DESALINATION

Desalination 222 (2008) 222–229

www.elsevier.com/locate/desal

Study of different alternatives of tertiary treatments for wastewater reclamation to optimize the water quality for irrigation reuse

J. Illueca-Muñoz[a], J.A. Mendoza-Roca[a]*, A. Iborra-Clar[a], A. Bes-Piá[a], V. Fajardo-Montañana[b], F.J. Martínez-Francisco[c], I. Bernácer-Bonora[c]

[a]*Department of Chemical and Nuclear Engineering, Polytechnic University of Valencia, Camino de Vera s/n, 46071 Valencia, Spain*
Tel. +34 96 387 96 33; Fax +34 96 387 76 39; email: jamendoz@iqn.upv.es
[b]*Empresa General Valenciana del Agua, Santa Amalia 2, 46009 Valencia, Spain*
[c]*Entidad Pública de Saneamiento de Aguas residuales, Generalitat Valenciana, Álvaro de Bazán 10, entlo, 46010 Valencia, Spain*

Received 20 December 2006; accepted 7 January 2007

Abstract

Due to the water scarcity in Spain and in particular in the Mediterranean areas such as Valencian Region, water authorities have enhanced the wastewater reuse in the municipalities. Different treatments can be applied according to the aim of the wastewater reclamation. In this work different alternatives of tertiary treatment (conventional treatments and one treatment including ultrafiltration) were evaluated using two pilot plants (2 m^3/h of capacity) located in the wastewater treatment plant of Quart-Benager in Valencia. Settling (with and without chemicals addition), conventional sand filtration, UV disinfection and ultrafiltration were the processes included in the different alternatives. Results showed that the most efficient conventional alternative consisting in settling + filtration + UV radiation and the treatment including ultrafiltration eliminated almost the 100% of the total coliforms. However COD removal was very much higher in the alternative including ultrafiltration (60%) in comparison with the other process combinations.

Keywords: Tertiary treatment; Wastewater reclamation; Ultrafiltration

1. Introduction

Due to the water scarcity in Spain and in particular in the Mediterranean areas such as Valencian Region, water authorities have enhanced the wastewater reuse in the municipalities. Water demand will continue to increase and an appropriate management of the water resources is a challenge for the authorities.

*Corresponding author.

Presented at the conference on Desalination and the Environment. Sponsored by the European Desalination Society and Center for Research and Technology Hellas (CERTH), Sani Resort, Halkidiki, Greece, April 22–25, 2007.

doi:10.1016/j.desal.0000.00.000

In order to solve the problem, tertiary treatments are being implemented in conventional wastewater treatment plants (WWTP) after the secondary settling of the activated sludge treatment. The aim is the agricultural use of the reclaimed wastewater.

Processes applied in tertiary treatments can be divided into two groups: treatments that do not remove salts (they hardly affect the wastewater conductivity) and treatments that include salts removal (those including nanofiltration, reverse osmosis or electrodialysis). Conductivity removal is needed when the salt concentration in the reclaimed wastewater could damage the irrigated crop. Concerning this issue some studies have been carried out for selecting the desalination technique and even for selecting the pretreatment [1]. These authors optimized the physical–chemical treatment previous to the RO stage after testing different chemicals and coagulant concentrations. Usually, except from WWTP of coastal areas where infiltration of sea water is produced, salt removal processes are not required as tertiary treatments in Spain. This work focus on the tertiary treatments that do not include salts separations.

The standards required by the local authorities for the reclaimed wastewater are becoming more stringent, although there are globally accepted legal standards neither in Europe nor particularly in Spain.

Processes studied in the bibliography for tertiary treatment include filtration, sedimentation, disinfection and more recently ultrafiltration.

Lubello et al. [2] used a combination of sand filters and peracetic acid and UV disinfection to reuse reclaimed wastewater for nursery ornamental plants. Results indicated that the final water could be used for unrestricted irrigation according the Italy law. Turbidity was reduced from 2.16 to 0.90 NTU (mean values) and total coliforms were not detected in the final water. However the COD increased slightly, due to the peracetic acid addition.

