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# Recycling of textile wastewater with a membrane bioreactor and reverse osmosis plant for sustainable and cleaner production

Imran Ali, Seu-Run Kim, Sung-Pil Kim, Jong-Oh Kim*

*Department of Civil and Environmental Engineering, Hanyang University 222 Wangsimni-ro, Seongdong-gu Seoul 133-791, Republic of Korea, emails: imran.engineer41@gmail.com (I. Ali), sr013@hanmail.net (S.-R. Kim), Tel. +82 2 2220 4703; email: pillsp@naver.com (S.-P. Kim), Tel. +82 2 2220 0325; Fax: +82 2 2220 1945; emails: jk120@hanyang.ac.kr, jongohkim1221@gmail.com (J.-O. Kim)*

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ABSTRACT

Due to increasing industrial and human water consumption, as well as increasing water and wastewater disposal costs, recycling of industrial wastewater is of growing importance. The textile wet processing industry discharges a significant volume of wastewater with considerable organic contamination and residuals. In Yunus Textile Mills (YTM) in Pakistan, we successfully recycled textile wastewater using a membrane bioreactor (ultrafiltration) followed by reverse osmosis (RO). This textile wastewater recycling plant is the first of its kind in Pakistan and is an important benchmark for all future developments in textile wastewater treatment (WWT). In YTM, wastewater was treated with a series of environmentally friendly processes including heat recovery from hot wastewater using a custom-designed heat exchanger with an operating efficiency of 65.9% and reducing the wastewater temperature from 70 to 43°C. Neutralization of wastewater was achieved by mixing power plant exhaust emissions, thereby reducing wastewater pH from 12.1 to 8.4. Membrane bioreactor and RO plants reduced chemical oxygen demand, biological oxygen demand, and total dissolved solids up to 96.2, 97.1, and 96.4%, respectively, and removed color from the wastewater. This treated wastewater was then reused in the textile processes such as fabric washing and rinsing. Thus, the combination of the membrane bioreactor and the RO plant is feasible for textile WWT and reuse.

*Keywords:* Membrane bioreactor; Recycling of textile wastewater; Cleaner production practice; Waste heat recovery; Low waste discharge

## 1. Introduction

The textile industry has many sub-sectors including spinning, weaving, and wet processing. The textile wet processing industry comprises different processes, such as pre-treatment, dyeing, printing, washing, and finishing. It is also a major contributor to environmental pollution [1–3]. Textile industry wastewater is toxic to aquatic life and may present health risks to human beings [4,5]. A typical textile wet processing industry fabric flow diagram is shown in Fig. 1. The main environmental impacts of the textile wet processing industry include: high water and energy consumption and use of chemicals such as dyes, caustic soda, detergents, and salts [6–8]. Due to excessive use of these

*Corresponding author.

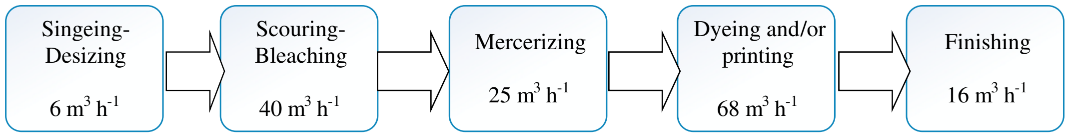


Fig. 1. Fabric process flow diagram of the textile wet processing industry.

resources, the textile wet processing industry produces many types of waste including: wastewater, solid waste, and exhaust emissions [9]. Wastewater production amounts to approximately 21–377 L $kg^{-1}$ of textile products [10]. Wastewater produced from textile wet processing is high in color, biological oxygen demand (BOD), total dissolved solids (TDS), chemical oxygen demand (COD), and salt [2,11,12]. Also, the final wastewater stream released after fabric bleaching, mercerizing, rinsing, and washing has a high temperature of 65–85˚C. Wastewater characteristics from the textile wet processing industry are shown in Table 1 [13].

Conventional physicochemical and biological processes are primarily utilized for the treatment of textile wastewater [14]. Most conventional biological treatment processes provide good BOD and COD removal; however, these conventional wastewater treatment (WWT) processes are not efficient in color removal due to chemical dye stability [15,16]. Chemical coagulation is also a very common treatment for textile wastewater, but this method generates a hazardous sludge that requires additional treatment for safe disposal [17]. Unfortunately, these conventional WWT processes do not produce water that is of high enough quality that it can be reused in any textile production process [18].

