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Research article

Concentrate minimization and water recovery enhancement using pellet precipitator in a reverse osmosis process treating textile wastewater

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ABSTRACT

Industrial wastewater reuse together with zero or near zero liquid discharges have been a growing trend due to the requirement of sustainable water management mandated by water scarcity and tightening discharge regulations. Studies have been conducted on the reclamation of textile industry wastewater using RO processes. However a lot of scientific attention has been drawn upon limiting the amount of concentrate generated from RO processes, which depends on the concentrations of scale forming ions in the concentrate stream. Hence, this study aims at investigating the applicability of an ultra-filtration (UF) membrane integrated pellet reactor to remove scale forming ions, i.e. Ca^{2+}, Mg^{2+} and Si from the concentrate of a pilot-scale textile industry RO process, for the first time in the literature. The resulting effluent was further tested in a secondary RO process to decrease concentrate volume and increase total water recovery. The pellet reactor operated at an extremely low hydraulic retention time of 0.1 h removed scale forming ions, i.e. Ca^{2+}, Mg^{2+}, with 90–95% efficiency, which improved the secondary RO process performance up to 92–94% overall water recovery, i.e. near zero liquid discharge was reached. Ozonation of the concentrate partially removed COD and color, which further improved the secondary RO filtration performance.

1. Introduction

Global water demand increases due to increasing population and improving life standards. The water demand components are mainly human consumption, agriculture and industrial usages. The increasing demand necessitates the reuse of reclaimed wastewater for sustainable water management (Gude, 2017). Hence, wastewater should be seen as a new water resource rather than a waste to be disposed (Giwa et al., 2016; Kellis et al., 2013; Van Der Bruggen et al., 2003). Therefore, wastewaters should be treated to a proper level for many reuse applications (USEPA, 2012).

Many industries have to reuse wastewaters in their process line or for other purposes due to water shortage, difficulty to meet discharge standards and some other reasons including pressures of customers. Textile is one of these industries due to their high amount of water usage. Additionally, it is quite difficult to treat textile industry wastewater due to presence of acids, alkalis, dyes, hydrogen peroxide, starch, surfactants dispersing agents and metals in the wastewater. Due to the mentioned ingredients, textile wastewater has a high color, high BOD/COD ratio and salts (Holkar et al., 2016). Generally biological treatment processes may not enough to get reasonable color removal efficiencies as some of the dye molecules or other components are toxic or unaffected by the biological processes (Holkar et al., 2014, 2016). Hence, some newly isolated bacteria was also used to improve decolorization efficiency (Holkar et al., 2014). In recent years, researchers have also focused on membrane bioreactors (MBRs) to increase the process performance (Jegatheesan et al., 2016) and to recover wastewater after some additional salt removing processes, i.e. reverse osmosis membrane (Aktaş et al., 2017). Therefore, recent studies on textile wastewater focused on the selection of optimal processes for water recovery due to sectoral needs enforced by water scarcity especially in Mediterranean region.

Reverse osmosis (RO) is a desalination process in which membranes permeable to water but not to salts are used. In this context, RO is commonly used to remove salts and various organic and inorganic matters from water (Gude, 2017; Subramani et al., 2011, 2012). RO can also be used to reclaim wastewaters after biological treatment to improve its quality for various reuse applications and it becomes a standard technology for desalination and water reuse. However, RO has a limitation of generating concentrate having disposal problem due to

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much higher concentration of pollutants compared to the original feed water (Dialynas et al., 2008; Kim et al., 2017; Salvador Cob et al., 2012; Subramani and Jacangelo, 2014). Hence, the reduction in RO concentrate volume has two fold benefits, which are decreasing waste volume and improving overall water recovery. Although several methods have been tested in the literature, polymeric membrane based processes for further decreasing RO concentrate volume and increasing water recovery may be considered one of the applicable methods considering the experiences and the costs of maintenance and operation (Gabelich et al., 2007; Giwa et al., 2016; Rahardianto et al., 2007, 2010).

In the RO process, inorganic species are rejected by membrane and concentrated in the concentrate stream. The sparingly soluble inorganics, e.g. $CaCO_3$, $CaSO_4$ and $BaSO_4$, may exceed their solubility levels and the precipitates accumulated on the membrane may limit the membrane water recovery (Gabelich et al., 2007). The average water recovery of RO processes for biologically treated domestic wastewaters is around 70–75%, which means 25–30% of the wastewater should be discharged as concentrate (Aktaş et al., 2017; Daigger et al., 2015). Hence, it is a challenge to increase the water recovery using secondary RO processes. For this purpose, the first RO step is operated until the concentrations of scale forming ions reach critical membrane scaling threshold. Before feeding the concentrate to the secondary membrane process, the scale forming ions should be removed from water with an efficient and economical way. Pellet reactor, which is also called fluidized bed precipitator or fluidized bed reactor, has been used in water and wastewater treatment for various purposes ranging from softening of drinking water to heavy metal removal from wastewater (Tran et al., 2012). The process was suggested by Zhou et al. (1999) for the removal of metals from industrial wastewater. The process consisted of a sand-filled up-flow reactor. In the operation, metals and the precipitating agent (carbonate, sulfide or alkaline, etc.) are simultaneously fed to the reactor. The fluidized sand bed provides high amount of specific area to precipitate metals (Zhou et al., 1999). Two major events play significant role in the crystallization process, nucleation and crystal growth. In the nucleation process, solute molecules form clusters on nano-scale and become stable and constitute nuclei formation. Subsequently, crystals are formed from the nuclei growth. The presence of seeds in the crystallization process provide higher surface area for the subsequent nuclei growth (De Luna et al., 2015). In this context, ideal environmental conditions are generated in the pellet reactor for controlled crystallization. The high surface area provided by the sand particles favors the heterogeneous nucleation, which allows operation under slightly supersaturated conditions and the formation of fines are avoided. Under high up-flow velocities fluidization and good mixing can be obtained (Guillard and Lewis, 2002). Dense sludge formation is possible with this technology as coagulation, flocculation, sludge-water separation and sludge dewatering processes are combined in one reactor (De Luna et al., 2015) and the metal salts covering the pellets may be recovered by washing the bed with concentrated acid (De Luna et al., 2015).

