Journal of Cleaner Production 171 (2018) 220–233

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Hot wastewater recovery by using ceramic membrane ultrafiltration and its reusability in textile industry

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A R T I C L E I N F O

Article history:
Received 15 May 2017
Received in revised form
15 September 2017
Accepted 2 October 2017
Available online 3 October 2017

Keywords:
Textile wastewater
Best available techniques
Hot wastewater recovery
Ceramic membrane ultrafiltration

A B S T R A C T

Ceramic membrane filtration is a viable option for recovery of hot discharges due to their high mechanical, chemical and thermal durability. Recovery of hot discharges in textile industry with this method has not been studied in detail previously. In this study, the potential recovery of hot textile wastewater discharges was assessed in situ taking into consideration the amount, pollutant content and costs of the water. Samples were selected from potential recovery points according to wastewater amount, temperature and accessibility and were evaluated using laboratory scale ceramic membrane filtration with four different MWCO (300 kDa, 50 kDa, 15 kDa and 3 kDa) membrane sizes. The pollutant size distribution correlated with removal efficiency of the method and the highest pollutant removal efficiency was achieved with the 3 kDa ceramic membrane. However, the mixed hot wastewater and disperse printing washing baths mix permeate from the 3 kDa membrane had high COD and TOC contents and was not optimal for reuse without additional treatment. The printing washing baths hot discharges mix was the most appropriate option for reuse with 67 ± 12 mg COD/L, 21 ± 4 mg TOC/L and 23 ± 7.7 mg $CaCO_3$/L Total Hardness values which could be reused in dense dyeing and printing baths washing after 3 kDa ceramic membrane ultrafiltration. In order to define the fouling mechanism, resistance-in-series model was used and physically removable resistance was the main contributor to overall fouling.

With this method, not only the reuse requirements will be met but also 22% of total water consumption may be reused and thus wastewater, energy and water related expenses may be reduced significantly in textile industry.

1. Introduction

Global industrial water consumptions would increase 1.8 times from 800 billion m^3 in 2009 to 1500 billion m^3 in 2030 under an average economic growth scenario (Vajnhandl and Valh, 2014). Using treated wastewater to reduce raw water consumption and amount of discharged wastewater is already an optimal solution due to limited water resources especially in the heavy water consumption industries such as food, textile, steel, pulp, paper and chemistry [EUROSTAT, 2016].

Best Available Techniques (BAT) have been identified as the reduction of raw material usage and water consumption in many countries, especially for the textile sector [US EPA, 1978; US EPA, 1996; US EPA, 1997; EC, 2003; Barclay and Buckley, 2000, Vajnhandl and Valh, 2014].

In Europe, yearly average fresh water consumption is approximately 600 million m^3 and 108 million m^3 of this amount need to be treated as a textile wastewater with 36 million tons of various pollutants [Voljamer Valh and Le Marechal, 2009; Voljamer Valh et al., 2012].

The textile industry include different unit operations such as desizing, printing, dyeing, sieving scouring, washing, rinsing, bleaching, mercerizing, carbonization, finishing and dyeing processes [Bisschops and Spanjers, 2003; Ozturk et al., 2016a; US EPA, 1997]. Most of these processes require the use of water in huge quantities and also produce wastewater in large quantities [Voigt

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https://doi.org/10.1016/j.jclepro.2017.10.015

et al., 2001; Ozturk et al., 2015; Sahinkaya et al., 2017]. Although the water consumption vary depending on the process and fabric type, generally is around 2.5–932 L per kg of product [Marcucci et al., 2001; Bisschops and Spanjers, 2003; Brik et al., 2006; Kocabas, 2008; Amar et al., 2009]. Moreover, the specific water consumption according to the Textile Best Available Technique (BAT) Reference (BREF) document varies between 10 and 645 L per kg of product (mean 22–184 L/kg product) in the textile industry [Ozturk et al., 2016b; EC, 2003].

In Turkey, textile industry is the second industry in the sector with the most intensive water consumption, corresponding to 15% of the industrial water consumption. [TSI, 2010; Alkaya and Demirer, 2014; Guyer et al., 2016]. It has been reported that the consumption of water in Turkey was 410 million m^3 in 2000 but this has been estimated to increase to 22 billion m^3 by 2030 [Barceló, and Petrovic, 2011].

In addition to water consumption, textile industry consumes a considerable amount of energy due to the need for heating the baths in wet processing which require the use of huge amount of water [Kocabas et al., 2009]. Therefore, recovery of hot wastewater is important both in terms of energy efficiency and reduction of the wastewater amount, and thus may decrease energy, water and wastewater costs [Voigt et al., 2001].