Presently, due to increased industrial and human water consumption, as well as increasing water and wastewater disposal costs, recycling of industrial wastewater is highly desired [19,20]. Membrane technology for industrial WWT and recycling is a better alternative to conventional WWT processes due to reduced water consumption and cost [21]. Membrane technology can remove color from wastewater. For example, indigo dyes can be successfully removed from wastewater using PVDF ultrafiltration (UF) membranes [22]. By combining nanofiltration and reverse osmosis (RO) membranes, treated wastewater can be reused again in dyeing processes [21]. Furthermore, membrane bioreactors (MBR), especially, those used for industrial WWT, have many advantages such as the production of high-quality water, less space requirements, less sludge production, high organic loading rate, and treated wastewater can be reused for certain purposes [20,23].

The objective of this study was to evaluate the recycling of textile wastewater with low waste discharge, a process that was developed in order to achieve a cleaner production practice. The entire tex-

Table 1
Wastewater characteristics from different textile wet processing industry processes

| Process | Chemicals in the textile process | Temp. (˚C) | pH | BOD (mg $L^{-1}$) | COD (mg $L^{-1}$) | TDS (mg $L^{-1}$) | TSS (mg $L^{-1}$) |
|---|---|---|---|---|---|---|---|
| Desizing | Enzymes, PVA, starch | 50–70 | 6–8 | 500–1,070 | | 1,580–4,030 | 400–600 |
| Scouring/ bleaching | Wax, soda ash, $H_2O_2$, surfactants, sizes (PVA, starch etc.) | 60–90 | 10–11 | 800–1,300 | 1,100–4,000 | 1,400–5,500 | 100–200 |
| Mercerizing | NaOH | 60–80 | 13–14 | | 700–800 | 2,000–3,500 | 300–800 |
| Dyeing | Dyes, surfactants, salts, urea, NaOH | 60–80 | 10–11 | 600–1,250 | 2,000–4,500 | 1,000–3,000 | 300–400 |
| Printing | Urea, binder, dyes, soda ash, gums | 30 | 8–11 | 80–120 | 300–3,000 | 1,000–3,800 | 50–300 |
| Finishing | Resins, hydrocarbons, formaldehyde | 30 | 8–10 | | 500–800 | | 200–300 |

Notes: Temp. = temperature, PVA = polyvinyl alcohol, BOD = biological oxygen demand, TDS = total dissolved solids, COD = chemical oxygen demand, TSS = total suspended solids.

tile WWT scheme included the following processes: energy recovery in the form of heat from hot wastewater, pH reduction through mixing of the power plant exhaust emissions with wastewater, and further treatment of textile wastewater with MBR UF and RO membranes to make water reusable in textile processes (e.g. fabric washing and rinsing).

## 2. Analytical methods

Water was sampled two times per week for 30 d. For the BOD test, an incubator plus BOD track apparatus (HACH, USA) was used. For COD and color measurement, a spectrophotometer (HACH, DR 3800, USA) was used. For conductivity and TDS analyzing, a Mettler Toledo (S230K, USA) conductivity meter was used. A Mettler Toledo (S220K, UK) pH meter was used to measure pH and the APHA method was used to evaluate hardness. For turbidity measurement, a Turbidimeter (HACH, 1720E, USA) was used. TSS analysis was outsourced to the PERAC Research and Development Foundation (PRD lab); all other analysis were performed in-house. Wastewater analyzing instruments were calibrated before starting and again during analysis.

## 3. A description of the WWT process

This study was carried out at Yunus Textile Mills (YTM), located in Karachi, Pakistan, with a fabric production capacity of 100 million m year$^{-1}$. YTM is the largest exporter of home textile products from Pakistan, through its manufacture of cotton and polyester fabrics. It has customer service offices located in the USA and Europe. YTM has its own power plant to generate electricity from natural gas and has a coal boiler for steam generation. The water consumption of different processes at YTM is shown in Fig. 1. The total water consumed by YTM is approximately 185 m$^3$ h$^{-1}$. Wastewater generated from various processes is collected through a channel system. Cold and hot wastewater is collected separately, as shown in Fig. 2.

