MUNICIPAL WASTEWATER REUSE IN AGRICULTURE BY AN INNOVATIVE REACTOR WITH LOW ENVIRONMENTAL IMPACT

REUTILISATION DES EAUX USEES EN AGRICULTURE PAR UN RÉACTEUR INNOVANT AVEC UN FAIBLE IMPACT ENVIRONNEMENTAL

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ABSTRACT

The water availability is becoming limiting in several European Countries. Agriculture represents the main water user therefore the reuse of wastewater in agriculture could provide a valuable increasein freshwater resources for other needs. A plan for an effective wastewater reuse should be based on compact delocalized treatment plants located in the same area where water has to be reused.Sequencing Batch Biofilter Granular Reactor (SBBGR) technology could deal with this requirement.This system is characterized by excellent treatment performances in removing organic pollutants, suspended solids and nitrogen. However these parameter couldn't ensure a safely wastewater reuse because water could still contain microbial pathogens. The aim of this study was to evaluate the effectiveness of raw domestic sewage treatment by SBBGR for agricultural reuse.Particular attention was dedicated to microbiological quality of water monitoring a wide group of microbial indicators (total coliforms, *E. coli,Salmonella*,*C. perfringens*,Somatic coliphages, *G.lamblia* and *C.parvum)*.The possibility of SBBGR enhancement with physical and chemical disinfection processes was also evaluated.

RÉSUMÉ

La disponibilité de l'eau est de plus en plus limitée dans plusieurs pays européens. L'agriculture représentant le principal utilisateur, la réutilisation des eaux usées dans l'agriculture pourrait fournir des ressources supplémentaires en eau douce pour d'autres besoins. Un plan pour une réutilisation efficace des eaux usées devrait se baser sur des usines de traitement compacts et délocalisées, situées dans la zone où l'eau doit être réutilisée. La technologie de Sequencing Batch Biofilter GranularReactor (SBBGR) pourrait faire face à cette exigence. Ce système se caractérise par d'excellentes performances pour l'élimination des polluants organiques, des solides en suspension et de l'azote. Cependant cela pourrait ne pas être suffisant pour assurer une réutilisation des eaux usées en toute sécurité, parce que l'eau pourrait encore contenir des agents pathogènes microbiens. Le but de cette étude est d'évaluer l'efficacité du traitement des eaux usées domestiques brutes par SBBGR pour la réutilisation agricole. Une attention particulière a été consacrée à la qualité microbiologique de l'eau par le suivi d'un large groupe de micro-organismes indicateurs. La possibilité d'améliorer les performances du SBBGR par des processus de désinfection physiques et chimiques a également été évaluée.

Keywords: Wastewater reuse; Disinfection; Pathogen; *Escherichia coli*.

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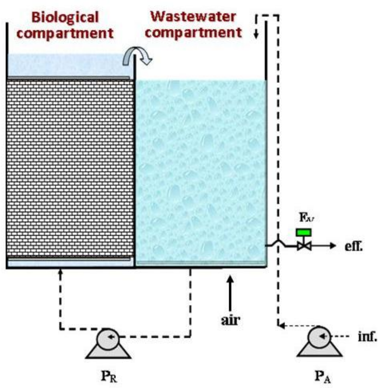
1. Introduction

During the last decades the awareness that high quality water is not unlimited started to arise in both people and government organization.A study by the European Environment Agency (EEA report N.1/2012) reported that about fifty per cent of European Countries are characterized by a water exploitation index (the ratio of annual freshwater abstraction to long-term water availability) higher than 10%. This value indicates that the water availability is becoming a constraint of country development. Moreover the study utilizes average data from each country and it doesn't take care of regional differences, therefore the actual situation is generally worse than that reported. Thus a reduction of water demand or increase of water reuse represent an urgent need and a challenge for the next future. Agriculture accounts from 33% up to 80%of total water use in Europe (EEA report N.1/2012). Therefore the reuse of treated wastewater in agriculture could significantly increasefreshwater resources availability for other needs.To comply the agriculture water demand a reduction of centralization level of the wastewater systems would be required. In fact, delocalized plants are more flexible and can adapt easily to the local conditions. Furthermore, this approach leads to treatment and reuse of water in the same area where it has been consumed. Among the new systems recently proposed that can comply with this request,Sequencing Batch Biofilter Granular Reactor system (SBBGR), developed by the Water Research Institute (IRSA) of the Italian National Research Council (CNR), seems to be somewhat interesting. This system increases the simplification of treatment scheme for treating and reusing municipal wastewater and improves the management of water demand and supply. Indeed SBBGR system is able to carry out the entire wastewater treatment train (i.e., primary, secondary and tertiary treatment) in a single stage with a very low solid residues production. This technology has been already applied for treatment of municipal wastewater with the final aim of treated wastewater discharge in surface water showing excellent treatment performances in removing organic pollutants, suspended solids and nitrogen (Di Iaconi et al. 2014). However these conventional parameter couldn't ensure that the water quality is compatible with a safely agricultural reuse because treated wastewater could still contain pathogens.