Hamoda et al. [3] studied deeply the combination of sand filtration and chlorination for producing reclaimed wastewater for agricultural uses in three different WWTP in Kuwait. In all cases the mean values of suspended solids (SS), chemical oxygen demand (COD) and total coliforms were lower than 10 mg/L, 50 mg/L and 2 MNP/100 mL. SS and COD mean values of the secondary effluent were 13.9 and 62.5 mg/L, respectively.

Petala et al. [4] evaluated the efficiency of a tertiary treatment consisting in a moving-bed sand filter, a granular activated carbon adsorption bed and ozone disinfection. The sand filter eliminated

Fig. 1. Photograph of the pilot plant A.

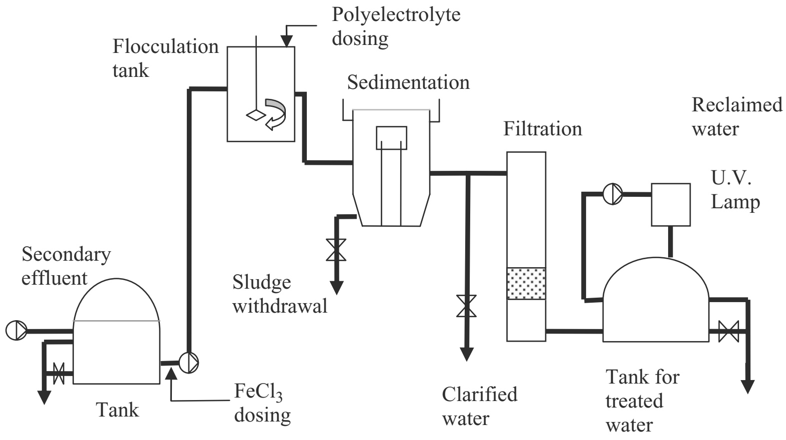

Fig. 2. Scheme of the pilot plant A.

approximately a 45% of the secondary effluent turbidity and the adsorption removed almost the 80% of the total organic carbon. Concerning to the total coliforms, the measured value of this parameter decreased from 93,000 in the secondary effluent to 240 and <2 (total coliforms/100 mL) combining filtration and adsorption with ozone doses of 7.1 and 26.7 mg O_3/L, respectively. However, the high ozone dosing produced an increase in effluent toxicity.

Ultrafiltration has been also studied in the literature to produce water to be reused. Lubello et al. [5] used hollow fiber ultrafiltration membranes and obtained reductions in SS, turbidity and COD of 94.5, 98.7 and 35% respectively. Concerning coliforms removal, no *E. Coli* were detected in the permeates, whereas the total coliforms TC) were 11 TC/100 mL in the worst cases. Côté et al. [6] also evaluated the ultrafiltration process after the conventional activated sludge treatment, concluding that this technique was the best available technology for water reuse.

In the present work, five alternatives of tertiary treatment (four conventional treatments and one

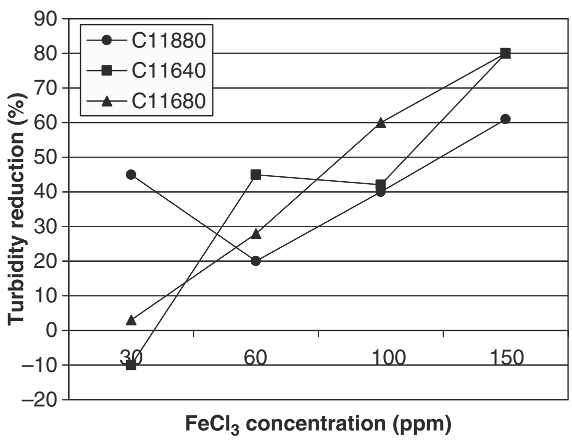

Fig. 3. Jar-test results in terms of turbidity removal for three cationic polyelectrolytes.

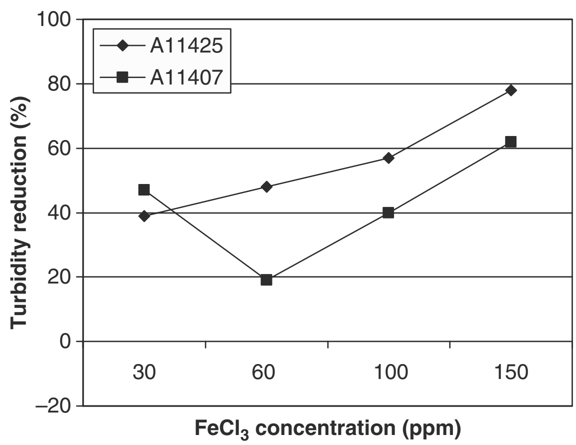

Fig. 4 . Jar-test results in terms of turbidity removal for two anionic polyelectrolytes.