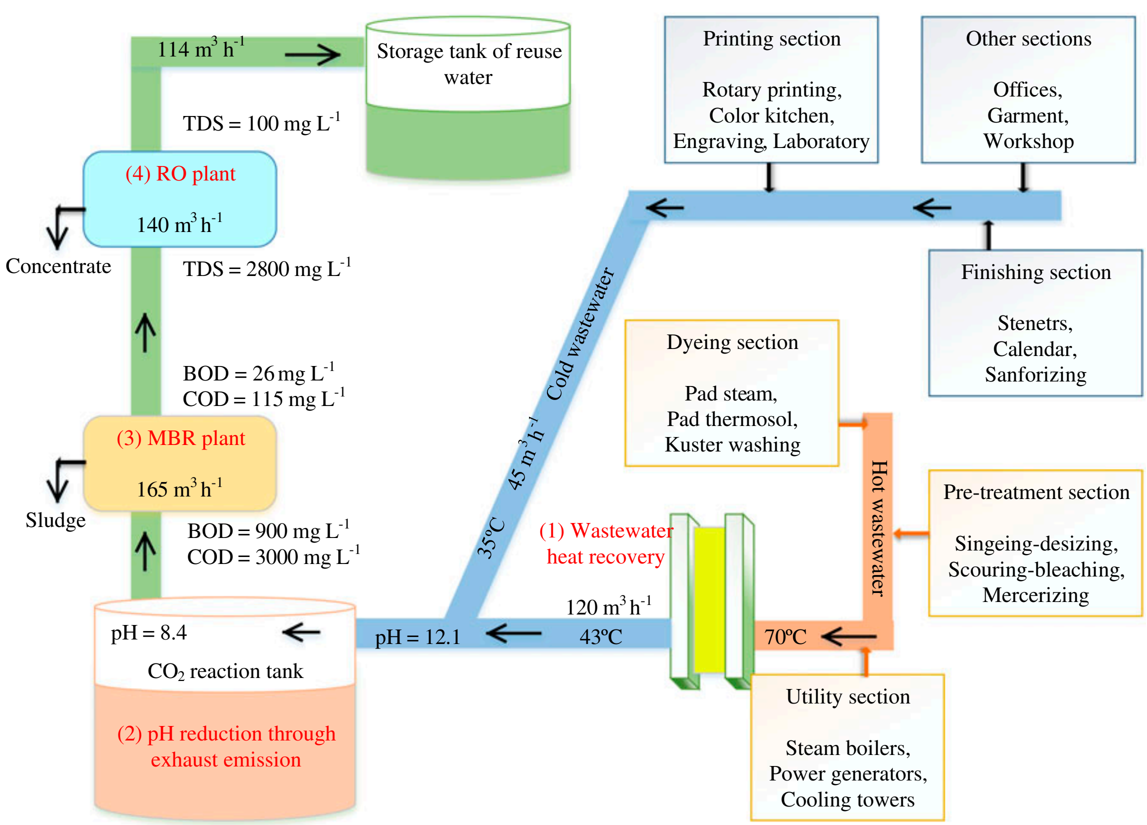


Fig. 2. Overall wastewater collection and treatment at Yunus Textile Mills.

As per the typical protocol in YTM, wastewater was treated with the following series of environmentally friendly processes:

(1) Heat exchanger to gain heat energy from hot wastewater.
(2) Wastewater pH reduction through the mixing of power plant exhaust emissions.
(3) WWT with a MBR UF membrane.
(4) Further MBR product water treatment with an RO membrane.

### 3.1. Wastewater heat recovery (WHR) plant

Wastewater resulting from bleaching, dyeing, washing, and rinsing processes has a high temperature (70℃) and should be cooled for effective WWT. Wastewater temperature reduction was carried out via indirect incorporation of hot wastewater with fresh cold water using a custom heat exchanger. The hot wastewater first entered a distributor then passed through inlet pipes where it transferred its heat energy to incoming fresh cold water. The fresh hot water was then collected in a storage tank.

