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TECHNICAL AND ECONOMIC ASPECTS OF REUSING TEXTILE EFFLUENT AS PROCESS WATER: A CASE STUDY OF DENIM WASHING FACTORY

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Abstract

Textile and apparel industries are the major role-players in the fast-growing economy of Bangladesh. However, the textile sector consumes a large amount of water for various wet processing operations. Currently 98% of the water used by local textile factories is groundwater, which is causing depletion of ground water levels at a high rate. Considering the gravity of groundwater crisis in future, Bangladesh Government and international brands and retailers are advocating local textile factories to reuse textile effluents and implement ZLD (zero liquid discharge) option in the upcoming years. However, it is a new concept for Bangladesh textile sector, and there is limited understanding regarding technical and economic issues associated to advanced treatment and reusing textile effluent. In this paper, a case study is presented to analyse the application of advanced membrane treatment of conventional ETP (effluent treatment plant) treated water of a denim washing factory. The corresponding technical and economic issues of water recycling and reusing were also analyzed. The selected denim washing factory runs a conventional biological effluent treatment plant (ETP) which satisfies the basic requirements of national and international standards. For advanced treatment, a mobile setup of ultrafiltration (UF) and reverse osmosis (RO) unit was used at factory premises to further treat ETP treated water. The advanced treatment was carried out for three different permeate to reject ratios to observe changes in the permeate and reject water quality. Capital expenditure and operational costs were also assessed to see the economic feasibility of the approach. This study will help local textile factories with real time data to understand the technical and economic issues associated to reusing textile wastewater as process water.

Keywords: textile effluent; denim washing factory; groundwater; advanced treatment; ultrafiltration; reverse osmosis; reuse textile effluent.

1. Introduction

Textile industries have been the backbone of the economy of Bangladesh for many years. Bangladesh exports almost 750 textile and readymade garment products in global market, which includes USA, Europe, China and Japan's market [1]. The ready-made garment (RMG) industry has occupied a unique position in the economy of Bangladesh. It is the largest exporting industry in Bangladesh and in the last four decades, it has experienced phenomenal growth [2][3].

Textile industries in Bangladesh consume a large amount of water every day which is extensively used in wet processing operations. But The gap between the water demand of textile wet processing factories and availability of high-quality water (water that can be used in wet processing operations) is continuously increasing. Currently, 98% of the water used by these industries is groundwater [4]. Recently It has been reported that in Dhaka city, a permanent declining trend of groundwater level was observed due to excessive withdrawal for city water supply and around Dhaka city for industrial withdrawal [5]. And the situation of other industrial zones near to Dhaka is no different. So, some alternative sources of freshwater would be beneficial for these areas. Textile industries treat their process effluent water with effluent treatment plants (ETP) and then release them in the environment according to the guideline given in ECR 1997. But instead of completely discharging them into the environment, reusing this effluent water in the industries as process water would certainly help to decrease the dependency on groundwater.

Local textile factories use traditional chemical, physico-chemical and biological effluent treatment plants (ETPs) to comply with local and international standards for treated water parameters. Nowadays, membrane processes have become the technology-

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of-choice as tertiary treatment of ETP treated water and to provide reusable water to factories. Ultrafiltration and reverse osmosis membranes are becoming popular as tertiary treatment units. Ultrafiltration membranes are used for many applications. Some of them can remove dissolved compounds like colloids, carbohydrates, proteins, etc. that have high molecular weight. UF membranes cannot remove sugar or salt. They can also remove viruses and can produce rinse water of high purity in the industries [6].

Reverse osmosis is a technology that uses a semipermeable membrane to remove contaminants from water. It can remove dissolved solids, organics, pyrogens, submicron colloidal matter, colour, nitrate and bacteria from water. Feedwater is delivered under pressure through the semi-permeable membrane, where water permeates the minute pores of the membrane and is delivered as purified water called permeate water [7].