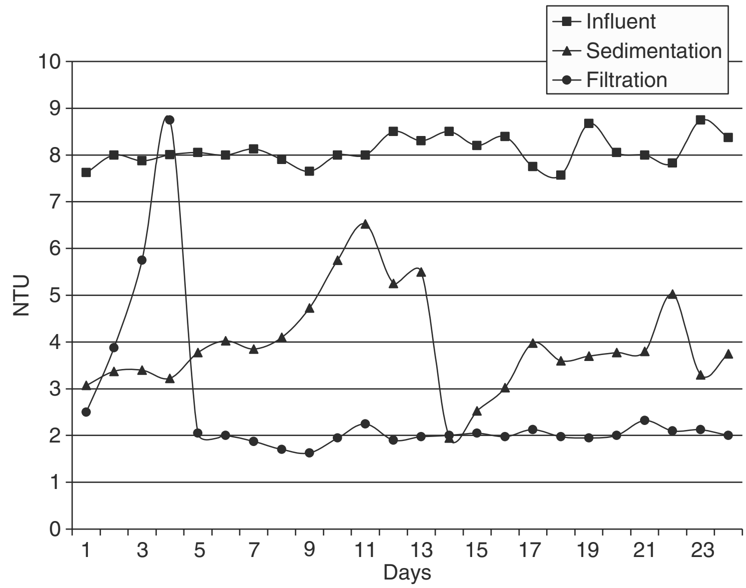

Fig. 5. Turbidity evolution with the time for the samples from influent, after sedimentation and after filtration.

treatment including ultrafiltration) were evaluated using two pilot plants (2 m^3/h of capacity) located in the wastewater treatment plant of Quart-Benager in Valencian Region. Settling (with and without chemicals addition), sand filtration, UV disinfection and ultrafiltration were the processes included in the different alternatives.

2. Material and methods

2.1. Pilot plants

Two pilot plants located at the Quart-Benager WWTP (Valencian Region) were used in order to carry out the experimental work. The tertiary treatment based on sedimentation, filtration and disinfection was tested by means of a 2 m^3/h pilot plant (pilot plant A). Although it includes the whole treatment for a municipal wastewater, only the tertiary treatment was used, pumping the secondary effluent of the WWTP to the tertiary treatment of the pilot plant.

In Fig. 1 a photograph of the pilot plant A can be observed. The tertiary treatment is delimited by the line depicted.

The scheme of the process is illustrated in Fig. 2.

Although the maximal plant capacity was 2 m^3/h, the feed flow rate was maintained at 0.9 m^3/h. The diameter of the sedimentation tank was 76 cm. The filter is characterised by

Table 1
Disinfection efficiency of the UV radiation for the alternative 1

Sample	FC/100 mL before UV radiation	Dose (J/m^2)	SS (mg/L)	FC/100 mL after UV-radiation
1	90,000	16	3	10
2	90,000	16	2	10
3	10,000	15	3	10
4	10,000	15	3	6

Table 2
Treated wastewater characterization after coagulation + flocculation, sedimentation, filtration and UV radiation

Parameter	Mean values
SS (mg/L)	2
Turbidity (NTU)	2.53
pH	7.7
Conductivity (mS/cm)	2.25
FC/100 mL	9
COD (mg/L)	40

a filtration surface of 0.5 m^2 and a 100 cm thick layer of sand of 1 mm of diameter. Concerning the UV disinfection, doses ranging from 9 to 12 mW/m^2 for a maximal flow rate of 10 m^3/h were considered.

Both Ferric chloride and polyelectrolyte were dosed by an electromagnetic pump. Pilot plant B is an ultrafiltration plant equipped with a 5-microns filter as membrane pretreatment and a pressure vessel with a UF spiral wounded membrane provided by PTI Advance Filtration with a MWCO of 10 KDa.