### 3.2. Wastewater pH reduction process

Wastewater from the textile wet processing industry exhibited a pH above 12. This high pH value was the result of alkali reagents, especially caustic soda. As most of the textile wet processes are achieved in an alkaline medium, neutralization is required for effective WWT and safe sewer disposal. Considering sustainability, which is an essential driver of innovation, considerable research and development effort has gone into devising cheaper, more reliable alternatives to sulfuric acid, the typical alkali neutralizing agent. The flue gas exhaust from the electric generator and turbine was diverted by a liquid ring pump. Then, these flue gases were injected into a carbon dioxide ($CO_2$) reaction tank, as shown in Fig. 3. The $CO_2$ in the exhaust gas reacted with the wastewater thereby producing carbonic acid ($H_2CO_3$). This reduced the wastewater pH and sulfuric acid ($H_2SO_4$) consumption at the WWT level. Moreover, this method offered an indirect environmentally friendly use of exhaust emissions thereby avoiding their direct discharge into the atmosphere.

### 3.3. The membrane bioreactor plant

Previously, YTM relied on a conventional activated sludge (CAS) WWT plant that had a WWT capacity of 2,500 $m^3 d^{-1}$ and utilized conventional aeration followed by a clarification process. This generated a large amount of sludge. With the increasing fabric production capacity of YTM and because of the need of cleaner production practices for water resource management, a recycling WWT plant with MBR and RO was installed. Airlift MBR (Norit, Netherlands) with a WWT capacity of 5,500 $m^3 d^{-1}$, more than double the previous CAS WWT plant capacity, was used. This textile wastewater recycling plant is the first of its kind in Pakistan and is an important benchmark for all future developments in textile WWT.

Herein, recycling of wastewater included activated sludge treatment with a biomass separation process carried out by UF membranes mounted vertically outside the bioreactor and followed by RO membranes filtration. The overall plant recovery was greater than 94%. MBR generated less sludge, because the entire process was a biological treatment, shown in Fig. 4. Incoming wastewater was first passed through a fine grating to remove debris then, from the equalization

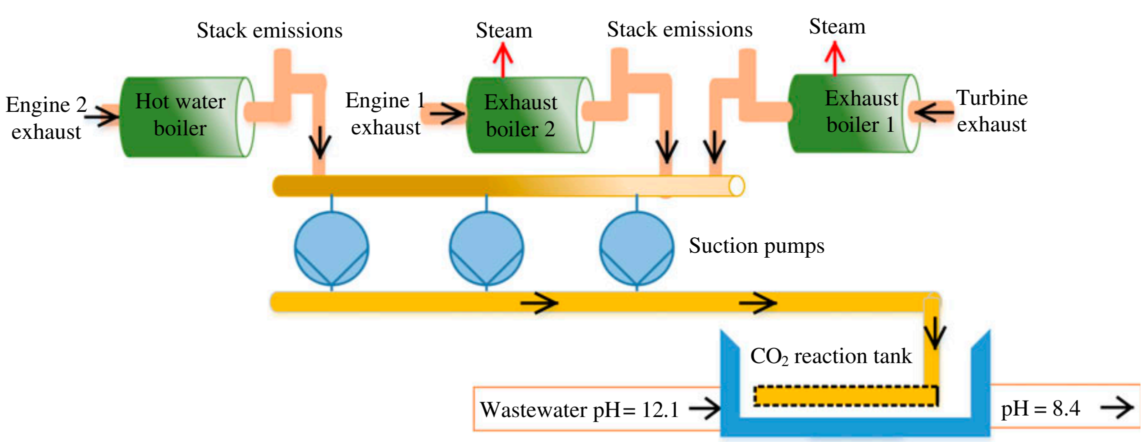


Fig. 3. Wastewater pH control using power plant exhaust emissions.

