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Integration of an innovative biological treatment with physical or chemical disinfection for wastewater reuse

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HIGHLIGHTS

- SBBGR system showed high effectiveness in removing TSS, COD and nitrogen.
- Pathogen removal by a compact system may encourage wastewater reuse in agriculture.
- SBBGR system showed disinfection efficiency higher than conventional WWTP.
- *E. coli* content after biological treatment was only 10^3 MPN/100 mL.
- *E. coli* concentration after UV or PAA disinfection was less than 10 MPN/100 mL.

GRAPHICAL ABSTRACT

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ABSTRACT

In the present paper, the effectiveness of a Sequencing Batch Biofilter Granular Reactor (SBBGR) and its integration with different disinfection strategies (UV irradiation, peracetic acid) for producing an effluent suitable for agricultural use was evaluated. The plant treated raw domestic sewage, and its performances were evaluated in terms of the removal efficiency of a wide group of physical, chemical and microbiological parameters. The SBBGR resulted really efficient in removing suspended solids, COD and nitrogen with an average effluent concentration of 5, 32 and 10 mg/L, respectively. Lower removal efficiency was observed for phosphorus with an average concentration in the effluent of 3 mg/L. Plant effluent was also characterized by an average electrical conductivity and sodium adsorption ratio of 680 μS/cm and 2.9, respectively. Therefore, according to these gross parameters, the SBBGR effluent was conformed to the national standards required in Italy for agricultural reuse. Moreover, disinfection performances of the SBBGR was higher than that of conventional municipal wastewater treatment plants and met the quality criteria suggested by WHO (*Escherichia coli* < 1000 CFU/100 mL) for agricultural reuse. In particular, the biological treatment by SBBGR removed 3.8 ± 0.4 log units of *Giardia lamblia*, 2.8 ± 0.8 log units of *E. coli*, 2.5 ± 0.7 log units of total coliforms, 2.0 ± 0.3 log units of *Clostridium perfringens*, 2.0 ± 0.4 log units of *Cryptosporidium parvum* and 1.7 ± 0.7 log units of Somatic coliphages. The investigated disinfection processes (UV and peracetic acid) resulted very effective for total coliforms, *E. coli* and somatic coliphages. In particular, a UV radiation and peracetic acid doses of 40 mJ/cm^2 and 1 mg/L respectively reduced *E. coli* content in the effluent below the limit for agricultural reuse in Italy (10 CFU/100 mL). Conversely, they were both ineffective on *C. perfringens* spores.

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1. Introduction

In past centuries, water was considered as a renewable, unlimited resource. During the last decades, however, the awareness that high quality water is not unlimited has started to arise in both people and government organizations around the world. Moreover, the increase of the word population and occurring climate changes suggest the need for a more rational use of water resources.

A recent study by the European Environment Agency (EEA—European Environment Agency, 2012) evaluated the annual total water withdrawal of European countries with respect to total freshwater resources. The results indicated that, for the year 2010, about 50% of European countries were characterized by a water stress index higher than 10%, indicating that water availability is becoming a constraint for the countries' development. These studies are based on average data coming from each country, and they do not take account of regional differences within each country. Therefore, the local situation could be generally worse than that reported (i.e., based on average values).

Agriculture plays an important role in water consumption, representing the major freshwater use in most countries. It accounts for about 70% of global freshwater withdrawals (Alexandratos and Bruinsma, 2012; Levine and Asano, 2004). According to this, the reuse of treated wastewater in agriculture could provide an effective alternative for meeting agriculture's demand and also increase freshwater resources for other needs. To comply with agricultural water demand, a reduction of the centralization level of wastewater systems would be required. In fact, decentralized plants are more flexible and they might lead to the treatment and reuse of water in the same area where it is consumed.

Among the new systems recently proposed that can comply with this request, the Sequencing Batch Biofilter Granular Reactor (SBBGR), developed by the Water Research Institute (IRSA) of the Italian National Research Council (CNR) during the last decade, seems to be somewhat interesting. SBBGR belongs to attached biomass systems operating in a fill-and-draw mode. Therefore, SBBGR combines the advantages of attached biomass systems (i.e., greater robustness and compactness) with those of periodic systems (i.e., greater flexibility and stability).

