Desalination 357 (2015) 140–149

Contents lists available at ScienceDirect

Desalination

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

Comparison of pre-treatment technologies towards improving reverse osmosis desalination of cooling tower blow down

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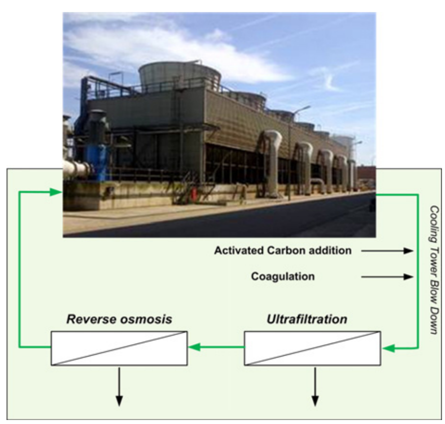
HIGHLIGHTS

- CTBD of high DOC shows to be challenging for membrane treatment.
- Membrane based desalination of CTBD is affected by pre-treatment conditions.
- PAC dosage proves beneficial for membrane filtration performance on CTBD.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 16 August 2014
Received in revised form 18 November 2014
Accepted 20 November 2014
Available online 1 December 2014

Keywords:
Pre-treatment
Powdered activated carbon
Ultrafiltration
Reverse osmosis
Wastewater reuse
Cooling tower blow down

ABSTRACT

The suitability of three different pre-treatment technologies namely powdered activated carbon (PAC) adsorption, coagulation with ferric chloride and ultrafiltration (UF) as pre-treatment to reverse osmosis (RO) desalination of a cooling tower blow down (CTBD) was investigated. Special attention was paid to the capability of the pre-treatment options to remove dissolved organic carbon (DOC) from the CTBD by applying advanced DOC characterization. Furthermore, the direct effect on the performance of reverse osmosis (RO) desalination was investigated.

Advanced DOC analysis showed clear differences between the pre-treatment technologies in removal of total DOC and in removal of certain DOC fractions. By investigation of RO normalized flux decline after different pre-treatments an improvement of 10–20% by UF treatment and an additional improvement of 10–20% by PAC/UF treatment were found in comparison to RO performance on not pre-treated CTBD. The achieved results indicate the negative influence of chemical additives in the CTBD matrix on RO fouling and performance as well as pre-treatment efficiency.

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http://dx.doi.org/10.1016/j.desal.2014.11.018

With PAC/UF pre-treatment resulting in the least fouling development the normalized flux decline remained high with roughly 40%–50% over 5 days of RO operation indicating the challenging nature of high DOC CTBD treatment for re-use.

1. Introduction

With only 0.8% of all water on earth being fresh water, several regions suffer from severe water scarcity. Traditional fresh water sources are diminishing due to over-exploitation and become saline by salt water intrusion in coastal areas. Even more challenging is the fact that in such water depleted areas industrial processes often need a considerable amount of the available fresh water. Among these, large water consumers are cooling towers (CT) which discharge large volumes of wastewater in the form of cooling tower blow down (CTBD). Wang et al. [24] reported that 60%–70% of industrial fresh water demand is used in CT. In 2005, 49% of fresh water withdrawal in the U.S. was mainly caused by usage in CT for thermoelectric power generation. Water treatment technologies such as desalination for fresh water production or water reuse are considered a key factor for sustainable development in the future [10,12]. The large water demand and the large volume of discharged wastewater by CT allow for large water saving potentials in industrial processes through CTBD re-use [4,30].

