal that can be obtained in wastewater treatment line, otherwise, or together, in the dedicated treatment of the internal nitrogen recycle; with an innovative treatment; In Figure 1 it is indicated, by moving from the actual removal levels of the wastewater line, and by estimating different removal efficiencies for the dedicated treatment for the concentrates, which could be the total removal efficiency that could be obtained. It is possible to observe that removals of the order of 80 % are very difficult also in presence of dedicated treatment for the concentrated fluxes. This treatment can be considered in any case useful.

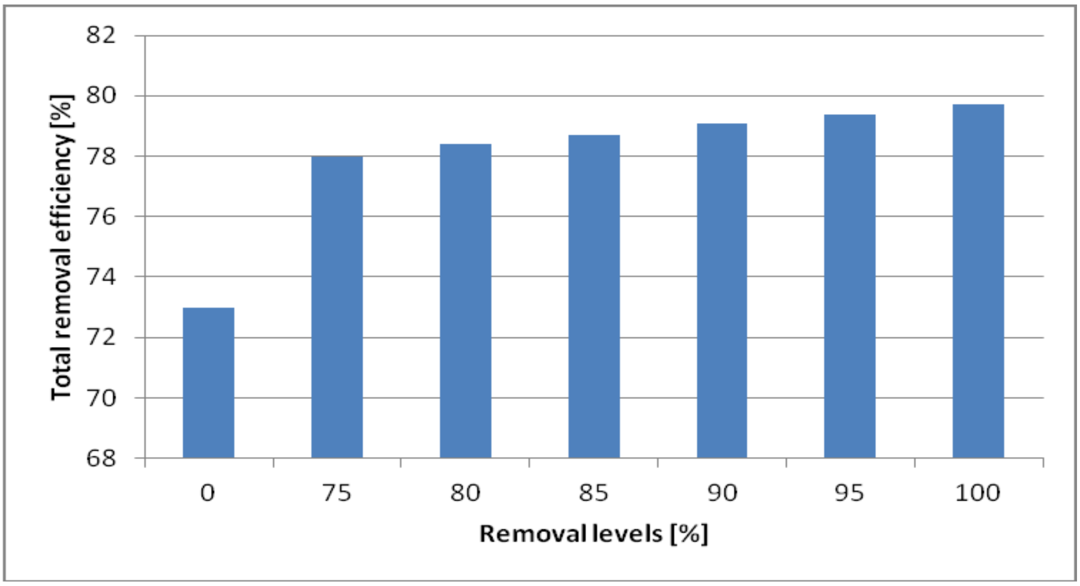

Figure 1: Total plant nitrogen abatement efficiency with different supernatant nitrogen abatement efficiency

4. Possibilities for intervention in the water line

As it was indicated in the previous point, a very important intervention possibility, very useful in order to approach the required removal levels, is linked to an increase in the nitrogen removal in the wastewater biological treatment operation; to this aim different strategies can be individuated, and they correspond to:
a) utilisation of an external carbon source in anoxic phase. This operation from the point of view of the process parameters is possible in account of the fact that the present tank volumes are sufficient; moreover it can be considered convenient in the hypothesis that a total by-pass of the primary sedimentation (with a consequent higher alimentation of carbon in the anoxic zone) cannot be feasible; from the other side the operation presents an important limit in the additional operative cost that is consequent to the use of an external carbon source (methanol probably), and also in the presence of risks deriving from the product manipulation; also a reagent overdosing could be a negative aspect. In any case, on the basis of the quantity of nitrogen that must be removed, of the stoichiometric methanol feed, and also of the estimated cost for methanol, it is possible to arrive to an additional expenditure for the plant of approximately 500,000 €/y, with an effect on the operative cost of nearly 4 %.
b) process automation: to obtain best removal results, it is possible to implement interventions (Won and Ra, 2011) for better regulation and control, in the oxygen introduction on the basis of ammonia measurements (this operation could lead also to an energy saving, by feeding only the strictly required air flow used to oxidise the present ammonia). Also a regulation in the recycle flow-rate of the aerated liquor on the basis of a measure of nitrates can be implemented. It has also be proposed a conduction technology that is based on time – alternating cycles for oxidation and de-nitrification, to be optimised as a sequences schedule on the basis of the field indication of the exhaustion of the different operating phases. More in general it is important to observe that integrated and automatic meter solutions concerning dissolved oxygen, ammonia nitrogen, nitrates, suspended solids and redox potential, if they are correctly calibrated and verified, can lead to synergic effects toward an improvement in the de-nitrification efficiencies and in an efficient energy utilisation. The examined plant must be evaluated in order to establish improvement perspectives: in the different sections there is the presence of meters for redox, ammonia nitrogen, nitrates and dissolved oxygen; for these meters an improvement in the conduction system can be considered.

