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Recovery of cooling tower blowdown water for reuse: The investigation of different types of pretreatment prior nanofiltration and reverse osmosis

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ABSTRACT

The suitability of two different pretreatment methods, i.e., coagulation-filtration and ultrafiltration (UF), and two final membrane treatment technologies, namely nanofiltration (NF) and reverse osmosis (RO), for desalination of a cooling tower blowdown (CTBD) was investigated. Particular attention was paid to ensuring that the best pretreatment method could enhance the permeate flux and lifespan of the NF and RO membranes and decrease the membranes' fouling characteristics. Furthermore, the difference of NF and RO performances in CTBD treatment was investigated.

In order to find the most appropriate type of coagulant, coagulant dosage, pH and co-coagulant dosage, 21 jar tests were performed. The results showed that 50 mg/L of Polyaluminium chloride (PACl) in the presence of 0.5 ppm co-coagulant in pH of 6.5–7.5 has the best treatment performance. Silt density index (SDI), chemical oxygen demand (COD), turbidity, electrical conductivity, and membrane permeate flux tests were performed for both pretreatment and treatment stages. Both pretreatment methods produced appropriate feed for NF and RO in terms of SDI and turbidity. Using the coagulation–filtration pretreated water instead of raw water as a feed for NF and RO membranes showed about a 25 and 33 percent improvement in permeate flux after 100 min in 10 and 15 bar applied pressure for NF and RO, respectively.

1. Introduction

Petrochemicals, refineries and power plants are among the biggest water-consuming industries. Cooling tower systems consume the most water of all systems such that the feed water of cooling towers accounts for the largest portion of water demand. Since a significant amount of water is lost due to evaporation, wind action, leakage, and drainage, a large amount of make-up water is needed to maintain the water balance and keep cooling water operation at a steady state. The amount of lost make-up water is relative to climate conditions and the configuration of cooling system equipment. In this regard, drainage loss (blowdown), which constitutes the biggest portion of feed water loss, varies greatly with changes in source water quality and cooling water treatment [32].

For a long time, cooling tower blowdown was discharged directly to surface water bodies and was not reused as treated make-up water in many countries. Environmental contamination and an increase in wastewater were two of the dire consequences of blowdown water discharging [32]. Scarcity of water, large quantities of cooling tower blowdown water, and an increase in water prices have been the primary motivations driving recent studies and researches on blowdown water treatment and reuse [32,27,30].

Also, new multiple technologies for water conservation, in particular high-concentration circulation water treatment technology, have been progressively used in circulating cooling water systems to utilize water more efficiently, [31,33,23,17,11]. Both scale and corrosion inhibitors are the main pollutants of the blowdown water of cooling systems. Blowdown water is a suitable resource to use as

Abbreviations: ΔP, operation pressure (MPa); Δt, permeation time (h); A, membrane effective area (m^2); Alum, aluminum sulfate; BOD, biological oxygen demand; COD, chemical oxygen demand; CTBD, cooling tower blowdown; DOC, dissolved organic carbon; EC, electrical conductivity; $FeCl_3$, ferric chloride; GAC, granulated activated carbon; J, permeate water flux (kg/m^2 h); M, mass of permeated water (kg); MF, microfiltration; NF, nanofiltration; PAC, powdered activated carbon; PACl, polyaluminum chloride; RO, reverse osmosis; SDI, silt density index; SiO_2, silicon dioxide; TDS, total dissolved solids; UF, ultrafiltration.

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makeup water for cooling waters if the particles and colloids stably dispersed in the cooling water system have been treated properly. Otherwise, when the blowdown of cooling systems is reused as cooling water without any proper treatment, the dispersed particles and colloids could scale, deposit or block the pipe. Recent studies suggest that membrane filtration such as nanofiltration (NF) and reverse osmosis (RO) are effective processes for removing soluble and insoluble organic and inorganic contaminants in wastewater [25,7]. However, passing the feed directly through the NF and RO membranes is renders it susceptible to irreversible fouling [3,18,12,13]. The coagulation-filtration process has the ability of altering the stability of colloidal particles, which has a high tendency to make membranes fouled [26]. Ultrafiltration membrane can effectively remove colloidal particles, bacteria, coagulates and viruses which are NF and RO foulants. In fact, problems caused by fouling will adversely affect operation costs, energy demand, membrane cleaning, and lifespan of the membrane elements [12]. Pretreatment of feed, use of proper membrane materials, surface modifications and changes in operating parameters are some measures which could be taken to preclude membrane fouling [13]. Concerning operation parameters and processes, combination of NF and RO with a pretreatment method such as coagulation-filtration and ultrafiltration (UF) can be more effective than a process without any pretreatment [27,14].

The used pretreatment generally comprises various steps of coagulation/flocculation, sand filtration, and sorption with activated carbon. [1] studied the treatment of an effluent containing organic matter for reuse with the help of coagulation, adsorption with activated carbon, and UF. [10] also compared three different methods of pretreatment for RO: (I) microfiltration, (II) conventional treatment (comprising coagulation, flocculation, sedimentation, and filtration), and (III) treatment by conventional coupling of ozonation and biofiltration. In addition, [24] studied the MF, UF, coagulation, and adsorption as pretreatment for seawater desalination system with RO.

