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Removal of pollutants and pathogens by a simplified treatment scheme for municipal wastewater reuse in agriculture

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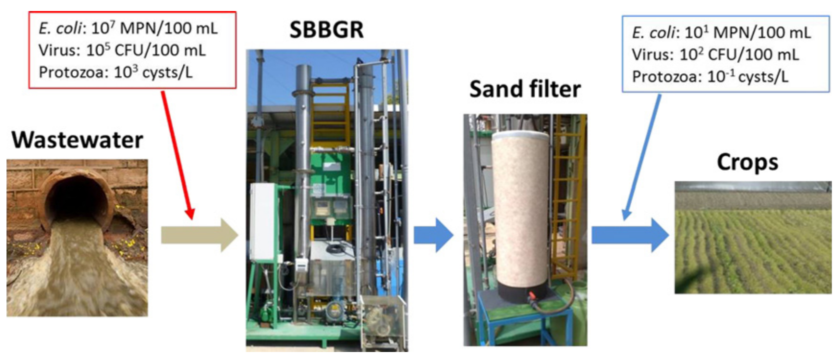
HIGHLIGHTS

- Wastewater reuse in agriculture requires a compact and reliable treatment scheme.
- *E. coli* content after biological treatment was lower than 10^3 MPN/100 mL.
- Protozoa concentration in plant effluent was lower than 1 cysts/L.
- Plant effluent wouldn't need chemical disinfection for its reuse in many countries.

GRAPHICAL ABSTRACT



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ABSTRACT

The availability of high quality water has become a constraint in several countries. Agriculture represents the main water user, therefore, wastewater reuse in this area could increase water availability for other needs. This research was aimed to provide a simplified scheme for treatment and reuse of municipal and domestic wastewater based on Sequencing Batch Biofilter Granular Reactors (SBBGRs). The activity was conducted at pilot-scale and particular attention was dedicated to the microbiological quality of treated wastewater to evaluate the risk associated to its reuse. The following microorganisms were monitored: *Escherichia coli*, *Salmonella*, *Clostridium perfringens*, somatic coliphages, adenovirus, enterovirus, *Giardia lamblia* and *Cryptosporidium parvum*. The possibility of SBBGR enhancement with sand filtration was also evaluated. The SBBGR removed >90% of suspended solids and chemical oxygen demand, and 80% and 60% of total nitrogen and phosphorous, respectively. SBBGR was also effective in removing microbial indicators, from 1 (for *C. perfringens*) up to 4 (for *E. coli*) log units of these microorganisms. In particular, the quality of SBBGR effluent was already compatible with the WHO criteria for reuse (*E. coli* ≤10^3 CFU/100 mL). Sand filtration had positive effects on plant effluent quality and the latter could even comply with more restrictive reuse criteria.

1. Introduction

Climate change, population growth and water scarcity represent major challenges for economies and societies around the world. A

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recent study aimed to assess the impact of climate change on water scarcity (Gosling and Arnell, 2016) highlighted that about 2 billion people are currently living under water scarcity condition in several areas of the world. Considering that >70% of the water withdrawn globally is used for agricultural irrigation (UNESCO – United Nations Educational Scientific and Cultural Organization, 2003), the reuse of reclaimed urban wastewater has received more and more attention in recent years (Levine and Asano, 2004; Pereira et al., 2011).

The use of compact and simple wastewater treatment schemes would facilitate its actual reuse in agriculture. In fact, the treatment plants could be realized nearby of cultivated fields. Thus the treated wastewater would not need to be transported for long distance from big centralized treatment plants. However, reuse needs to be safely implemented to prevent transmission of pathogens and to avoid endangering public health and the environment.

From a technological point of view, a multi barrier treatment scheme, including several steps, has been proposed for protecting public health when reclaimed wastewater effluents are used for irrigation. Such a complex treatment scheme, however, is hardly attainable in small rural communities where compact and simple (short treatment line) plants are required. Furthermore, taking into account the significant fluctuations of wastewater composition and flow rate occurring in small communities, a treatment line ensuring stable performances is also required. A recent system known as Sequencing Batch Biofilter Granular Reactor (SBBGR), developed by the Water Research Institute (IRSA) of the Italian National Research Council (CNR), seems to fulfil these needs. This system is able to carry out the entire wastewater treatment train (i.e., primary, secondary and tertiary treatment) in a single stage with excellent treatment performances in removing organic pollutants, suspended solids and nitrogen and with a very low solid residues production (Di Iaconi et al., 2014). In a recent study carried at laboratory scale, the authors have shown that SBBGR is also able to perform an efficient disinfection action producing an effluent with a quality higher than that of conventional treatment systems based on primary and secondary treatments (De Sanctis et al., 2016). However, SBBGR treatment needed to be chemically or physically enhanced for improving effluent quality and complying with the standards of agriculture reuse in European countries (De Sanctis et al., 2016; Paranychianakis et al., 2015; Sanz and Gawlik, 2014).