In this paper, a denim washing factory was selected for the case study. This factory is located at Gazipur, Dhaka. For fabric processing and other sanitary purposes, the factory requires fresh water at a rate of 800 m^3/day. For treating this wastewater, the industry has a full-scale effluent treatment plant (ETP). This is a conventional biological ETP, which contains a screening unit followed by an equalization unit, pH control unit, aeration unit, sedimentation unit, sludge thickening unit and finally a sludge dewatering unit from which sludge is disposed. This study produces industry-based data to analyse technical and economic aspects of reusing textile effluent water. This study will help factory owners and policy makers to plan and set target to implement water recycle and reuse options to reduce water consumption and water footprint for textile wet processing.

2. Materials and Methods

2.1. Wastewater and ETP treated water characterization

Untreated wastewater and ETP treated water samples were collected from the inlet and outlet of the effluent treatment plant of a denim washing industry located at Gazipur, Dhaka. The main parameters that were used to characterize the wastewater were pH, total dissolved solids (TDS), total suspended solids (TSS), colour, biological oxygen demand (BOD5) and chemical oxygen demand (COD). pH was measured using a pH meter from HANNA. TDS was measured using TDS meter from HANNA. TSS, colour and COD were measured using DR 6000 spectrophotometer from HACH. BOD5 was measured using standard method 5210B.

2.2. Membranes

A Pre-treatment filter was used to treat the effluent coming out of the ETP which contained 5 standard 40" string wound filter cartridges. The pore size of the pre-treatment filter was 100 microns. CLRO20 filter made by Hydromaster which is a combination of ultrafiltration and reverse osmosis system along with the pre-treatment filter was used for this study. The technical details of the membrane systems are given in table 1. Figure 1 shows the mobile setup of UF and RO membrane used in this case study.

Table 1.

Technical details of ultrafiltration and reverse osmosis units

Particulars	Ultrafiltration	Reverse osmosis
Model	U850	UP-LRO 8040
Material	Hydrophilic modified PAN, PVDF or PTFE (Teflon)	Thin-film composite, Polyamide
Module	Hollow fiber	Spiral wound, FRP wrapping
Pore size	0.02 micron	0.001 micron
Surface area	35 m^2/membrane	37.1 m^2
Number	2	1

Fig 1: Schematics of the applied advanced treatment of the ETP treated water

A part of the effluent from the ETP was stored in a tank and then taken into the filtration system using a submersible pump. The pump flows the water through the pre-treatment filter. Water from this filter was then passed to the ultrafiltration membranes. Water flowed through the membranes in parallel and the combined permeate was passed to the reverse osmosis unit. The maximum pressure of the feed in the reverse osmosis unit was 145 psi (10 bar). Figure 2 represents the schematics of the advanced treatment process of the ETP treated water.

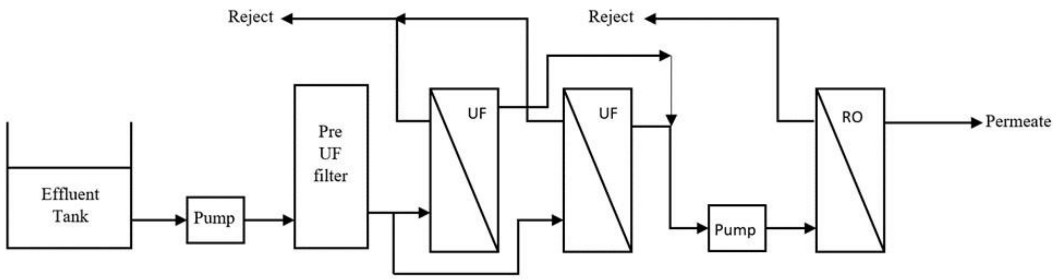

Fig 2: Schematics of the applied advanced treatment of the ETP treated water

2.3. Effluents analysis

The reverse osmosis unit of the mobile filtration unit can be configured to change the flowrate of reject (i.e., saline water) or permeate (i.e., treated water) stream. In this study, flowrate of the reject stream was varied. Reject flowrate was varied to achieve three set of permeate flowrate to reject flowrate ratio: 80:20, 60:40, and 50:50. For each set permeate water and reject water, samples were collected.