2.2. Coagulant and flocculant selection

Selection of the chemicals and their concentrations used in the alternative including physical–chemical treatment was performed by means of laboratory jar-tests. The coagulant was ferric chloride and the flocculant was chosen among 5 different polyelectrolytes of SIDASA. The general procedure consisted in introducing 1000 mL of wastewater in the jars, adding the coagulant in the selected dose and mixing rapidly (120 rpm) during 5 min. Then, the flocculant was added and the paddles velocity reduced (30 rpm during 15 min). Finally, the paddles were withdrawn so that the particles could settle in Imhoff cones during 30 min. The influence of coagulant and flocculant concentration and type were studied. Wastewater pH was not modified and remained between 7.15 and 7.85 in the experiments.

2.3. Analyses

The parameters analysed were conductivity, pH, COD, turbidity, suspended solids a fecal coliforms. COD was determined with Spectroquant Nova 60 from Merck and turbidity with a turbidimeter HI93761 from HANNA. Both conductivity and pH were measured with CRISON apparatus. Suspended solids and fecal coliforms were analysed according to Standard methods [7].

3. Results

Experiments were performed treating the secondary wastewater in three different alternatives.

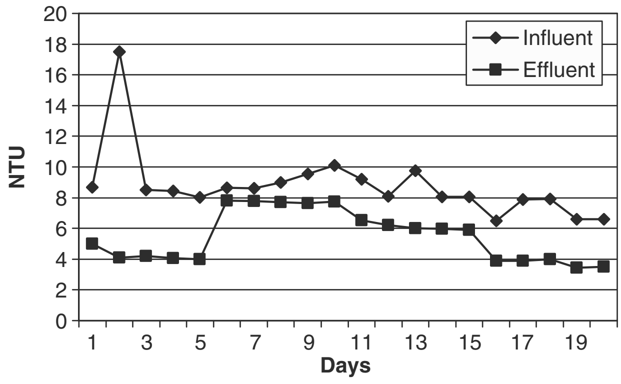

Fig. 6. Turbidity variation for samples of the influent and effluent from tertiary treatment.

Table 3
Treated wastewater characterization after filtration and UV radiation

Sample	FC/100 mL before UV radiation	Dose (J/m^2)	SS (mg/L)	FC/100 mL after UV-radiation
1	110,000	12	4	500
2	110,000	12	5	600
3	70,000	13	4	90
4	70,000	13	6	100
5	70,000	16	5	9
6	70,000	16	6	5

3.1. Alternative 1: Coagulation–flocculation + sedimentation + filtration + UV–radiation

Laboratory jar-tests were performed to select the coagulant concentration and the polyelectrolyte type to add for the starting-up of the pilot plant A.

Figs. 3 and 4 illustrate the turbidity reduction obtained in the jar-tests for different ferric chloride concentrations and cationic and anionic polyelectrolytes, respectively. The polyelectrolyte concentration was 1 mg/L in all cases.

In spite of achieving better turbidity elimination efficiencies, a coagulant concentration of 150 mg/L entailed a high sludge production and a supernatant pH reduction. Thus, the selected ferric chloride concentration was 60 mg/L for starting-up the pilot plant. Coagulant and flocculant concentrations were modified in the plant operation according to the obtained efficiencies.

Fig. 5 shows the turbidity values measured every day in a total time period of 24 days. Measurements correspond to samples of the feed wastewater, of the stream after coagulation – flocculation + sedimentation and of the effluent after filtration. It can be observed an anomalous behaviour of the tertiary treatment in the first four days, especially in the filtration stage. This behaviour can be explained by the fact that the chemicals concentrations determined in the jar-tests were not appropriate for their use in the pilot plant. It was observed that an excessive polyelectrolyte concentration entailed diminution in the filtration efficiency. This is the reason why chemicals doses were changed during these experiments in order to optimize both the sedimentation and filtration. In the last operating days (the highest turbidity removal efficiencies) the coagulant and flocculant concentrations were 0.5 and 20 mg/L, respectively.

Table 1 shows the fecal coliforms (FC) in the secondary effluent and the tertiary treatment for two different UV-radiation doses. It can be observed that a dose of 15 J/m^2 was enough to reduce the fecal coliforms down to 1000 FC/100 mL.

Suspended solids of wastewater samples are included in the table due to the effect of this parameter on the UV-radiation efficiency.