When evaluated according to composition and volume, the textile wastewater is considered to have many different pollutants compared to other industrial sectors. The characteristics of the wastewater originating from the textile industry are very different depending on the type of process, equipment, the kind of the fabric and the amount of wastewater [Koyuncu and Topacik, 2003; Bisschops and Spanjers, 2003; Verma et al., 2012; Vajnhandl and Valh, 2014]. Generally, wastewaters originated from dyeing, scouring, desizing, mercerization and finishing processes where have the potential for recovery and reuse [Wang et al., 2011], however, contain various compounds such as dye, detergents, sulphides, solvents, heavy metals, inorganic salts, surface active agents [Wang et al., 2011, Majewska-Nowak, 2010]. Between April 1976 and 2017, 2415 studies have been published on Web of Science concerning the treatment of textile wastewater (retrieved on the 27th April 2017). Most of these studies are related to the treatment and recovery of textile industry wastewater using chemical, biological and advanced treatment technologies [Lin and Chen, 1997; Seif and Malak, 2001; Bes-Pia et al., 2002; Schoeberl et al., 2005; Aslam et al., 2004; Van der Bruggen et al., 2005; Somensi et al., 2010]. The use of membrane technologies have been recommended as very effective option by many researches for reuse of wastewater and the chemical recovery [Sojka-Ledakowicz et al., 1998; Marcucci et al., 2001; Akbari et al., 2002; Capar et al., 2006; Majewska-Nowak, 2010; Verma et al., 2012; Sahinkaya et al., 2017]. Polymeric membrane filtration is the most commonly used method but it is not appropriate for high acidic/basic (pH:0–3; 11-14) or waters with high temperature (>70 °C) and requires bringing wastewater with high temperature (70–90 °C) to low temperatures in order to avoid problems in membrane structure which proves this method difficult for high temperature or higher acidic/basic wastewater treatment. Ceramic membranes are a good alternative to treat these types of water due to resistance to heat, acid, base, oxidants and organic solvents [Cheryan, 1998, Finley, 2005; Sondhi et al., 2003, Zhao et al., 2005; Freeman and Shorney-Darby, 2011]. These advantages result in longer prolife and less replacement requirement for ceramic membranes, additional to possibility of aggressive cleaning [Lee et al., 2013; Lamminen et al., 2004; Lee et al., 2002; Guerra and Pellegrino, 2013]. Moreover, as higher membrane fluxes are obtained with decreased viscosity and increased temperature [Cheryan, 1986; Snow et al., 1996; Kallioinen et al., 2007; Vladisavljevic et al., 1992; Zhao.et al., 2005; Lindmark et al., 2011], ceramic membranes have been emphasized by Cromey et al. (2015) for their utility in hot wastewater recovery for various industries due to their high permeability at high temperatures [Cromey et al., 2015]. Another advantage of the ceramic membranes over polymeric membranes is that the physically removable cake fouling in addition to their thermal and mechanic robustness [Lee et al., 2013, Lee and Kim, 2014, Cromey et al., 2015]. Hence, the need for chemical cleaning duration is longer and it is possible to gain higher flux for a longer duration with ceramic membranes (Lee et al., 2013, Cromey et al., 2015).

Even though the Textile BREF 2003 document is one of the most comprehensive documents giving information about cleaner production processes for textile industry, it only provides general recommendations for textile processes' wastewater treatment and reuse [Vajnhandl and Valh, 2014]. Further, studies concerning hot wastewater recovery and reusability, in particular for textile processes are limited in the current literature. In this study, applicability of ceramic membrane ultrafiltration for recovery of hot wastewater in textile industry was investigated which has not been studied in detail previously. Therefore, potential recovery points were selected and cross flow ceramic membrane filtration experiments were performed in this study in order to evaluate the reusability in the processes and to calculate water related costs. The results of this assessment would be a guide for hot wastewater recovery by ceramic membrane filtration in textile industry.

2. Materials and methods

2.1. Place of work and selections of potential hot wastewater recovery points

Investigated textile factory is located in Bursa Industrialized Region, Turkey and their production is based on order request from various famous brand textile companies. Studied textile factory is producing mainly cotton and viskon textile products about 15 tons/day and their water consumption is about 3200m^3/day and 214 L/kg product.

Various chemicals, dyes, cleaning additives and huge amounts of water are being used in the studied textile processes which consist of dyeing, printing, mercerization, scouring, desizing and various washing steps (Fig. 1). Wastewater amount, temperature and accessibility considered when the selection of potential recovery points for hot wastewater recovery targets. Selected points are disperse printing washing baths (number 2 and 3 hot discharges), disperse printing and reactive printing washing baths hot discharges mixing point (printing washing baths hot discharges mix) and mixed hot wastewater point, all over 50 °C degrees discharges collecting points, emphasized **as sample point** in Fig. 2. Particularly, the auxiliary chemicals used in disperse and reactive printing washing baths are soap, caustic, hydrosulfide and acetic acid. All kind of chemicals, soaps, various dyes (disperse, reactive, azo, etc.), other used agents may exist in mixed hot wastewater point. The most frequently used dyes are reactive and disperse types in various color types (reactive blue 72, reactive blue 49, disperse blue 106, disperse yellow 54, etc.) in the printing processes within this factory.

2.2. Analytical measurements

During wastewater characterization period, 40 hot wastewater samples were collected from selected four sample points. Electrical conductivity (EC), pH, chemical oxygen demand (COD), total organic carbon (TOC), color, total hardness analyzes were performed for the raw wastewater and permeate samples. The pH and