Specifically for blowdown water treatment, some works studied the capability of reusing blowdown water by means of membrane filtration methods. [2] demonstrated that a nanofiltration membrane treatment on a side stream of recirculating cooling tower water could decrease water usage and discharge in total. In this method, the treated permeate was returned to the cooling tower's water cycle and the concentrated water was discharged to the sanitary sewer. They studied flow rates, pressure and the chemistry of water. Their findings showed that the maximum amount of makeup water and discharge reduction were 16% and 49%, respectively. Evidence of a decrease in permeate flux was membrane fouling or scaling. Nanofiltration membrane fouling reduction by a pretreatment process for water can greatly increase water flux and membrane lifespan. They concluded that using membrane system was economically feasible as long as permeate recovery remained high.

[15] studied and compared three different pretreatment methods in order to make cooling tower's blowdown water an appropriate feed for RO membrane. These three methods were powdered activated carbon (PAC) adsorption, coagulation with ferric chloride and ultrafiltration. The primary purpose of the study was to measure the capability of the pretreatment options for removing dissolved organic carbon (DOC) from cooling tower blowdown (CTBD) by applying advanced DOC characterization. They also studied the direct effect of UF pretreatment on the performance of RO. They concluded that the UF process was able to enhance RO performance by reducing turbidity and removing suspended solids from cooling tower blowdown water. In addition, PAC adsorption could reduce all DOC fractions to a minor extent with a clear performance towards lower molecular weight organic substances. Furthermore, coupling UF and PAC adsorption was found to be the most appropriate process combination to improve RO filtration characteristics. Coagulation with Fe^{3+} as another pretreatment method was most suitable for reducing the DOC concentration in cooling tower blowdown water with perfect biopolymer removal at sufficient Fe^{3+} dosage (50 mg/L). However, the hybrid membrane process Fe^{3+}/UF failed to improve the RO process because of the foulant characteristics of the residual Fe^{3+} for the RO membrane after a long service (5 days).

As another pretreatment method, [9] evaluated the use of discarded RO membrane for pretreatment of blowdown stream. They studied the combination of coagulation/flocculation/sand filtration as the best method for achieving values of 0.3 NTU for turbidity and 5.5 for SDI_5. The RO discarded membranes showed high salt retention (about 97%) and analysis of permeate indicated the possibility of reuse. [31] did a pilot test of UF pretreatment before RO filtration for cooling tower blowdown water for reuse in power plants. Their study showed the ability of UF pretreatment for decreasing RO fouling. They also studied conventional treatments such as coagulation in this work. [26] investigated coagulation as a pretreatment of a membrane distillation system, which improved the permeate flux of membrane. [27] also evaluated bench-scale and pilot-scale coagulation pretreatment for wastewater reused by RO in cooling systems. They explored the optimal dosage of four acrylamide polymer coagulants by coagulation–flocculation jar tests in laboratory. Then, the coagulation–flocculation process was tested in a petrochemical plant. The main coagulant was PACl and the results showed that PACl could be used successfully in wastewater pretreatment for the RO process. Their coagulation–flocculation process produced water with low SDI (less than 5) and low turbidity (less than 0.26 NTU), which is suitable for the RO feed.

In this study, the effects of two pretreatment methods on fouling reduction and flux increment of two final membrane treatment processes, i.e. NF and RO, were investigated. Coagulation–filtration and ultrafiltration were separately used as pretreatment methods. In order to identify appropriate coagulant type, coagulant and co-coagulant dosage, and water pH, jar test analysis was carried out. In addition, a thorough comparison between the filtration of untreated water and pretreated water (coagulation–filtration and UF) by NF and RO membranes was made. This study combines pretreatment methods and final membrane treatment and makes a comparison between all blowdown treatment methods. In view of water scarcity and the huge amounts of water required for cooling tower blowdown water, this study has focused on the best hybrid method for reuse and recovery of cooling tower blowdown water. The immense significance of fouling reduction in NF and RO membranes calls for a thorough examination of such water characteristics as SDI_{15}, COD, turbidity and EC.

2. Materials and methods

2.1. Feed water

Blowdown water was obtained from cooling towers of Tehran Oil Refinery Company located about 20 km south of Tehran, Iran. The selected feed water is well known for causing significant membrane fouling without pretreatment. The feed water also offered high levels of turbidity, TDS and COD, which was essential for assessing the impact of pretreatment and membrane fouling.

After a comparison between source water and treated water, the source water was well characterized. Table 1 shows the characteristics of the blowdown water (feed).

As Table 1 shows, pH of the feed water is in the neutral range, about 7. SDI of the feed water shows that the feed water is highly capable of fouling the membranes. The high amounts of COD in the feed water is probably because of some oil leakage into the cooling