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A new optional recycled water pre-treatment system prior to use in the household laundry

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HIGHLIGHTS

- A small pre-treatment unit for recycled water purification was introduced.
- The performance of the zeolite material for reducing water hardness was analysed.
- The operability and cost-effectiveness of the zeolite filter system were discussed.
- The capacity and column service life for a household laundry were calculated.
- Field trial operations and scale-up pilot studies should be further performed.

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ABSTRACT

With a constantly growing population, water scarcity becomes the limiting factor for further social and economic growth. To achieve a partial reduction in current freshwater demands and lessen the environmental loadings, an increasing trend in the water market tends to adopt recycled water for household laundries as a new recycled water application. The installation of a small pre-treatment unit for water purification can not only further improve the recycled water quality, but also be viable to enhance the public confidence and acceptance level on recycled water consumption. Specifically, this paper describes column experiments conducted using a 550 mm length bed of zeolite media as a one-dimensional flow reactor. The results show that the zeolite filter system could be a simple low-cost pre-treatment option which is able to significantly reduce the total hardness level of recycled water via effective ion exchange. Additionally, depending on the quality of recycled water required by end users, a new by-pass controller using a three-level operation switching mechanism is introduced. This approach provides householders sufficient flexibility to respond to different levels of desired recycled water quality and increase the reliability of long-term system operation. These findings could be beneficial to the smooth implementation of new end uses and expansion of the potential recycled water market. The information could also offer sound suggestions for future research on sustainable water management and governance.

1. Introduction

Recycled water for a household laundry has been increasingly regarded as a prospective new end use since significant fresh water savings could be achieved if potable-quality water used for clothes washing is replaced with recycled water (Chen et al., 2012). However, despite that many water authorities have encouraged the new applications of recycled water in dual pipe systems and stipulated corresponding policies, guidelines and regulations, the use in practice of recycled water with relatively close human contact is still quite limited. International research has identified significant community resistance to the use of recycled water in some circumstances, resulting in the abandonment of such projects. These instances include the Toowoomba, Australia, San Diego, USA and Lichi Rijin, the Netherlands (Hurlimann and McKay, 2006). Public concerns on individual health, water clarity, cost and machine durability might be major issues that prevent the society from establishing and promoting the new end use (Pham et al., 2011).

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Notably, the recent social surveys in three different locations of Australia (i.e., Port Macquarie, Melbourne and Sydney) indicated that the community's confidence on the use of recycled water in a household laundry would be greatly enhanced with the operation of a small unit for pre-treatment of recycled water prior to use in a washing machine (Chen et al., 2013). Hence, this paper aims to analyse the feasibility and cost-effectiveness of employing a small pre-treatment unit for water purification in the household laundry.

1.1. Recycled water sample

The actual recycled water (Class A) samples from the City West Water (CWW) Western Treatment Plant, Melbourne, Australia, have been considered for experimental analyses. The Western Treatment Plant has been supplying 37 GL per year of recycled water for agriculture and landscape irrigation (e.g., golf club, parks, zoos and wetlands) in the Werribee area, a suburb around 32 km southwest of Melbourne's CBD. The dual pipe recycled water systems have already been installed in front/back yard of 2000 new homes in Wyndham Vale, and Werribee and Class A recycled water will be supplied to local households in December 2013 or early 2014 (City West Water, 2012). Thus, if the pre-treatment unit is demonstrated to be beneficial to ensure the reliability and consistency of recycled water consumption, the system can be widely adopted in real cases. By this means, residents are likely to be more optimistic and confident in establishing and implementing new applications of recycled water. This would further contribute to significant freshwater savings and to achieving water recycling targets toward a sustainable water cycle development.

1.2. Hardness of recycled water

When it comes to water hardness, the majority of the hardness ions are calcium and magnesium, but small amounts of other ions such as iron and manganese can contribute as well. Hard water minerals in recycled water can react with soap anions which might cause difficulty with soap lathering, decreasing the cleaning efficiency. The insoluble precipitates can also induce scaling problems and serious mechanical failures by forming crusty deposits in household appliances, thereby shortening the life of the washing machines and reducing the machine efficiency (City West Water, 2009; Seo et al., 2010). Other problems not so visible but quite significant are deposits on clothes fabrics, namely soap curd or scum, after they have been washed. Dull whites and colours caused by soap curd might not be easily removed in the rinse cycles. This can also shorten the life of clothes that are washed and worn frequently (Wist et al., 2009).