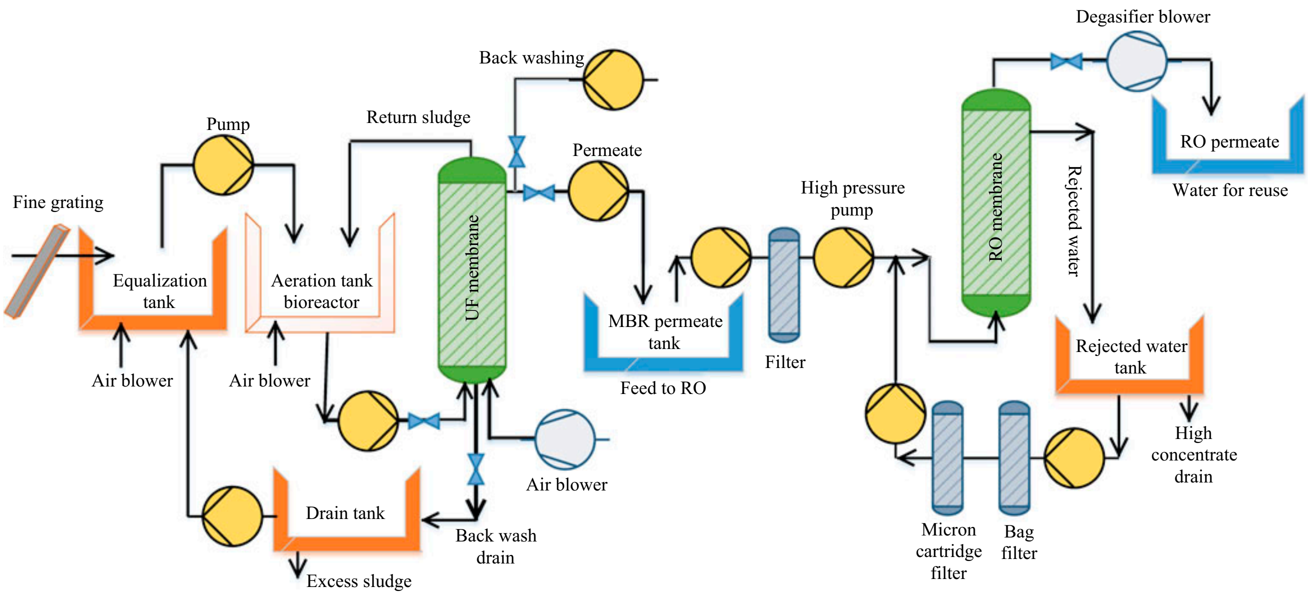


Fig. 4. Combined schematic diagram of the membrane bioreactor and RO plant.

tank, it was pumped into the bioreactor tank. Another pump fed wastewater from the bioreactor to the bottom of each module where air was also injected. The sludge mixture was discharged from the top of each module and returned to the bioreactor tank. Back washing was initiated on a timed cycle for each module of 8 s for every 8 min to remove any cake formation inside the membrane and to maintain flux rates. Back wash drain water was collected in a drain tank, from where it is pumped to an equalization tank. Excess sludge was collected from the drain tank, transferred to a centrifuge for dewatering, and then sent to a landfill.

MBR technical details and operating parameters are shown in Table 2. The bioreactor tank volume was 4,500 $m^3$ and there was 30 d of testing. The operating membrane pressure was 0.5 bar and the molecular weight cut-off was 0.25 micron.

### 3.4. Reverse osmosis plant

MBR reduced the COD and BOD from wastewater. However, removal of TDS and color from wastewater was also required to make water reusable. The RO plant was installed to capture MBR permeate, as shown in Fig. 4, with a water treatment capacity of 5,340 $m^3 d^{-1}$. The MBR permeate first passed from a cartridge filter, then a high-pressure pump fed water into RO membranes. The RO permeate was then passed from the de-gasifier and collected in a tank, from which it was sent for reuse in textile processes such as fabric washing and rinsing. The water that was rejected by the RO membrane was also collected in a separate tank, from which it was pumped to a bag filter and micron cartridge filter. Then, it passed through another high-pressure pump and to an RO membrane. Flushing was also performed on a 45-min timed cycle of flushing every 12 h to remove cake formation inside the membrane and to maintain flux rates.

RO technical details and operating parameters are shown in Table 3. The NaCl retention was 96% and the working temperature was 36°C. The RO process efficiently works at pH 6–7; therefore, the pH was maintained at 6.5 with the addition of acid.

## 4. Results and discussion

Treatment of textile wastewater is a cumbersome process because of the high temperature, pH, TDS, BOD, COD, and color.