Therefore SBBGR system increases the simplification of the treatment scheme for treating and reusing municipal wastewater and improves the management of water demand and supply. Furthermore, it is able to reduce the quantity of sludge usually produced during wastewater treatment, and this represents one of the most concerning issues in non-centralized plants because of the absence of sludge-treatment facilities. SBBGR treatment can also be chemically or physically enhanced when a high effluent quality is needed for agriculture reuse.

The effectiveness of the SBBGR system has already been investigated on different kinds of wastewater (municipal and industrial effluents) with the aim of producing an effluent suitable for direct discharge to the environment. In these applications, the SBBGR system has always shown high and stable removal efficiencies, producing a very low quantity of solid residues (Di Iaconi et al., 2004; Di Iaconi et al., 2010; Di Iaconi et al., 2011; Di Iaconi et al., 2014; Lotito et al., 2012). In the present study, the effectiveness of the SBBGR system for producing an effluent to be reused in agriculture is evaluated. As is known, wastewater reuse in agricultural irrigation poses serious risks to the environment and public health, and, for this reason, specific levels of effluent quality are required. It must be pointed out, however, that, despite the high interest in wastewater reuse, common quality standards for wastewater reuse in agriculture are still missing at the European level. In fact, while several countries have limited the quality criteria to a few main chemical and physical parameters (i.e., COD, suspended solids, total coliforms, faecal coliforms or *Escherichia coli*), there are countries that have adopted more stringent parameters, including emerging pollutants, metals and different kinds of microbial indicators (Brissaud, 2006; Li et al., 2009; Salgot et al., 2006).

In the present study, a larger group of physical, chemical and microbiological parameters was considered for evaluating the effectiveness of the SBBGR system for municipal wastewater treatment and reuse. SBBGR enhancement with chemical (by peracetic acid, PAA) or physical (by UV radiation) disinfection was also evaluated.

The monitored physical and chemical parameters included all those indicated by the Italian regulation (details on Italian limits for wastewater reuse are available as Supplementary material — Table S.1). Differently, the analysis of microbiological parameters was not limited to the two parameters required by this regulation (*E. coli* and *Salmonella*). Indeed, the microbial indicators were chosen considering that most human pathogens that could be derived from the 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 rates in wastewater treatment. Therefore, microorganisms belonging to these domains were selected to evaluate the quality of the treated wastewater. The selected microbial indicators were total coliforms, *E. coli* and *Salmonella* (representative of bacteria), *Clostridium perfringens* spores (representative of spore-forming bacteria), Somatic coliphages (representative of viruses) and *Giardia lamblia* cysts and *Cryptosporidium parvum* oocysts (representative of protozoa).

2. Materials and methods

2.1. Biological treatment

Biological treatment was performed by a laboratory scale SBBGR reactor as shown in Fig. 1. It was based on a cylindrical Plexiglass reactor with a working volume of 21 L filled to 40% with plastic wheel-shaped elements packed between two sieves. The reactor was equipped with a filling pump for feeding the reactor from a wastewater storage tank, an aerator for air supply in the liquid phase over the bed, a recycle pump for allowing (by means of an external loop) the liquid and dissolved oxygen to flow through the reactor bed and a motorized valve for effluent discharge.

The operation of the biological system was automated by a programmable logic controller (PLC) and based on a succession of 8 h treatment

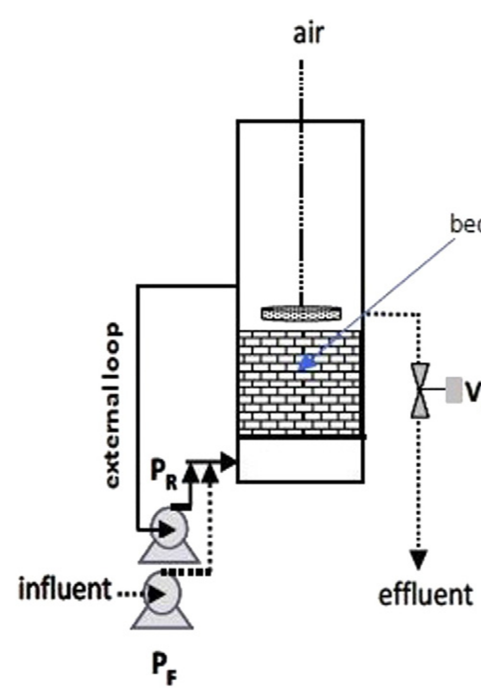

Fig. 1. Sketch of the lab-scale SBBGR system used for biological treatment. P_R: recirculation pump; P_F: feeding pump; V_M: electric valve for effluent discharge.