A time dynamic analysis of the performance of membranes was also conducted. For this study, the filtration system was run for 2 hours at a specific permeate flowrate to reject flowrate ratio. The permeate flowrate to reject flowrate ratio that was selected for this study was 60:40. After continuous operation of 2 hours, samples from the same streams were collected again. For the water samples, TDS, TSS, Colour, BOD, COD and pH were measured in the laboratory.

3. Results and Discussion

3.1. Contaminants removal

The untreated wastewater sample and ETP treated water sample from the denim washing factory were collected for characterization and TDS, TSS, colour, BOD, COD and pH values were measured. ETP treated water satisfied the national DOE standard for discharge in inland surface water presented in ECR 1997. However, quality of ETP treated water was inferior to that of process water, surface water or groundwater, and cannot be reused as process water. TDS, TSS, colour, BOD, COD and pH values of untreated wastewater, ETP treated water, DOE standards and process water are listed in table 2.

At the industry, for the three set of permeate flowrate to reject flowrate ratio: 80:20, 60:40, and 50:50, selected water quality parameters were measured and the values of those are listed in table 3.

The test results given in table 3 are average of three readings. In TDS removal, good performance was observed for all cases.

For permeate to reject flowrate ratio of 60:40, 80:20 and 50:50, the removal efficiency was found to be 93%, 95% and 98% respectively. In all cases, no suspended solid was found in the permeate. Colour was completely removed from the ETP treated water (feed) for permeate to reject flowrate ratio of 60:40 and 80:20. In the case of permeate to reject flowrate ratio of 50:50, 99% colour removal was observed which indicates practically the same efficiency in removing colour from the ETP treated water containing colour of 177 Pt-Co. Significant amount of BOD and COD removal was obtained. For permeate to reject flowrate ratio of 60:40, The removal efficiency for BOD and COD were found to be 90% and 91% respectively. For other ratios, efficiency was found to be 92% for both BOD and COD. For permeate to reject flowrate ratio of 80:20, 60:40 and 50:50, pH was 7.8, 7.5 and 7.6 respectively. A decreasing pattern of TDS removal was observed with increase in initial permeate flowrate percentage from the RO unit. TSS and colour removal were found to be almost constant. BOD removal varied from 90% to 92% whereas COD removal varied from 91% to 92%. With the increase in initial permeate flowrate percentage, BOD and COD removal remained mostly consistent. pH was found to vary between 7.5 and 7.8.

Since feed water property might have changed slightly during the operation, the actual removal percentage of contaminants may vary from the measured values. The variation of parameter TDS, TSS and colour with increase in initial permeate flowrate percent from the RO unit is presented in figure 3. Through analysis of the permeate water after 2 hours of continuous operation, pH, TDS, TSS, colour, BOD and COD were measured for the permeate to reject flowrate ratio of 60:40. The values of these parameters are presented in table 4. It was observed that the contaminant removal percentages did not vary significantly. Since all the parameter values did not vary notably even after 2 hours of operation, it can be considered that water quality also did not vary significantly. But with time, their flowrate will decrease due to build-up of resistance across the membranes.

Table 2.
TDS, TSS, colour, BOD, COD and pH values of untreated wastewater, ETP treated water, DOE standards and process water

Parameter	Untreated wastewater	ETP treated water	DOE standard for process water	
			inland surface water	(Groundwater)
TDS (mg/l)	587	1120	<2100	80-180
TSS (mg/l)	38	6	<150	Nil
Colour (Pt-Co)	3350	177	-	Nil
BOD (mg/l)	603	25	<50	0.5-10
COD (mg/l)	1440	85	<200	10-30
pH	7.2	8	6-9	6.5-7.5

Table 3.
Permeate to reject flowrate ratio of 60:40, 80:20 and 50:50 in the RO unit