The aim of this experimentation was to evaluate the effectiveness of raw domestic sewage treatment by SBBGR for agricultural reuse focusing on some main physical, chemical and microbiological parameters.In particular the microbial indicators were chosen considering that most of the human pathogens that could derive from reuse of wastewater belong to the domains of bacteria, viruses and protozoa and these microorganisms are characterized by different physiological characteristics and consequently different survival rate in wastewater treatment plants. Thus the following microbial indicators were selected: total coliforms, *Escherichia coli* and *Salmonella* (representative of bacteria), *Clostridium perfringens* spores (representative of spore-forming bacteria), Somatic coliphages (representative of viruses) and *Giardia lamblia* and *Cryptosporidium parvum*(representative of protozoa). The possibility of SBBGR enhancement with slow sand filtration and chemical (by adding peracetic acid, PAA) or physical (by UV radiation) disinfection was also evaluated.

2. Materials and methods

2.1 Plant scheme and operation



The SBBGR system operates in discontinuous sequential mode and it is based on a submerged biofilter.The SBBGR plantconsists of a single tank divided into two compartments: biological and wastewater compartment (Figure 1). Biological compartment is the reactive zone as it contains the biomass. The biomass, consisting of a mixture of biofilm and granules, is completely confined in this compartment (thanks to the use of a filling plastic material entrapped between two grids).Wastewater compartment is the zone of the liquid phase; its role is to supply the process air by a diffuser device located in the bottom of the compartment. Biological and wastewater compartments are hydraulically connected by means of a pump which continuously recycles the liquid between them during reaction phase.The SBBGR was provided of a pressure metermeasuring on-line the biofilter head losses due to the biomass growth andcaptured suspended solids occurring in the influent. When a fixedset value of head loss was reached, a washing step was carried out by compressed air. The operation of the SBBGR was based on a succession of treatment cycles (six hours), each consisting of three consecutives phases: filling, reaction and drawing.

Figure 1 - SBBGR sketch. P_R: recirculation pump; P_A: feeding pump; E_v: electric valve for effluent discharge.

The slow sand filter (SSF) received the treated wastewater from the SBBGR. It was constituted of one cylindrical unit partially filled with graveland river sand as follows: 10 cm of gravel on filter bottom, 40 cm of sand, 5 cm of gravel to favor homogenous wastewater diffusion.The filter was washed when the flow rate decreased under 3 L/h.

Tertiary disinfection was performed on the SSF effluent by means of physical (UV radiation) or chemical (peracetic acid, PAA) processes.The UV disinfection was conducted with a low pressure mercury lamp having 40 W power and 254 nm emission peak. The plant effluent flowed through the UV lamp by means of a submerged pump leading to a supply UV dose of 40 mj/cm^2. Chemical disinfection was conducted by adding a commercial PAA solution (15 gPAA/L and 10 gH_2O_2/L, OXIFIBRO, Nuova Farmec, Italy). After PAA addiction the solution was maintained under stirring for 30 minutes and then sampled and stored at 4°C until the microbiological analysis (within 24 h). Considering the high cost of PAA and the increase in COD concentration caused by its addition to the effluent 1 mg/L of PAA was dosed in plant effluent.

2.2 Process performances evaluation

The process performances were evaluated in terms of depuration efficiency (by measuring the main physical and chemical gross parameters) and disinfection efficiency (by measuring the microbial indicators).The physical and chemical parameters were analyzed according to standard methods (APHA, 2005).To better evaluate the suitability of wastewater for agricultural use the Sodium Adsorption Ratio (SAR) in SBBGR influent and effluent was also periodically monitored.The microbial indicators were monitored according to the following procedures: total coliforms and *E. coli* concentrations were determined by using IDEXX Colilert-18 and Quanti-Trays/2000 according to the manufacturer instructions (IDEEX Laboratories, Inc. 2013);somatic coliphages were detected according to method ISO 10705-2:2000;s*almonella* were detected according to method ISO 19250:2010 in 1 L of sample;spores of *C. perfringens* were quantified with a method adapted from ISO 7937:2004;pathogenic protozoan parasites *C. parvum* and *G. lamblia* were detected by US EPA methods 1622 and 1623 respectively.