### 4.1. Wastewater heat recovery (WHR) plant

For reducing the wastewater temperature from 70 to 43°C, previously YTM used cooling towers (CTs), which consumed electricity at 24 kW. The cost of that electricity was around US$10,000 $year^{-1}$. At the time of this publication, YTM used custom heat exchangers for WHR with an operating efficiency of 65.9%. Fresh water was used at a rate of 39.8 $m^3 h^{-1}$ with final temperature of 45.5°C. The fresh hot water was then used in fabric rinsing and washing processes and required less steam to achieve the target temperature. This resulted in an environmental benefit of a reduction in

Table 2
Membrane bioreactor plant technical details and operating parameters

| Parameter | Value | Unit |
|---|---|---|
| *Technical data* | | |
| MBR system | External airlift | |
| Plant capacity | 5,500 | $m^3\ d^{-1}$ |
| Number of skids | 6 | |
| Skid flow rate | 38.2 | $m^3\ h^{-1}$ |
| Number of modules | 180 | |
| Membrane material | Polyether sulfonate | |
| Membrane pore size | 25 | nm |
| Membrane area | 33 | $m^2$ |
| Membrane life time | 3 | years |
| Bioreactor tank volume | 4,500 | $m^3$ |
| Project cost | 2,500,000 | US$ |
| Membrane pH limit | 6–9 | pH |
| Temperature limit | 15–40 | ℃ |
| *Operational data* | | |
| MLSS | 10,000 | $mg\ L^{-1}$ |
| VSS | 8,000 | $mg\ L^{-1}$ |
| Organic loading rate | 2–3 | $kg\ COD\ m^{-3}\ d^{-1}$ |
| Working pH | 8.2 | pH |
| Working temperature | 37 | ℃ |
| Membrane pressure | 0.5 | bar |
| Molecular weight cut-off | 0.25 | micron |
| Back wash frequency | 8 | min |
| Back wash time | 8 | s |
| Flux | 55 | Lmh |
| SRT | 30 | d |
| HRT | 20 | h |
| Biological process time | 22 | h |
| Air pressure | 0.7 | bar |
| Electric consumption per $m^3$ of water | 2.2 | kW |

Notes: US$ = US dollars, MLSS = mixed liquor suspended solids, VSS = volatile suspended solids, Lmh = $L/m^2\ h^{-1}$, SRT = solid retention time, HRT = hydraulic retention time.

$CO_2$ emission by of 2,500,000 kg $year^{-1}$ and annual savings of US$220,000 (Table 4). The entire process consumed 5.5 kW of electricity. The payback of the system was approximate 1.5 years. This centralized heat recovery system was beneficial to recover heat energy from hot wastewater, instead of recovering heat from individual textile processes, and was easier to control and operate.

### 4.2. The wastewater pH reduction process

Previously, to reduce the wastewater pH, sulfuric acid consumption was 2,200,000 kg $year^{-1}$. This costs approximately US$30,000. When the exhaust emissions were mixed with wastewater, which formed carbonic acid, the pH of the wastewater was reduced from 12.1

Table 3
Reverse osmosis plant technical details and performance (operating) parameters

| Parameter | Value | Unit |
|---|---|---|
| *Technical data* | | |
| Plant capacity | 5,340 | $m^3\ h^{-1}$ |
| Number of trains | 3 | |
| Train flow rates | 115, 115, and 35 | $m^3\ h^{-1}$ |
| Number of modules | 354 | |
| Membrane material | Polyamide | |
| Membrane pore size | 0.001 | nm |
| Membrane area | 37.2 | $m^2$ |
| Membrane life time | 3 | years |
| Project cost | 1,440,000 | US$ |
| Membrane pH limit | 2–11 | pH |
| Temperature limit | 18–45 | ℃ |
| *Operational data* | | |
| NaCl retention | 96 | % |
| Working pH | 6.5 | pH |
| Working temperature | 36 | ℃ |
| Flushing frequency | 12 | h |
| Flushing time | 45 | min |
| Feed water pressure | 12 | bar |
| Electric consumption per $m^3$ of water | 1.0 | kW |

Table 4
Energy-related overview of a wastewater heat recovery plant

| Parameter | Value | Unit |
|---|---|---|
| Fresh water temp. inlet | 21.1 | ℃ |
| Feed water temp. outlet | 45.5 | ℃ |
| Heat gain (in terms of water temp. difference) | 25.4 | ℃ |
| Fresh water quantity | 39.8 | $m^3\ h^{-1}$ |
| Recovered energy | 4,229,700 | $kJ\ h^{-1}$ |
| Effective fuel heating value (at 80%) per $m^3$ | 28,618.9 | kJ |
| Recovery in terms of fuel | 1,300,000 | $m^3\ year^{-1}$ |
| Natural gas (fuel) price per $m^3$ | 0.17 | US$ |
| Energy saving per year | 220,000 | US$ |
| $CO_2$ emission factor per $m^3$ of fuel | 1.9 | kg of $CO_2$ |
| $CO_2$ emissions reduction | 2,500,000 | $kg\ year^{-1}$ |
| Total cost of the project | 330,000 | US$ |
| Payback | 1.51 | years |

Notes: Temp. = temperature, kJ = kilo joule.