Permeate to reject flowrate ratio	Parameter	Feed	Reject from ultrafiltration	Permeate from reverse osmosis	Reject from reverse osmosis	contaminant removal (%)
80:20	TDS (mg/l)	1120	1132	74	3920	93
	TSS (mg/l)	6	1	0	1	100
	Colour (Pt-Co)	177	175	BDL	420	100
	BOD (mg/l)	25	110	2	17	92
	COD (mg/l)	85	259	7	118	92
	pH	8	7.8	7.8	7.9	-
60:40	TDS (mg/l)	1120	1132	53	2640	95
	TSS (mg/l)	6	1	0	1	100
	Colour (Pt-Co)	177	175	BDL	308	100
	BOD (mg/l)	25	110	2.5	29	90
	COD (mg/l)	85	259	8	88	91
	pH	8	7.8	7.5	7.9	-
50:50	TDS (mg/l)	1120	1132	24	2070	98
	TSS (mg/l)	6	1	0	1	100
	Colour (Pt-Co)	177	175	1	233	99
	BOD (mg/l)	25	110	2	43	92
	COD (mg/l)	85	259	7	195	92
	pH	8	7.8	7.6	8.1	-

Table 4.
Permeate to reject flowrate ratio of 60:40 in the RO unit at the beginning and after operating 2 hours

	Parameter	Feed	Reject from ultrafiltration	Permeate from reverse osmosis	Reject from reverse osmosis	contaminant removal (%)
at t=0 hr	TDS (mg/l)	1120	1132	53	2640	95
	TSS (mg/l)	6	1	BDL	1	100
	Colour (Pt-Co)	177	175	BDL	308	100
	BOD_5 (mg/l)	25	110	2.5	29	90
	COD (mg/l)	85	259	8	88	91
	pH	8	7.8	7.5	7.9	-
at t=2 hr	TDS (mg/l)	1120	1171	38	1473	97
	TSS (mg/l)	6	1	BDL	1	100
	Colour (Pt-Co)	177	172	BDL	257	100
	BOD_5 (mg/l)	25	36	4	49	84
	COD (mg/l)	85	143	12	128	86
	pH	8	7.7	7.7	7.9	-

BDL: below detection limit

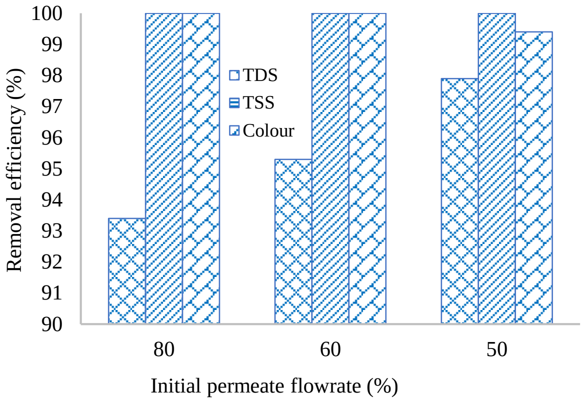

Fig.3. Change in removal efficiency of TDS, TSS and colour with the change in initial permeate flowrate percentage in the RO unit

3.2. Operating and Investment costs and water requirement of the factory

Based on the results obtained, the following economic considerations can be drawn. Considering permeate quality and backwash for RO unit, permeate and reject flowrate ration 60:40 was considered the optimum ratio out of three set ratios used in this study. Considering the membrane surface areas of UF and RO units used in this study, costs to treat full volume of ETP treated water of that specific factory were calculated. For the above assumptions, the following economic data can be found (table 5).

Real-life data was collected from international membrane suppliers (KOCH Separation Solutions Ltd. and SUEZ Water Technologies and Solutions Ltd.) to calculate the capital cost and operating cost of UF and RO. The cost calculation is shown in table 5; the cost for advanced water treatment was found to be **24.29 BDT/m^3** over the period of 5 years. If high permeate flowrate to reject flowrate ratio is used, freshwater production rate will increase. But at the same time, more frequent backwash will be required, and depreciation of the membranes will be faster. This will in turn increase the water production cost since membranes will have less longevity and will be needed to change more frequently.