3. Results and Discussion

The plant operated in stationary condition for more than one year to evaluate its effectiveness in producing an effluent suitable for agricultural reuse. The chemical and physical parameters were monitored only in SBBGR influent (Table 1) and effluent,while the microbiological quality of water was monitored after each treatment (SBBGR, SSF, UV and PAA).

The values of electrical conductivity (EC) and Sodium Adsorption Ratio (SAR) represents two agronomical key parameter. High values of these parameters (EC > 3000 μS/cm; SAR > 10) can cause severe effects on plant growth and soil properties(Rahimi et al 2000). The plant effluent was characterized by values of EC and SAR always lower than 1000 μS/cm and 3 respectively which are compatible with crop irrigation.Other two key parameter to assess the suitability of treated wastewater for agriculture reuse are TSS and COD. High concentration of TSS could cause severe damage to the irrigation network especially in case of use of drip irrigation systems due to clogging of the irrigation tubing system and water diffusers. Similarly presence of biodegradable COD could cause irrigation network clogging due to microbial growth. The plant performed very well in removing both these parameters. The TSS removal efficiency was always higher than 85% (on average 97%) and plant performances were not influenced by the influent TSS values which fluctuated between 92 and 1098 mg/L. The plant successfully removed also COD with an average removal efficiency of 91% and plant performances were not influenced by the variation in the wastewater composition (ranging from 304 up to 1470 mg/L) and the consequent fluctuation in the volumetric organic loading rate applied which reached values as high as 1.8 gCOD/L·d.

Table 1 – Wastewater composition (physical and chemical parameters).

Parameter		Mean value ± SD
Conductivity	Influent [μS/cm]	1223 ± 178
SAR	Influent	2.3 ± 0.5
TSS	Influent [mg/L]	408.9 ± 924.2
COD	Influent [mg/L]	711.7 ± 1,041.5
NH_4^+	Influent [mg/L]	56.0 ± 24.3
TN	Influent [mg/L]	80.9 ± 29.8
P-tot	Influent [mg/L]	11.2 ± 5.4

Regarding to nitrogen, the plant was able to remove about 79% of the influent TN. This result indicates that the plant was able to perform simultaneously the processes of nitrification and denitrification. The plant was particularly efficient in ammonia removal with an efficiency of about 97%. Notably ammonia removal wasn't influenced by the fluctuation of wastewater composition. Differently the presence of residual TN in plant effluent was a consequence of the variable presence of ready biodegradable COD in the fed wastewater which sometimes doesn't allowed the complete removal of NO_x generated during the nitrification process.

Phosphorous was only slight removed from the plant (about 52%), nevertheless it is (like nitrogen)a fundamental nutrient for crops and the presence of some residual phosphorus in the effluent should be considered an added value.The low phosphorus removal is a consequence of the low growing yield of the biomass in the SBBGR which led to a sludge production as low as 0.15 gTSS/gCOD. This value is about five times lower than that one reported for typical depuration processes based on the activated sludge technology. Furthermore, the sludge produced was characterized by a VSS/TSS ration in the range 0.50-0.55 and thus it can be considered already stabilized and then the digestion treatment, usually carried out at conventional wastewater treatment plants, is no longer required.Theselast two findings can be ascribed to the high age of the biomass that can be achieved by SBBGR system thanks to its particular structure (mixture of biofilm and granules packed in the filling material of the reactor). In these conditions, the microorganisms spend much time in the endogenous metabolism phase where the biomass decay rate is high, and thus the biomass production rate is low.

The SBBGR treatment resulted very effective also against the investigated microbial indicators with a removal ranging from 1.02 (for *C. perfringens*) up to 3.14 (for *E. coli*) log units depending on the indicator. Compared to traditional WWTPs theSBBGR treatment resulted particularly efficient for *E. coli* and protozoa removal. Indeed the average SBBGR effluent concentration of *E. coli* was already compatible with agricultural reuse criteria suggested by WHO (<10^3 CFU/100mL) and at least ten times lower than that one characteristic of activates sludge processes (Rossi et al 2007). With regard to protozoa, conventional plants usually remove less than 1 log unit as confirmed in a study by Castro-Hermida et al. 2008 on twelve Spanish municipal WWTPs. Differently SBBGR treatment allowed the removal of 1.65 log units of *G. lamblia* and the complete removal of *C. parvum*. Finally Salmonella was never detected in SBBGR effluent.

