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Research article

Optimized MBR for greywater reuse systems in hotel facilities

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ABSTRACT

Greywater is an important alternative water source, particularly in semi-arid, touristic areas, where the biggest water demand is usually in the dry period. By using this source wisely, tourist facilities can substantially reduce the pressure to scarce water resources. In densely urbanized touristic areas, where space has high value, compact solutions such as MBR based greywater reuse systems appear very appropriate. This research focuses on technical and economical evaluation of such solution by implementing a pilot MBR to a hotel with separated grey water. The pilot was operated for 6 months, with thorough characterisation of the GW performed, its operation was monitored and its energy consumption was optimized by applying a control system for the air scour. Based on the pilot operation a design and economic model was set to estimate the feasibility (CAPEX, OPEX, payback period of investment) of appropriate scales of MBR based GW systems, including separation of GW, MBR technology, clean water storage and disinfection. The model takes into account water and energy prices in Spain and a planning period of 20 years. The results demonstrated an excellent performance in terms of effluent quality, while the energy demand for air-scour was reduced by up to 35.2%, compared to the manufacturer recommendations. Economical evaluation of the entire MBR based GW reuse system shows its feasibility for sizes already at 5 m^3/day (60 PE). The payback period of the investment for hotels like the demonstration hotel, treating 30 m^3/day is 3 years.

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1. Introduction

Separating, treating and reusing grey water (water from showers, hand washing basins, laundry and kitchen) not only represents additional (and stable compared to rainfall) water source, but also a way towards sustainable urban water systems (Opher and Friedler, 2016; Li et al., 2009; Pidou et al., 2007). Apart from saving water, it can reduce the load on wastewater (WW) disposal systems, support the cities' green infrastructure and indirectly bring benefits such as amenity, cleaner air, urban agriculture, and if used for heat recovery they contribute to energy demand reduction. Therefore, GW separation and reuse should not only be seen as alternative water source for water deficient areas, but they can trigger more sustainable use of other natural resources as well.

There are several obstacles toward more extensive implementation of GW systems, most important being: gaps in current legislation regarding GW, variable nature of the GW composition which makes the selection of appropriate treatment system more difficult and most importantly costs for separating GW and its treatment, i.e. its feasibility.

From a reuse perspective GW is considered as a WW, thus GW reuse has to comply with WW reuse standards of existing legislation. Globally, a key reference for safe water reuse are the WHO's guidelines with their last edition in 2006 (WHO, 2006). While the guidelines provide a framework for human safety in water reuse practices they are not covering regulatory aspects. ISO standards on the reuse of reclaimed water are under development, following a request from Japan, China and Israel (ISO/TC 282 committee on Water re-use), targeting the standardisation of water re-use of any kind and for any purpose. USA produced national Guidelines for Water Reuse with the last update in 2012 (USEPA, 2012). The guidelines among other cover requirements for treated effluents from WWTP for urban reuse – restricted and unrestricted – including limit values of parameters like TSS, BOD, COD, Turbidity, Bacterial indicators and Pathogens. Australian national guidelines for water reuse (NRMMC-EPHC-AHMC, 2006), advocate a risk management framework based on the WHO guidelines (WHO,

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2006) and also include limit values of pollutants (similarly as in USEPA, 2012) for different treatment processes and on-site controls for designated uses of recycled water. A thorough review and comparison of international and EU policies on water reuse is given in BIO by Deloitte (2015) and Alcalde and Gawlik, (2014). At the EU level there is no legislation for water reuse, although it is (vaguely) encouraged in the Urban Wastewater Directive (91/271/EEC of 21 May 1991), where the level of reuse and development of appropriate standards are left to each member state. Local standards for water reuse are most notably implemented in Cyprus, France, Italy, Greece, Portugal and Spain (Alcalde and Gawlik, 2014). The Spanish legislation (RD 1620/2007) regulates water reuse depending on the final destination of the reclaimed water. It distinguishes between (1) urban uses, (2) agricultural, (3) industrial, (4) residential and (5) environmental, where following parameters are monitored: nematodes, *E. coli*, TSS, Turbidity and other criteria defined for each use.

Variability of GW composition is causing difficulties in the selection of appropriate treatment technologies and reuse systems. Literature reports values of COD between 13 and 550 mg/L, BOD_5 between 90 and 360 mg/L total nitrogen between 0.6 and 74 mg/L and total phosphorous between 4 and 14 mg/L (Eriksson et al., 2002; Jefferson et al., 2004). These variances come from different types of GW and different use of detergents, soaps and other personal care products. With respect to GW biodegradability, some authors find good biodegradability of GW in spite of its variable chemical composition (Nolde, 2005; Bullermann, 2001), whereas others show higher non-biodegradable content than sewage (Jefferson et al., 2004; Metcalf et al., 2004). The most important feature of grey water with regard to biodegradation is its nutrient imbalance. Literature reports COD:N:P ratios, such as 100:20:1 (Metcalf et al., 2004), 250:7:1 (Franta et al., 1994), 100:2.25:0.06, 100:2.91:0.05 and 100:1.77:0.06 for bath, shower and hand basins respectively (Jefferson et al., 2004). Jefferson et al. (2004) indicate that GW is deficient in both nitrogen and phosphorus, which could cause problems for biological treatment processes.