Table 5
Overview of the wastewater pH reduction process using power plant exhaust emissions

| Parameter | Value | Unit |
|---|---|---|
| Inlet pH | 12.1 | pH |
| Outlet pH | 8.4 | pH |
| Previous sulfuric acid consumption | 2,200,000 | kg year$^{-1}$ |
| Sulfuric acid rate | 0.02 | US\$ kg$^{-1}$ |
| Sulfuric acid cost | 30,000 | US\$ year$^{-1}$ |
| Electric consumption of the project | 50 | kW |
| Electric rate | 0.08 | US\$ kW$^{-1}$ |
| Electric cost | 20,000 | US\$ year$^{-1}$ |
| Saving | 10,000 | US\$ year$^{-1}$ |
| Equivalent $CO_2$ emission factor per kg of sulfuric acid | 0.09 | kg of $CO_2$ |
| $CO_2$ emissions reduction | 190,000 | kg year$^{-1}$ |
| Project cost | 40,000 | US\$ |
| Payback | 3.86 | years |

to 8.4 without the need of sulfuric acid. The entire process consumed 50 kW of electricity and saved approximately US\$10,000 year$^{-1}$ (Table 5). The environmental benefit of $CO_2$ emission reduction was 190,000 kg year$^{-1}$. The payback of the system was approximately 3.8 years. In this manner, YTM reduced its carbon emissions and increased sustainability.

### 4.3. The membrane bioreactor plant

MBR is a biological process with negligible odor. The biological process was carried out for 22 h. The organic loading rate was 2–3 kg COD m$^{-3}$ d$^{-1}$ and the ratio of BOD/COD was 0.23–0.30. As the organics depend upon the influent wastewater characteristics and there is high variation in textile processes, there were also variations in these ratios. Some chemicals used in the textile processes (such as PVA) were not readily biodegradable during a short HRT period, so the HRT time was extended to 20 h for efficient removal of these chemicals.

The MBR plant reduced the COD of the wastewater from 3,000 to 115 mg L$^{-1}$ (96.2% removal) and the BOD from 900 to 26 mg L$^{-1}$ (97.1% removal) with an average water flow rate of 165 m$^3$ h$^{-1}$. The MBR produced high-quality treated wastewater below the effluent limits defined by the Pakistan EPA (Table 6) and generated a small amount of sludge compared to the CAS system. With the water recycling system, the YTM MBR average sludge production was 1,500 kg d$^{-1}$, which was sent to a land fill, but may be used in the future as a soil conditioner. Previously, the YTM CAS system average sludge production was 1,785 kg d$^{-1}$. The MBR water analysis results compared to Pakistan EPA wastewater disposal limits [24] are shown in Table 6. Wastewater TDS (average 2,800 mg L$^{-1}$) are not removed by MBR because it is a biological process, but even TDS were below the effluent limits (3,000 mg L$^{-1}$) defined by the Pakistan EPA. Thus, MBR is the optimum solution for treating textile wastewater for recycling and to make water suitable for the subsequent RO treatment process.

### 4.4. Reverse osmosis plant

As MBR does not remove TDS, an RO plant was installed to treat the MBR permeate. The RO plant reduced the TDS of the wastewater from 2,800 to 100 mg L$^{-1}$ (96.4% removal) and produced colorless water at a rate of 140 m$^3$ h$^{-1}$. The RO permeate was reused in textile processes including fabric washing and rinsing. In this way, YTM could achieve a more environmentally friendly process and become less dependent on water from an outside source. The RO concentrate stream was generated at a rate of approxi-