The present experimentation was planned on the base of the previous one with the multiple purposes of investigating the effect of the process scale-up and different plant configuration, and overcoming the need for chemical or physical enhancement.

In particular, differently from De Sanctis et al., 2016, a pilot plant was used for this experimentation. Moreover, a new SBBGR design (two-compartment configuration vs single compartment plant used in De Sanctis et al., 2016) is proposed in the present paper treating a raw sewage. This plant configuration was chosen as it reflects that one of a hypothetical full scale plant. Furthermore, in order to avoid the enhancement of SBBGR treatment with chemical (i.e. addition of chlorine, peracetic acid, ozone) or physical (i.e. UV radiation) process, evaluated in De Sanctis et al. (2016), a combination of SBBGR treatment and sand filtration (SF) was assessed. Considering that SF is an easy to handle and cost effective disinfection technique able to reduce up to 1–2 log units of coliforms and viruses (Elliott et al., 2008; Harrison et al., 2000; Schuler et al., 1991), its combination with SBBGR treatment could allow a safe wastewater reuse in absence of conventional tertiary disinfection. This would avoid the release in the environment of hazardous by-products generated during tertiary disinfection (i.e. chlorine addition; Watson et al., 2012). Indeed, a recent study by da Costa et al. (2014) evaluated the effect of tertiary wastewater disinfection on algae, insects, shellfish and fish. The research showed that all the disinfection strategies evaluated (i.e. chlorine, peracetic acid, ozone and UV) increased the toxicity of a WWTP secondary effluent.

Currently a common EU directive on wastewater reuse is still lacking and each country set its own quality parameters considering a number of microbiological and physical-chemical parameters. An overview of the current water quality parameter applied in EU countries is provided in Sanz and Gawlik (2014) and Paranychianakis et al. (2015). *E. coli* is the most common microbiological parameter and its maximum concentration range between 10 and 250 CFU/100 mL for Italy and France respectively, in case of unrestricted agricultural reuse (i.e. irrigation of crops which are eaten uncooked). Referring to the physical-chemical parameters they usually include: total suspended solids (TSS), biochemical oxygen demand (BOD5), chemical oxygen demand (COD), pH, Heavy metals, electrical conductivity (EC), sodium adsorption ration (SAR), chloride, nitrogen, phosphorus and several priority substances. As an illustration the quality limits for wastewater reuse in Italy are detailed as Supplementary material (Table S.1).

The effectiveness of the proposed treatment has been evaluated in terms of some main gross parameters such as TSS, COD, BOD_5, nitrogen, phosphorus, pH, EC, and SAR. Furthermore, from the microbiological point of view, a wide group of pathogens and indicators of faecal contamination were considered including *Escherichia coli* and *Salmonella* (representative of bacteria), *Clostridium perfringens* spores (representative of spore-forming bacteria), somatic coliphages, human enteroviruses and adenoviruses (representative of viruses), *Giardia lamblia* and *Cryptosporidium parvum* (representative of protozoa). In addition to these parameters the other compounds required by Italian regulation (e.g. heavy metals) were analysed during the experimental trial also.

2. Materials and methods

2.1. Pilot plant description

The pilot plant used in the present study consisted of a SBBGR unit followed by a sand filter as shown in Fig. 1. The main feature of SBBGR lies in the complete separation of biomass and wastewater, where the biomass is confined in a dedicated compartment (also known as biofilter) with a volume of about 120 L (diameter: 22 cm; height: 320 cm) and filled with plastic filling material (features: 7 mm high, 11 mm diameter, 650 m^2/m^3 specific area, 0.95 g/cm^3 density, 0.7 bed porosity and 50–80 mm^3 voids dimension) entrapped between two perforated plates.

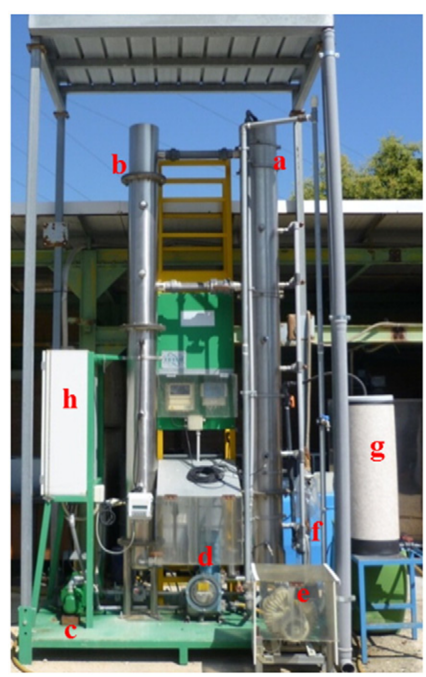

Fig. 1. A photograph of the treatment plant used in the present study. a: aerator; b: biofilter; c: recirculation pump; d: filling pump; e: blower; f: drawing valve; g: sand filter; h: PLC.