Also the sand filter showed good performances in removing all the microbial indicators with a removal ranging from 1.05 and 1.87 log units for *E. coli* and coliphages respectively. Indeed the combined system SBBGR+SSF was so effective that the average *E. coli* effluent concentration was only 62 MPN/100mL thus compatible with water quality requirement for agricultural reuse in Germany (<200 CFU/100mL of *E. coli*).The high efficiency of the combined system observed against protozoa (almost completely removed) and*C. perfringens*is more relevant considering the quitehigh resistanceof these

Table 2 – Concentration of the microbial indicators in the plant influent (raw wastewater) and their removal by each treatment step..

Parameter		Mean value ± SD
Total coliforms	Influent [MPN/100ml]	$1.1 \pm 3.0 \cdot 10^7$
	SBBGR rem. [log n/n_0]	2.44 ± 0.83
	SSF rem. [log n/n_0]	1.36 ± 1.47
	UV rem. [log n/n_0]	1.79 ± 0.41
	PAA rem. [log n/n_0]	2.41 ± 1.06
E. coli	Influent [MPN/100ml]	$1.1 \pm 3.1 \cdot 10^7$
	SBBGR rem. [log n/n_0]	3.14 ± 1.11
	SSF rem. [log n/n_0]	1.05 ± 0.71
	UV rem. [log n/n_0]	1.76 ± 0.29
	PAA rem. [log n/n_0]	2.49 ± 0.35
***C. perfringens* spores**	Influent [CFU/100ml]	$5.6 \pm 5.6 \cdot 10^5$
	SBBGR rem. [log n/n_0]	1.02 ± 0.41
	SSF rem. [log n/n0]	1.57 ± 0.69
	UV rem. [log n/n0]	0.08 ± 0.19
	PAA rem. [log n/n0]	0.05 ± 0.12
Somatic coliphages	Influent [PFU/100ml]	$3.1 \pm 3.4 \cdot 10^5$
	SBBGR rem. [log n/n_0]	1.30 ± 0.10
	SSF rem. [log n/n0]	1.87 ± 0.51
	UV rem. [log n/n0]	1.49 ± 1.18
	PAA rem. [log n/n0]	1.08 ± 0.55
***G. lamblia* cysts**	Influent [PFU/100ml]	$1.9 \pm 1.6 \cdot 10^3$
	SBBGR rem. [log n/n_0]	1.65 ± 1.07
	SSF rem. [log n/n0]	1.81 ± 0.39
***C. parvum* oocysts**	Influent [PFU/100ml]	$6.0 \pm 5.4 \cdot 10^1$
	SBBGR rem. [log n/n_0]	1.98 ± 0.29

microorganisms to both chemical and physical disinfection processes derived from their ability to generate spores (*C. perfringens*) and cysts (protozoa) as reported in literature (Castro-Hermida et al 2008, Cacciò et al. 2003, Gehr et al 2003). Moreover the average coliphages concentration in the effluent, about 300 PFU/100mL, acquire importance on the bases of a study by Gantzer et al. (Gantzer et al. 1998) evaluating the relationship between presence of coliphages and enterovirus (pathogenic for humans) in treated wastewater. In this study enterovirus were never detected in 20 L samples when somatic coliphages concentration was lower than 10^3 PFU/100mL. Therefore enterovirus shouldn't be present in plant effluent.Thus, the integrated plant SBBGR+SSF seems to produce an effluent quality compatible with its safety reuse in agriculture and also complying with several present normatives about wastewater reuse without the addition offurther disinfection treatments.

Both the tested tertiary disinfection strategies resulted effective against total coliforms, *E. coli* and coliphages.In particular, they guaranteed an effluent *E. coli* concentration lower than 10 CFU/100mL thus complying with the extremely strict Italian limit for reuse in agriculture. Notably this results was reached with a PAA dose about five times lower than the typical dosage used in conventional activated sludge process. Differently UV and PAA were completely ineffective for *C. perfringens* removal due to its ability to generate spore.

4. Conclusions

The biological treatment of raw municipal wastewater by SBBGR produced an effluent with properties compatible with its agricultural reuse according to the WHO quality criteria. The integration of SBBGR with SSF further increased microbiological quality of the plant effluent that could comply with more strict agricultural reuse criteria like those ones of Germany or Spain.After treatment with low dosages of UV (40 mj/cm^2) or PAA (1 mg/L) plant effluent could met the Italian requirement for reuse (<10 CFU/100mL of *E. coli*).

5. Acknowledgments

This study is part of the Water4Crops – EU project (Grant Agreement N. 311933), which has been financially supported by the EU Commission within the thematic priority Food, Agriculture and Fisheries, and Biotechnology of the Seventh Framework Programme (FP7-KBBE-2012-6).

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