Table 6
Water analysis results of the membrane bioreactor plant, compared to the Pakistan EPA wastewater discharge limit

| Parameter | Unit | Inlet | Avg. | Outlet | Avg. | NEQs limit |
|---|---|---|---|---|---|---|
| Water flow | m$^3$ h$^{-1}$ | 100–185 | 165 | 90–170 | 150 | |
| Temp. | ℃ | 31–43 | 37 | 30–39 | 37 | 40 |
| COD | mg L$^{-1}$ | 2,500–3,800 | 3,000 | 89–148 | 115 | 150 |
| BOD | mg L$^{-1}$ | 800–1,200 | 900 | 18–42 | 26 | 80 |
| TDS | mg L$^{-1}$ | 2,550–4,570 | 2,860 | 2,500–4,500 | 2,800 | 3,500 |
| pH | | 7.9–8.8 | 8.2 | 7.7–8.7 | 8.0 | 6–9 |
| Turbidity | NTU | | | 0.6–1.2 | 0.8 | |
| TSS | mg L$^{-1}$ | | | 0.0–2.0 | 1.0 | 200 |

Notes: Avg. = average, NTU = nephelometric turbidity unit, EPA = environmental protection agency, NEQs = national environmental quality standards.

Table 7
Water analysis results of the reverse osmosis plant, with water reuse limits for textile processes

| Parameter | Unit | Inlet | Avg. | Outlet | Avg. | Reuse limit |
|---|---|---|---|---|---|---|
| Water flow | $m^3\ h^{-1}$ | 125–160 | 140 | 102–132 | 114 | |
| TDS | $mg\ L^{-1}$ | 2,500–4,500 | 2,800 | 45–250 | 100 | 65–300 |
| pH | | 5.5–7.0 | 6.5 | 5.0–6.5 | 6.2 | 6.5–7.5 |
| Turbidity | NTU | 0.3–1.5 | 0.8 | 0.0–0.0 | 0.0 | 0.0 |
| Conductivity | $\mu S\ cm^{-1}$ | 5,050–9,100 | 5,600 | 94–520 | 205 | 200–800 |
| TSS | $mg\ L^{-1}$ | 0.0–2.0 | 1.0 | 0.0–0.0 | 0.0 | 0.0 |
| Hardness | $mg\ L^{-1}$ | | | 1.0–5.0 | 2.0 | 5–30 |
| Color | | | | | N.D | Colorless |

Note: N.D. = not detectable.

mately 15–25 $m^3\ h^{-1}$. A possible treatment of the RO concentrate stream is under development, and the use of multiple effect evaporator is promising.

The RO water analysis results are shown in Table 7; they are below the limits for water reuse for the textile wet processing industry [19]. From the RO water results, it can be concluded that most of the treated water parameters are within the reuse limits of water used by the textile industry. This combination of membrane filtration system (MBR and RO) is suitable for textile WWT, accomplishing high pollutant removal, and permitting reuse of wastewater in textile processes.

## 5. Conclusion

In this study, recycling of textile wastewater with a MBR UF membrane and RO plant was evaluated and deemed successful at YTM. This textile wastewater recycling plant is the first of its kind in Pakistan. In YTM, wastewater was treated with a series of following environmentally friendly processes.

The wastewater heat recovery system reduced the temperature of hot wastewater from 70 to 43˚C. The recovered heat energy from hot wastewater was used to heat fresh cold water. This less steam was needed to raise the temperature of fresh cold water for textile processes such as fabric washing and rinsing. The environmental benefit was a reduction in $CO_2$ emissions by 2,500,000 kg $year^{-1}$.

pH reduction was achieved through the mixing of power plant exhaust emissions with highly alkaline textile wastewater. This reduced the pH of wastewater from 12.1 to 8.4, which reduced the sulfuric acid consumption required for neutralization of wastewater. This resulted in less direct emissions of greenhouse gases into the atmosphere with a $CO_2$ emission reduction of 190,000 kg $year^{-1}$.

The MBR plant had an overall recovery greater than 94% and reduced COD and BOD levels from wastewater up to 96.2–97.1%, respectively. The MBR produced high-quality treated wastewater. It is a biological process with negligible odor and a small quantity of sludge was generated compared to the CAS system for textile WWT.

An RO plant was installed to treat the MBR permeate water and reduced TDS up to 96.4% from wastewater. The RO permeate water was then reused in textile processes including fabric washing and rinsing. This decreased the dependency on the raw water supply and, this way, the YTM can achieve a more environmentally friendly production process.

In conclusion, the combination of membrane-based separation processes (MBR and RO) is effective solution to treat textile wastewater. This will not only achieve high pollutant removal, but wastewater can also be reused.

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