Chemosphere 165 (2016) 202–210

Contents lists available at ScienceDirect

Chemosphere

journal homepage: www.elsevier.com/locate/chemosphere

# Reverse osmosis brine for phosphorus recovery from source separated urine

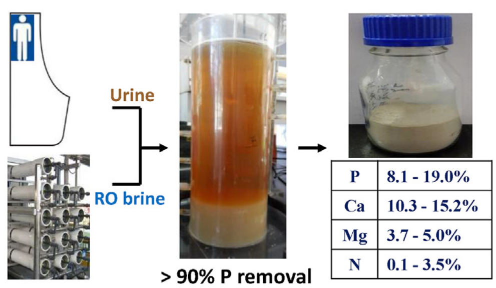
Xiujun Tian [a], Guotian Wang [a, b], Detian Guan [a], Jiuyi Li [a, *], Aimin Wang [a], Jin Li [a], Zhe Yu [a], Yong Chen [b], Zhongguo Zhang [c]

[a] *Department of Municipal and Environmental Engineering, Beijing Key Laboratory of Aqueous Typical Pollutants Control and Water Quality Safeguard, Beijing Jiaotong University, Beijing 100044, China*
[b] *China Construction Technology Consulting Co. LTD., Beijing 100044, China*
[c] *Environmental Protection Research Institute of Light Industry, Beijing Academy of Science and Technology, Beijing, China*

## HIGHLIGHTS

- RO brine from a power plant could be used as a precipitant to recover P from urine.
- More than 90% P could be removed at RO brine/urine of 1:1 (v/v) at pH ≥ 9.0.
- The precipitates contain 16–39% of $P_2O_5$ and could be used in fertilizer industry.
- RO brine is a low cost and widely available precipitant for P recovery.

## GRAPHICAL ABSTRACT




## ARTICLE INFO

*Article history:*
Received 2 May 2016
Received in revised form
8 September 2016
Accepted 10 September 2016
Available online 18 September 2016

Handling Editor: Hyunook Kim

*Keywords:*
Urine
Reverse osmosis brine
Phosphorus recovery
Precipitation
Nutrient

## ABSTRACT

Phosphorus (P) recovery from waste streams has recently been recognized as a key step in the sustainable supply of this indispensable and non-renewable resource. The feasibility of using brine from a reverse osmosis (RO) membrane unit treating cooling water as a precipitant for P recovery from source separated urine was evaluated in the present study. P removal efficiency, process parameters and precipitate properties were investigated in batch and continuous flow experiments. More than 90% of P removal was obtained from both undiluted fresh and hydrolyzed urines by mixing with RO brine (1:1, v/v) at a pH over 9.0. Around 2.58 and 1.24 Kg of precipitates could be recovered from 1 $m^3$ hydrolyzed and fresh urine, respectively, and the precipitated solids contain 8.1–19.0% of P, 10.3–15.2% of Ca, 3.7–5.0% of Mg and 0.1–3.5% of ammonium nitrogen. Satisfactory P removal performance was also achieved in a continuous flow precipitation reactor with a hydraulic retention time of 3–6 h. RO brine could be considered as urinal and toilet flush water despite of a marginally higher precipitation tendency than tap water. This study provides a widely available, low - cost and efficient precipitant for P recovery in urban areas, which will make P recovery from urine more economically attractive.


## 1. Introduction

Phosphorus is an essential element for all forms of life. The current one-way flow of phosphorus, *i.e.* from phosphate rock to farm to wastewater and finally to oceans, has resulted in the

* Corresponding author. Department of Municipal and Environmental Engineering, School of Civil Engineering, Beijing Jiaotong University, Shangyuancun 3, 100044 Beijing, China.
*E-mail address:* lijy@bjtu.edu.cn (J. Li).

http://dx.doi.org/10.1016/j.chemosphere.2016.09.037
0045-6535/

depletion of non-renewable phosphate reserves and, on the other hand, severe pollution of freshwater and costal marine ecosystems (Elser and Bennett, 2011). It was predicted that the global phosphate reserves, allowing economic mining and refining, will be depleted by the end of this century (Van Vuuren et al., 2010). Excessive phosphorus discharged by various wastewaters leads to eutrophication of rivers, lakes and costal seas. Phosphorus recovery and recycling from wastewater have been regarded as a crucial strategic approach for closing the loop of phosphorus flow and sustainable supply of this indispensable element in the future.