Mahvi et al. (2005) used pellet reactor for water softening and listed the possible advantages of the process as small in size, lower reaction time up to 16 times, clean waste generation (low volume and high purity), easy handling of crystals and possible recovery of the precipitates. Montastruc et al. (2003) reported that phosphorus can be recovered from wastewater using pellet reactor and they have developed a model for predicting reactor performance under varying conditions.

Ozonation is a promising treatment option for the RO concentrate due to its high efficiency (Weng et al., 2018). The concentration of organic pollutants in the RO concentrate may be significantly decreased after ozonation together with the increase in the following membrane performance (Van Geluwe et al., 2011; Vatankhah et al., 2018). Ozone gives quite fast reactions with the organics having unsaturated bonds due to its electrophilic character (Vatankhah et al., 2018). Studies reported that pre-ozonation alleviates the membrane fouling (Myat et al., 2017; Van Geluwe et al., 2011). Ozonation is also quite effective in decolorization as in the study of Lee et al. (2009) complete color removal was achieved with 6 mg/L ozone dose at 20 min contact time. Although studies on the treatment of RO concentrate with ozone have been performed (Lee et al., 2009), there is a gap in the literature on the impact of ozonation on the fouling mitigation of secondary RO process, which is applied to increase water recovery and decrease concentrate volume.

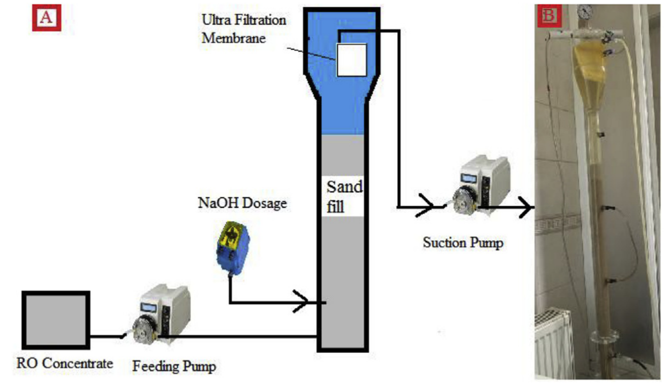

Fig. 1. Schematic diagram (A) and photo (B) of the experimental pellet membrane reactor system.

The non-precipitated crystals or fines may escape from the effluent of pellet reactor and should be removed before feeding to the RO process. Hence, the pellet reactor effluent should be pre-filtered (e.g. using ultra-filtration process) before feeding to RO process. In this context, the aim of this study is to evaluate the efficiency of an ultra-filtration integrated pellet membrane reactor (Fig. 1) to remove scale forming ions from the concentrate of an RO process receiving membrane bioreactor (MBR) treated textile organized industrial district wastewater. Although studies have been performed for RO concentrates originating from brackish ground and surface waters, to the best of our knowledge, this is the first study evaluating the performance of a pellet reactor for the treatment of RO concentrate originated from a textile wastewater. The pellet membrane reactor effluent was further subjected to a secondary RO process before and after ozonation process for enhancing water recovery and decreasing concentrate volume to achieve near zero liquid discharge (NZLD).

2. Materials and methods

2.1. Pellet reactor

The lab-scale pellet reactor (Fig. 1) was made of plexiglass with total and active volume of 4.5 and 1.38 L, respectively. The active volume consisted of 70 cm silica sand with a size range of 150–300 µm (density was around 2.65 g/mL) (Fig. 1). A flat-sheet ultra-filtration membrane (UF) (polyethersulfone with 0.02 µm nominal pore size) was integrated to the pellet reactor to remove fine and to allow direct feeding of the effluent to the secondary RO process. The membrane area of the flat-sheet UF module was around 0.0072 m^2. The membrane was operated at varying fluxes (20–45 L/(m^2.h) (LMH)). The UF module was operated under constant flux and the variation of the trans-membrane pressure (TMP) were measured to evaluate the impact of the flux on membrane fouling.

Pellet reactor was fed with two different streams. The first one was the RO concentrate and the second was 0.25 N NaOH solution to adjust the influent pH to the desired levels. Therefore, the concentrate and the NaOH solutions were fed to the reactor from a common port at bottom of the reactor and the separate streams were mixed just at the entrance of the pellet reactor.