5. Interventions on the internal recycle

As it was previously indicated, the waters that are deriving from the sludge treatment are particularly rich in ammonia nitrogen, and from the other side quite poor in carbon organic component. On the basis of these characteristics, in consideration of the possibility to feed this concentrated flux to a dedicated treatment system, many technologies have been studied with the purpose to treat this flux: these technologies were firstly operated with pilot experimentation, and afterwards they were translated in full scale applications. The corresponding literature informations are very large with complete reviews (Ahn, 2006) and biological studies (Jetten et al., 2002). The general concept of these systems is to operate in a regime partially or totally autotrophic, by largely reducing or also by eliminating the requirement for external carbon, and by limiting the oxidation need for ammonia nitrogen.
The proposed processes are:

- Processes for nitritation – denitritation (Hellinga et al., 1998);
- Processes for partial nitritation and anaerobic oxidation of ammonia in two following stages (Sharon + Anammox) (Van Hulle et al., 2010);
- Processes for partial nitritation and anaerobic oxidation of the ammonia in a single stage, that are indicated as CANON (Schmidt et al., 2003) or DEMON (Innerebner et al., 2007);
- Processes where a sequence of batch reactors is employed (Fatone et al., 2011).

The development of these processes (laboratory scale plants, semi- industrial pilot scale verifications, implementations in full scale), is able to obtain a short-circuit of the traditional system of nitrification – denitrification. The differences between the different processes can be individuated in the reactor configuration of the process (continuous, batch, suspended or fixed biomass), and in the control parameters. The following Table 4 summarises some of the different technologies that are reported.
By applying these considerations to the SMAT (2012) particular case, it was possible to evaluate the treatment scheme that could be defined; in Table 5 the fundamental characteristics of the plants that should be realised are reported; in this table in particular it is important to note the proposed removal efficiencies, the recommended control parameters, the total cost, and the process characteristics. It is necessary to consider the efficiency that doesn’t seem to be absolutely elevated, the probable complexity

in execution, the important realisation costs; the compactness, the low energetic consumption, the important contribution to the final objective of nitrogen removal can be considered as qualifying aspects.

Table 4. Different technologies

Process	Reactor configuration	Control
CANON – Completely Autotrophic nitrogen removal over nirite	SBR	DO, ammonia, AOB population
	Air pulsing SBR	
	Airlift	
	UASB	
	MBBR	
	MABR	
DEMON - DEamMONification	SBR	Time, pH, DO
	Continues	Time, pH, DO
OLAND-Oxygen-limited autotrophic nitrification and denitrification	RBC	-
	SBR	Time, pH
	SBR, high rate	Time, pH
Aerobic Deammonification	RBC	-
Anitamox	Kaldnes carrier	-
Cleargreen	SBR	-
SNAP Single Stage Nitrogen Removal	+ biomass carrier	HRT, aeration rate, T, pH

Table 5. Fundamental characteristics of the proposed plants

PARAMETER	
Nitrogen load	460 t/y
Reactor Volume	3,000 – 5,000 m^3
Reactor	CSTR/SBR
Abatement efficiency	80 – 85 %
Control	DO, T, NH_4^+, pH, Redox, NO_2^-, NO_3^-
Electrical Power	About 250 kW
Total cost	2 – 2.5 M€

6. Possibilities and final considerations

On the basis of the previously indicated elements, it can be considered as an obtained result the right individuation of the nature and dimensions of the problem actually proposed to the treatment plant of the city of Turin. After the observation that technological solutions exist that are able to reach the required respect of imposed limits, also if with quite high costs and with important plant modifications, it seems to be convenient to underline the necessity to evaluate the following points:

- It is necessary to evaluate, beyond the prescribed respect of the river discharge limits that are imposed, the balance between weights and costs for the interventions and the real benefits that can be obtained in terms of improvement in the quality of the receiving river body;
- It is convenient to evaluate, in a balanced manner or as alternatives, options for improvement of treatment systems for the water line and solutions for innovative treatments on the concentrated flux from the internal recycle; it must be verified the total configuration that is able to arrive to the required treatment levels, with consideration of the optimal solution from the point of view of costs and of management;
- It should be very useful to perform pilot experimentations in order to evaluate the effectiveness of different process and plant configurations;
- At the end of the definition and verification path, it should be very interesting to operate a treatment solution that can be considered as a meaningful example for a problem that is today very largely present in many metropolitan European areas.