Many studies have been conducted to recover phosphorus from various waste streams, such as livestock wastewater (Yetilmezsoy and Sapci-Zengin, 2009), rejected water generated from sludge digestion and dewatering process (Yoshino et al., 2003) and fertilizer industry (Hutnik et al., 2013), with urine being considered as one of the most promising options (Dai et al., 2014). Human urine contains around 50% of the phosphorus, 85% of the nitrogen and 55% of the potassium present in domestic wastewater, but only 1% of the total wastewater volume (Larsen and Gujer, 1996). Extensive studies and practical applications have demonstrated significant opportunities for phosphorus recovery from the source separated urine with the implementation of modern no-mix toilets and waterless urinals (Hanaeus et al., 1997; Jonsson et al., 1997; Larsen et al., 2001; Udert et al., 2003). In most of previous publications, phosphorus was harvested through simultaneous precipitation of soluble *ortho*-phosphate ($PO_4^{3-}$), ammonium ($NH_4^+$) and magnesium ($Mg^{2+}$) in the formation of struvite ($MgNH_4PO_4 \cdot 6H_2O$), with the addition of external $Mg^{2+}$ sources in the forms of MgO and $MgCl_2$ (Tilley, 2006; Wilsenach, 2006; Wilsenach et al., 2007; Ronteltap et al., 2010). Although struvite is generally considered as the optimal phosphorus mineral for recovery from urine as it contains 51.8% of $P_2O_5$ and could be used as a slow-release fertilizer, the addition of $Mg^{2+}$ sources make phosphorus recovery less financially attractive (Hao et al., 2013). Cheap alternative precipitants, such as bittern, wood ash and pretreated magnesite, have been reported, but their availability, low precipitation efficiency and contaminations constrain the application (Etter et al., 2011; Sakthivel et al., 2012; Dai et al., 2014; Krahenbuhl et al., 2016). Very recently, seawater, containing high content of magnesium, has attracted intensive interest in phosphate precipitation in coastal areas (Liu et al., 2013; Dai et al., 2014; Rubio-Rincon et al., 2014). In these research, very high (>95%) phosphorus recovery performance was achieved for hydrolyzed urine with varying seawater-to-urine ratios. Owing to the long transport distance, seawater is unlikely available for arid or semi - arid inland areas where most developing cities are situated. Therefore, other alternative low - cost P precipitants need to be explored.

Due to the shortage of fresh water resources, the reclamation and reuse of water are commonly implemented, during which the mineral constituents are usually concentrated. Huge amount of desalination facilities, mainly reverse osmosis (RO) membrane process, have been emerged worldwide, and more demands will be anticipated in the coming decades (Shannon et al., 2008). RO membrane operates under high pressure to produce a filtrate containing low salts, while derives most mineral components into the small volume of rejected concentrates, *i.e.* RO brine. In consequence, the disposal of RO brine is troublesome for both municipal and industrial desalination facilities, for example thermal power plants. Specifically, local legislative agents in northeast China mandatorily require all thermal power plants to replace surface water with reclaimed water as the supply of cooling water systems and reuse the wasted cooling water by RO desalination process, in order to achieve the so - called zero - discharge of wastewater. Considering the concentrating effects of water evaporation in cooling water system and RO membrane units, the RO brine usually constitutes 10–20% volume of incoming water supply and contains mineral salts around 5–10 times higher than the raw reclaimed water. The current disposal technologies for RO brine treatment and disposal, for example flash evaporation, are highly energy-intensive and pose huge cost burden on the thermal power plants (Alhazmy, 2014; Morillo et al., 2014). However, RO brine could potentially be a promising phosphorus precipitant owing to high content of inorganic ions, especially multivalent cations.

The aim of the present work is to investigate the phosphorus recovery from source separated urine by using RO brine generated in a thermal power plant. The phosphorus recovery efficiencies from both fresh and hydrolyzed urines with RO brine were studied in batch and continuous flow experiments. The production and composition of the precipitated solids were determined. In addition, the possibility of replacing tap water with RO brine as the toilet flush water was also evaluated in the study.

## 2. Materials and methods

### 2.1. Urine and RO brine samples

Undiluted urine samples were collected in a barrel from a male toilet in Beijing Jiaotong University in the period from January to December in 2015. The urine samples were daily harvested at 5 p.m. and the fresh urine (FU) was stored in a urine container in a refrigerator at 4 °C prior to use on the next day. The barrel and urine container were cleaned everyday with 1 M HCl solution to remove the possible deposit and to inhibit the hydrolysis of urea. A fraction of FU was stored in a sealed container in room temperature for more than 2 months to achieve a fully hydrolyzed urine (HU) with a stable ammonium concentration.

RO brine was collected from the RO membrane unit in a thermal power plant located in the suburb of Beijing, China. The power plant used reclaimed water generated from a nearby municipal wastewater treatment plant as the water supply for the recirculating cooling system, where the reclaimed water was concentrated three times with the aid of anti - scale (6 mg $L^{-1}$, JH501A, Jianghai Co., China) and anti - corrosion (6 mg $L^{-1}$, JH501B, Jianghai Co., China) chemicals. To improve water utilization efficiency, the wasted cooling water, *i.e.* concentrated reclaimed water, was desalinated in a RO membrane unit to produce a filtrate that could be reused in the cooling water system. The water recovery rate for the RO membrane unit was maintained at 60 percent with the addition of anti - scale reagent (1.5 mg $L^{-1}$, FLOCON 135, Bihua Co., China) into the influent of the RO process. Prior to the RO process, the concentrated reclaimed water was pretreated with an ultrafiltration filter, thus the RO brine did not contain suspended solids but high concentrations of dissolved salts (as listed in Table 1).

To evaluate the possibility of replacing tap water with RO brine as the toilet flush water, tap water in the lab of Beijing Jiaotong University was used as a control in the dynamic precipitation experiments. The typical properties of FU, HU, RO brine and tap water used in the study are listed in Table 1, which was determined by at least ten FU samples, five HU samples, three tap water samples and three RO brine samples.

### 2.2. Batch experiments

Three sets of batch experiments were conducted to assess the feasibility to use RO brine as a precipitant for phosphorus recovery from urine in urban sanitation environments. The first set of experiment investigated phosphorus recovery performance of mixing RO brine with urine (FU and HU) at varying volumetric ratios, to simulate the operation of water free urinals and urine -