The selected washing factory uses groundwater for various steps in their washing process. They pump water from the ground at a rate of 800 m^3/day. It can be observed that the quality of the water treated by the mobile filtration unit was satisfactory considering all the parameter values. For permeate to reject flowrate ratio of 60:40, water quality remained good enough to be reused as process water even after the continuous operation of 2 hours. No major change in parameter was observed but flowrate gradually decreased over time. The recommended backwash frequency for the ultrafilter membranes and reverse osmosis membrane was 8 hours and 24 hours respectively as suggested by the supplier. Chemical cleaning might also be required based on feed water quality.

Table 5.

Operating and investment costs for ultrafiltration and reverse osmosis membrane units to treat ETP treated textile wastewater (permeate to reject flowrate ratio of 60:40) (considering operating life of 5 years)

Classification/source of cost	Cost/unit
Capital cost	$75,000
Pumping energy	0.75 kWh/m^3 water
Per day electricity consumption	600 kWh
[a] Electricity consumption cost	$0.081/ m^3 water
Cleaning chemicals cost	$0.024/ m^3 water
Annual electricity consumption cost and cleaning chemicals cost (Operating Cost)	$28000

[a] *assuming electricity cost $0.091 per kWh as per Dhaka Power Distribution Company Limited (DPDC) and 330 working days in a year*

For all permeate to reject flowrate ratios, treated water quality was good to be successfully reused as process water.

If a long backwash interval is used, the membrane will not be cleaned properly, and the fouling layer will be compacted on the membrane, which increases the difficulty of foulant removal during the backwash process. This transition of the fouling layer from being reversible to irreversible causes a decrease in the backwash efficiency and an increase in energy demand. In contrast, backwashing with an overly high frequency uses more permeate for cleaning than what is required [8]. So, using high permeate to reject flowrate ratio will result in the need for more frequent backwash to obtain water of desired quality. That will result in frequent pressure build-up on the membrane material which will lead to a decrease in the longevity of the membranes.

Textile industry of Bangladesh has an immense water footprint in terms of agricultural water consumption for cotton farming, high water use in textile manufacturing and water pollution [9]. Grey water footprint is the volume of polluted water that associates with the production of all goods and services for the individual or community. Blue water footprint is the volume of consumed groundwater by industry, domestic use and agriculture [10]. Reusing the treated water as process water has many environmental benefits. This will reduce the grey water footprint because instead of discharging into the environment, the same water can be used in the industry. At the same time, it will help to preserve blue water footprint since less water will be required to pump from ground.

The management of reject needs to be considered carefully. Discharge of membrane concentrate without any treatment has adverse impacts on the environment. Direct land disposal of RO reject stream from effluent treatment plants caused soil and groundwater contamination by the diffusion of inorganic impurities from it, and thus soil and groundwater are turned unsuitable for human consumption for their harmful or toxic substances [11]. In this study, reject was continuously discharged in the environment at a significant flowrate. This reject can be further treated to recover salts and other chemicals present. It can be done in several ways like evaporation, electro-dialysis or chemical processes.

4. Conclusion

Membrane-based technologies can be an attractive future strategy because of its efficiency in treating textile effluent and resource recovery. By reusing the effluent water, this technology can directly result in environmental benefits.

The results of this study show that the ETP treated water from the washing factory satisfies the water quality guidelines to be discharged into the environment. But this water cannot be reused as process water in the factory. Ultrafiltration and reverse osmosis were used as advanced treatment methods for further treating the ETP treated water for the purpose of reusing it.

TDS, TSS, colour, BOD and COD from the ETP treated water were removed by the combined filtration unit (Ultrafiltration and reverse osmosis) with very high efficiency. For initial permeate to reject flowrate ratio of 80:20, 60:40 and 50:50, high contaminant removal efficiency was observed. In all cases, the permeate water quality was good enough to be reused in the industry taking groundwater quality as the baseline. The water quality remained almost same even after continuous operation of 2 hours for initial permeate to reject flowrate ratio of 60:40. Considering 5 years for operating life of membranes, the added treatment cost would be 24.29 BDT/m^3. However, it will give other direct and indirect benefits, such as: reduction of ground water consumption, reduction of ground water pumping cost, reduction of ground water treatment cost (when applicable), and reduction of grey and blue water footprint.

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