The Australian Drinking Water Guidelines (ADWG) state that there is no health guideline value for total hardness (referred to as calcium carbonate, $CaCO_3$), but an aesthetic value should not exceed 200 mg/L. Comparatively, the Canadian Guidelines regard the water with total hardness over 200 mg/L as poor quality, and 80–100 mg/L as an acceptable level (ADWG, Australian Drinking Water Guidelines, 2011; Health Canada, 2003). The average water hardness level in the drinking water supply from CWW at Werribee area, Melbourne, is approximately 30 mg/L, with maximum levels less than 50 mg/L. As the total hardness of CWW recycled water nearly approaches the ADWG guideline upper limit and is significantly higher than that of drinking water in the local community, the pre-treatment unit is primarily designed to mitigate the current hardness level so as to improve the performance of soaps and laundry detergents, and protect the washing machine from scaling during clothes washing activities.

There are many different methods that have been widely adopted as a means of effective water softening, including chemical precipitation, ion exchange process, membrane techniques (e.g., nanofiltration and reverse osmosis) and electromembrane systems (e.g., electrodialysis, electrodialysis reversal, and electro-deionization reversal). However, in the case of chemical precipitation, the choices of additional chemicals are restricted as some of them might be deleterious to human health. With respect to membrane and electromembrane systems, high power consumption and expenses are required for operation and maintenance of the equipment. Besides, when water hardness level is high, calcium deposits will quickly make the membrane less permeable, causing membrane fouling within a short period of time. The affordability and operability of these advanced techniques are likely to present barriers to their actual application at household levels (Gabrielli et al., 2006; Wist et al., 2009; Seo et al., 2010). Therefore, a cost-effective, simple and low energy consuming approach has been forced on water softening processes.

1.3. Potential application of natural zeolites for water softening

As zeolitic minerals have been discovered in many areas of the world, natural zeolites have found a variety of applications in adsorption, catalysis, building industry, agriculture, soil remediation and energy production. Natural zeolites are crystalline microporous minerals with a well-defined open framework structure, consisting of a three-dimensional network of SiO_2 and Al_3O_4 tetrahedra linked together by common oxygen atoms. The mobile non-framework cations are located in cavities and wander inside the hexagonal channel walls within the structure and so natural zeolites possess valuable physicochemical properties, such as high cation exchange and sorption capacities (Sivasankar and Ramachandramoorthy, 2011; Loiola et al., 2012).

Due to their intrinsic properties and significant worldwide occurrence, application of zeolites for water and wastewater treatment has become a promising technique (Wang and Peng, 2010). The effectiveness of applying zeolites on ammonium and heavy metal ion removal from wastewaters has been well documented in the literature (Cooney et al., 1999; Panayotova, 2001; Sarioglu, 2005). However, information regarding the capacity of zeolites for water softening in the process of ion exchange to remove total hardness from highly treated recycled water, which contains much lower concentrations of ammonium and heavy metal ions but relatively high levels of hardness ions, is still very limited (Cinar and Beler-Baykal, 2005). Consequently, considering the practicality, simplicity and economy of the small treatment unit, natural zeolites have been selected as the filtration material in the laboratory scale analyses. To simulate the real operating situations, the results of continuous flow experiments for zeolite column testing will be presented; these results can provide scale-up information to the design of a commercial scale zeolite pre-treatment system for actual application in local households.

2. Materials and methods

2.1. Feed solution

In this research, recycled water from CWW Western Treatment Plant has been employed as the feed solution. When the recycled water was insufficient, synthetic water was used to simulate the composition of CWW recycled water. The synthetic feed solution was prepared by dissolving 300 mg/L of $CaCl_2 \cdot 2H_2O$ in deionised water. Overall, the feed solution used for all the experiments had a total hardness level between 175 and 200 mg/L as $CaCO_3$, indicating relatively high levels of hardness.

2.2. Pre-conditioning of natural zeolites

The natural zeolites were provided by Castle Mountain Zeolites (Quirindi, New South Wales, Australia) which are clinoptilolite-rich minerals composed of clinoptilolite (around 85% by weight) and mordenite (around 15% by weight) with trace amounts of quartz. The nominal mineralogical composition of Castle Mountain Zeolites is listed in Table 1 and the Si/Al molar ratio calculated from the composition data is 5.03 (An et al., 2011; CMZ, Castle Mountain Zeolites, 2013). The