For instance You et al. [28] reported that wastewater from CT is invaluable among industrial wastewaters due to its high volumes and relatively little contamination. Nevertheless, wastewater of cooling towers contains considerable amounts of particles, colloids and salts. Chemicals added to the cooling water, such as ammonia and phosphate for corrosion control, are typical constituents of a CTBD [19]. In particular high amounts of ions such as Ca^{2+}, Mg^{2+}, CO_3^{2-} and HCO_3^- hinder the direct reuse and make treatments such as desalination necessary [24]. Among the available membrane desalination processes are reverse osmosis (RO), nanofiltration (NF) and electro dialysis (ED). However, the use of these technologies requires pre-treatment due to the sensitivity of the membranes towards fouling [10,24]. RO desalination has increasingly been applied and surpassed thermal desalination in 2001 when RO accounted for 51% of total new desalination capacity [12]. Furthermore, recent research activities on CTBD have mainly focused on membrane pre-treatment to RO such as microfiltration (MF) and ultrafiltration (UF) [30]. MF and UF as porous membrane processes for pre-treatment offer several advantages such as short treatment times, low space demand, complete particle removal and constant permeate quality [10]. The applicability of MF and UF processes for CTBD pre-treatment was shown with both processes being able to supply permeate of low turbidity and silt density index (SDI) values to the subsequent dense membrane desalination process at high water recovery rates of up to 95% [24,31]. However, membrane processes are associated with membrane fouling which reduces the process performance, and thereby, increases energy demand and maintenance requirements. Dissolved organic carbon (DOC) is often considered to be a crucial factor for fouling, causing pore clogging and gel formation [2,16]. Due to the addition of several chemicals such as anti-scalants, corrosion inhibitors and bio-dispersants to the cooling water [4,29], the chemical composition of CTBD is different from other typical water sources.

While several studies investigated the feasibility of membrane processes for the re-use of CTBD, little information on the direct comparison of different pre-treatment technologies on fouling development and process performance of an RO treatment of CTBD is available. Therefore, within this study three different pre-treatment technologies were applied to investigate the influence on RO fouling and process performance. The CTBD of a CT close to the Dow Benelux' premises (Zeeland, The Netherlands) was used for the experiments. Zeeland is considered a water scarce region due to a high water demand by industry, agriculture and households, exceeding the available freshwater sources. This makes the transport of fresh water over long distances necessary, raising fresh water costs and leading to intensified efforts to increase water management efficiency in the local industry [8].

Since the investigated CTBD is high in DOC concentration special attention was paid to the capability of the pre-treatment technologies to remove DOC from the water. Namely, the pre-treatment technologies investigated are UF, powdered activated carbon (PAC) adsorption and coagulation with $FeCl_3$. Following the investigation of DOC reduction by the different technologies, the influence of coagulation and PAC adsorption coupled to UF as hybrid membrane processes on RO performance and fouling development was studied and evaluated based on normalized flux development and fouling analysis.

The study was carried out to investigate economically feasible treatment schemes for re-use of high DOC CTBD by RO and study the contribution of DOC removal towards a stable RO filtration and reduced fouling development.

2. Material and methods

2.1. Water quality

The water used for the experiments was taken from the blow down of a CT next to the Dow premises in Terneuzen (Netherlands). The CT is operated as a natural draft counter flow CT. The CTBD contained various chemicals added in the CT, including sulfuric acid for pH adjustment, phosphate as corrosion inhibitor, anti-scalants and biocides to prevent microbiological growth. A rough process scheme is given in Fig. 1.

2.2. Coagulation

Coagulation with $FeCl_3$ (Tri-fer 200, Aregger Chemie, Switzerland) was performed in jar tests to investigate the influence on DOC profile and removal. In-line coagulation was applied when coupled to UF as indicated in Fig. 2.

The batch experiments were carried out with the Flocculator SW6 (Stuart, United Kingdom) in duplicates allowing the investigation of three parameter variations in parallel. Jars were filled with 2 L CTBD and placed in the Flocculator SW6. Fe^{3+} at concentrations of 10, 20 and 50 mg/L was simultaneously added to all flasks in the beginning of a fast stirring period of 1 min at 250 rpm. For the next 30 min a reduced stirring speed of 25 rpm was applied to support flock-building. Samples of the supernatant were taken 2 cm from the surface after 60 min of sedimentation.

When coagulation was applied in combination with UF, Fe^{3+} was dosed into a small contact reactor with a volume of about 100 mL. Dosage was performed with a membrane pump FMM 20 KPDC-P (KNF Neuberger GmbH, Germany) from a stock solution of $FeCl_3$ and deionized water with a concentration of 0.28 g Fe^{3+}/L with a pH of 3 in the stock solution.

2.3. Adsorption

Adsorption tests were carried out with PAC SAE Super (Norit Activated Carbon, The Netherlands). The chosen PAC has a specific surface area of 1300 m^2/g with a median diameter d_{50} of 15 mm. The iodine number and the methylene blue adsorption are 10.50 and 0.28 g/g, respectively [34]. Jars were filled with 200 mL CTBD and placed on a