Table 2 summarizes the mean values for the characterization parameters of the treated wastewater. These values correspond to a COD removal efficiency of only 21.5%. However the turbidity and suspended solids eliminations are higher

Table 4
Treated wastewater characterization after filtration and UV radiation

Parameter	Mean value for output water
Suspended solids	5 mg/L
Turbidity	7 NTU
pH	7.7
Conductivity	2.25 mS/cm
FC/100 mL	200
COD	49 mg/L

Table 5
Secondary effluent and UF membrane permeates average characterizations

Parameter	Secondary effluent	UF-permeate
Suspended solids (mg L^{-1})	12	0
Turbidity (NTU)	8.7	0.5
pH	7.6	7.5
Conductivity (mS/cm)	2.25	2.20 mS/cm
FC/100 mL	100,000	0
COD (mg/L)	58	29

Table 6
Comparison of removal efficiencies for the three tested alternatives

	COD (%)	FC/100 mL (%)	Turbidity (%)
Alternative 1	21.5	99.8	82
Alternative 2	≅0	99.8	50
Alternative 3	50	100	94

than 80%. On the other hand, the FC removal reached the 99.8%.

3.2. Alternative 2: Filtration + UV–radiation

The secondary effluent of the WWTP Quart-Benager was pumped directly to the sand filter (sedimentation stage was by-passed).

Fig. 6 shows the turbidity values measured for the secondary and the filtered effluents in the samples collected for 20 days.

It can be seen that between days 6 to 15 the filtration did not work properly because the turbidity reduction is hardly of 25% and turbidity values of the final effluent are very similar to those of the influent. The minimum turbidity values were reached during the last days (<4 NTU). Table 3 shows the fecal coliforms in effluent after the tertiary treatment for 3 different UV-radiation doses. It can be observed that a UV-radiation dose of 16 J/m^2 was necessary so that the fecal coliforms in the final effluent could be lower than 10 FC/100 mL. However, a dose of 12 J/m^2 is enough to reduce the FC value down to 1000 FC/100 mL.

In Table 4 the characterization of the samples (mean values) before and after the tertiary treatment can be observed. By means of this alternative COD was hardly removed and turbidity and suspended solids elimination efficiencies were approximately of 50%. However the FC removal reached the 99.8%.

3.3. Alternative 3: Ultrafiltration

Table 5 shows the mean values of the measured parameter for the secondary effluent and UF membranes permeates. During the 25 days of plant operation no fouling phenomena were observed and the fluxed remained almost constant around 150 L m^{-2} h^{-1}.

It can be observed that UF removed almost totally the wastewater turbidity and it was achieved a 50% of global COD reduction. No fecal coliforms were detected in the UF permeate.

Finally, Table 6 shows a comparison of the three alternatives from the point of view of COD, FC/100 mL and turbidity average removal efficiencies.

The three alternatives are compared in Table 6. Mean percentages are calculated in order to compare the three alternatives studied.

According to the results it is observed that all the alternatives are suitable to reduce the fecal coliforms in the secondary effluent down to the WHO recommendations for agricultural reuse. Concerning the organic matter removal, UF was the technique with a higher performance, though only a removal of 50% was obtained.

4. Conclusions

In order to improve the final quality of the WWTP effluents, tertiary treatments are currently being implemented when wastewater has to be reclaimed. For that different techniques can be used.

It can be concluded that ultrafiltration is the studied process that yields the best quality in the treated wastewater. However its use can be more expensive than the conventional techniques (sedimentation and filtration) if membrane fouling phenomena occur. Then, longer experiments with ultrafiltration should be carried out to study the economical feasibility of the process.

Conventional alternatives yield appropriate fecal coliforms removals to reuse the wastewater in agriculture. This is due to the applied UV radiation (15 J/m^{-2}). However, from the point of view of the suspended solids and COD removal, their efficiencies are lower than those analysed for the UF process. Comparing to coagulation + flocculation + sedimentation + filtration + UV radiation (alternative 1), filtration + UV radiation (alternative 2) removal efficiencies were lower.

However, the coagulants and flocculant costs and the problem in adjusting their concentration that could drive to either a diminution in the final effluent quality or filtration operation problems, makes doubtful the implementation of the physical-chemical treatment previous to the sand filter.

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