Related to the variable bio-chemical composition of the GW, there is a range of technologies with different requirements and performances that can fit the purpose (Li et al., 2009). The selection depends on the source and amount of GW to be treated, standards that need to be achieved related to the type of its reuse (toilet flushing, irrigation, service water, etc.) and available space to install the technology.

This paper focuses on strongly urbanized touristic city in the Mediterranean, where space has high value, water consumption is highest in the dry period, i.e. in summer due to tourist season and water quality requirements are high. GW systems based on membrane bioreactor (MBR) technology provide a solution known by its small footprint, superior and consistent effluent quality and its robustness to changes in the GW composition at the influent (Winward et al., 2008; Judd, 2010). MBRs are attractive solution for groups of buildings in urban areas achieving satisfactory removal efficiencies of organic substances, surfactants and microbial contaminations without a post filtration and disinfection step (Li et al., 2009).

Applying MBR based GW reuse system is related to relatively high price of the technology and of the GW separation system, i.e. GW piping. The price of the MBR largely depends on the scale of application. Compared to other small scale biological treatment plants MBRs are at the upper edge of the pricing (Fletcher et al., 2007). Recent study of Fountoulakis et al. (2016) confirms the high cost of MBR for single household systems, requiring a water price of at least 10 EUR/m^3 to justify the investment. Taking into account average water prices in Germany, i.e. 1.65 EUR/m^3 for freshwater and 2.36 EUR/m^3 sewage disposal cost, Jabornig (2014) evaluated small scale GW treatment technologies with high quality effluent. According to this research, MBRs of 500 L/day (10 PE) are economically feasible, with a payback time of 15 years. Friedler and Hadari (2006) took into account both, the GW separation system (piping) and the MBR and demonstrated its feasibility for multi storey buildings. In order to be feasible for four storey buildings, small subsidies are needed.

The major cause of high costs of MBRs is membranes fouling, accompanied with higher requirements for aeration and consequently energy demand. More than 50% of the energy consumption in MBRs goes for air scour to prevent the fouling of the membranes. Specific aeration demand (SAD) for membranes varies significantly from one application to another, e.g. 0.63 $m^3/m^2/h$ for a GW MBR pilot of 600 L (Atasoy et al., 2007) or 0.37 $m^3/m^2/h$ for full scale municipal WW plant (Monclús et al., 2015). De Wilde et al. (2008) recommend values between 0.1 and 0.3, which is much lower than the values recommended by manufacturers such as the recommended value of this research that was 0.75.

Ferrero et al. (2011) developed an automatic control algorithm for reducing air scour based on permeability evolution, which was successfully tested at the pilot scale MBR for WW, testing two types of membranes. The system achieved 21% of energy saving with respect to the minimal aeration recommended by the membrane supplier. The system was validated in a full scale MBR achieving similar reduction (Monclús et al., 2015).

The objective of this paper is to show the technical and economic feasibility of optimized MBR based GW reuse system, i.e. GW separation, MBR technology, clean water storage and disinfection, for hotels of various sizes, taking into account reuse conditions and water and energy prices in Spain. To do that, a pilot MBR for GW treatment was implemented to a hotel with separated grey water from showers in order to monitor its operation and optimize its energy consumption by using advanced air scour control system (Ferrero et al., 2011). Experimental data from six months of operation were used to set up a design and economic model and provide which sizes of MBR based GW reuse systems are economically feasible for urbanized touristic areas such as Lloret de Mar (Spain).

2. Materials and methods

2.1. Hotel and pilot MBR

The hotel is a large 3 star resort with 441 air conditioned rooms, green areas and exterior pools, conference rooms, bar and restaurant in the Costa Brava area (Lloret de Mar, NE Spain). In the past the water consumption at the hotel was very high, which triggered measures for water savings. Already in the 1990ies the hotel was advised that the biggest water consumption comes from toilet flushing. To reduce this particular consumption, the hotel separated greywater from rooms' showers and hand-wash basins. This water is gridded, collected in a GW tank and reused for toilet flushing. At the moment the GW is only being disinfected (with HClO, free Cl at around 2 mg/L) prior to its reuse. Today the water consumption of the hotel is on average 128 ± 35 and 67 ± 20 m^3/day in the high and low touristic season respectively. In average the hotel saves 10,000 m^3 of fresh water yearly due to GW reuse. The treatment of the GW, however, appears not always sufficient as there are episodes of odour in summer, which then triggers more chlorine disinfection.

2.2. MBR demonstration plant

A demonstration MBR plant was installed to treat up to 1 m^3 of GW per day. The pilot plant (Fig. 1) consists of an entrance tank, a membrane compartment, an aerobic/anoxic reactor (optional), a permeate tank/wash and several pumps. The membrane was a ZW-10 submerged ultrafiltration hollow fibre (UF-HF) membrane

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