References

Ahn Y.H., 2006. Sustainable nitrogen elimination biotechnologies: A review, Process Biochemistry, 41, 1709 – 1721.

Bilanovic D., Battistoni P., Cecchi F., Pavan P., Mata-Alvarez J., 1999. Denitrification under high nitrate concentration and alternating anoxic conditions, Water Research, 33, 3311- 3320.

Czerwionka K., Makinia J., Pajilla K.R., Stensel H.D., 2012. Characteristics and fate of organic nitrogen in municipal nutrient removal wastewater treatment plants, Water Research, 46, 2057 – 2066.

D. Lgs. 3 April 2006 n. 152 “Regulation in environmental field”, published on Gazzetta Ufficiale n. 88, supplemento ordinario n. 96 (in Italian).

Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy, Official Journal L 327, 22/12/2000.

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

Fatone F., Dante M., Nota E., Di Fabio S., Frison N., Pavan P., 2011. Biological short – cut nitrogen removal from anaerobic digestate in a demonstration sequencing batch reactor, Chemical Engineering Transactions, 24, 1135 – 1140.

Hellinga C., Schellen A.A.J.C., Mulder J.W., Van Loosdrecht M.C.M., Heijnen J.J.,1998. The SHARON process: an innovative method for nitrogen removal from ammonium-rich waste water, Water Science and Technology, 37, 135 – 142.

Innerebner G., Insam H., Franke-Whittle I.h., Wett B., 2007. Identification of anammox bacteria in a full scale deammonification plant making use of anaerobic ammonia oxidation, Systematic and Applied Microbiology, 30, 408 – 412.

Jetten M.S.M., Schmid M., Schmidt I., Wubben M., Van Dongen U., Abma W., Sliekers O., Revsbech N.P., Beaumont H.J.E., Ottosen L., Volcke E., Laanbroek H.J., Campos-Gomez J.L., Cole J., Van Loosdrecht M., Mulder J.W., Fuerst J., Richardson D., Van de Pas K., Mendez-Pampin R., Third K., Cirpus I., Van Spanning R., Bollmann A., Nielsen L.P., Op den Camp H., Schultz C., Gundersen J., Vanrolleghem P., Strous M., Wagner M., Kuenen J.G., 2002. Improved nitrogen removal by application of new nitrogen-cycle bacteria, Reviews in Environmental Science and Biotechnology, 1, 51 – 63.

Kim J.H., Chen M., Kishida N., Sudo R., 2004. Integrated real time control strategy for nitrogen removal in swine wastewater treatment using sequencing batch reactors, Water Research, 38, 3340 – 3348.

Panepinto D., Genon G., 2010. Modeling of Po River Water Quality in Torino (Italy), Water Resources Management, 24, 2937 – 2958.

Schmidt I., Sliekers O., Schmid M., Bock E., Fuerst J., Kuenen J.G., Jetten M.S., Strous M., 2003. New concepts of microbial treatment processes for the nitrogen removal in wastewater, FEMS Microbiology Reviews, 27, 481 – 492.

SMAT, 2012 (Società Metropolitana Acque Torino, Turin Metropolitan Water Company) Torino, website: <www.smatorino.it/servizi_idrici_integrati>, accesed 13/02/2012.

Van Hulle S., Vandeweyer H.J.P., Meesschaert B.D., Vanrolleghem P. A., Dejans P., Dumoulin A., 2010, Engineering aspects and practical application of autotrophic nitrogen removal from nitrogen rich streams, Chemical Engineering Journal, 162, 1 – 20.

Won S.G., Ra C.S., 2011, Biological nitrogen removal with a real time control strategy using moving slope changes of pH (mV) and ORP-time profiles, Water Research, 45, 171 – 178.