Desalination and Water Treatment
www.deswater.com
doi: 10.5004/dwt.2018.23226

136 (2018) 131–137
December

Performance evaluation of moving-bed biofilm reactor and dissolved air flotation for the treatment of textile wastewater

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Received 23 February 2018; Accepted 30 September 2018

ABSTRACT

A wastewater treatment plant was evaluated for its pollutant removal efficiency and operational cost. The plant consisted of a moving bed biofilm reactor and two dissolved air floatation tanks. Wastewater samples were collected from untreated water (outlet of equalization tank), outlet of moving bed biofilm reactor, outlet of dissolved air flotation tank and treated water. Samples were tested for pH, temperature, total dissolved solids, total suspended solids, chemical oxygen demand and biological oxygen demand. Effluent quality was compared with National and Punjab Environmental Quality Standards and buyer's (Levi's) standards. Following ranges of results confirmed that effluent from the textile company meets Punjab Environmental Quality Standards and Levi's standards; pH = 6.8–7.2, temperature = 30.2°C–36°C, BOD_5 = 22–28 mg O_2/L, chemical oxygen demand = 75–84 mg O_2/L, total dissolved solids = 1,210–1,310 mg/L and total suspended solids = 5–25 mg/L. Overall, pollutant removal efficiencies of the plant were 85.9%–89.2% for biological oxygen demand, 88.7%–90.2% for chemical oxygen demand, and 93.7%–98.8% for total suspended solids. Operational and management costs of the wastewater treatment plant were calculated as USD 15,656 per month. It was found that electricity consumes 51% and chemical usage requires 44% of the total operational and management cost of treatment plant.

Keywords: Moving bed biofilm reactor (MBBR); Textile wastewater; Removal efficiency; Biological treatment; Dissolved air flotation (DAF)

1. Introduction

Water and chemicals use in the textile industry are very high, and its effluent contains a high concentration of chemical oxygen demand (COD), biological oxygen demand (BOD), suspended and dissolved solids, and color [1]. Because water is a universal solvent, almost all kind of pollutants from industries enter into the water cycle [2]. Water contaminated by textile wastewater, when exposed to the organisms, leads to several health problems in them [3]. The toxicity and color of textile effluents are due to the high concentrations of additives, dyes, and other surface-active materials [4]. Disposal of colored wastewater causes environmental damage to aquatic plants, reducing their ability to photosynthesize. Moreover, the toxicity of wastewater due to the presence of metals, chlorides, and components of dyes causes water-borne diseases and contains carcinogens, mutagens, and cytotoxins [5,6]. Toxicity in textile effluents can be monitored by time and cost-efficient, *Vibrio fischeri* bioluminescence inhibition bioassay (VFBIA) [7]. Cytogenetic and mutagenic agents can also be identified in wastewater with *Vicia faba* bioassay which is also very easy to use and economical method of testing toxicity [8].

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Discharges from industries enter into water bodies either treated or untreated. In developing countries such as Pakistan, a large number of industries discharge contaminated water without even a primary level of treatment [9]. This is because advanced treatment technologies are either not available or are highly expensive. Furthermore, industries in Pakistan do not receive any significant incentive for treating their wastewater [10].

COD value for textile wastewater is generally very high, ranging from 700 to 10,000 mg O_2/L. High COD is because the waste streams of textile effluents contain pesticides, dyes and other non-biodegradable organic matter [11]. Such constituents make the treatment process of textile wastewater different from the municipal wastewater [12]. The presence of azo dyes in textile effluents also make the treatment process difficult because of their persistence in natural environmental conditions and upon degradation, they produce more toxic by-products [6].

Biological treatment alone is not always an effective option for removing pollutants from textile wastewater due to the presence of non-biodegradable chemicals and dyes [13]. Using oxidation method before or after biological treatment can breakdown the persistent dye molecules in textile wastewater. It improves the final effluent quality and reduces the cost of treatment in biological treatment [14]. Physicochemical treatment technologies or additives are being used in addition to the activated sludge process (ASP) to remove low biodegradable pollutants. For example, a study found an increase in the efficiency of an activated sludge treatment plant with the addition of additives such as powdered activated carbon [15]. Gamma radiation can significantly reduce the toxicity of textile wastewater [16]. Combination of gamma radiation and hydrogen peroxide is also found very effective treatment method in removing cytotoxicity and mutagenicity of textile wastewater [17].

Several biological, physical and chemical treatments, as well as combinations of each have been studied for the treatment of textile wastewater, including aerobic activated sludge treatment, rotating biological contactor, aerobic–anaerobic sequential batch, moving bed biofilm reactors (MBBRs), and dissolved air flotation (DAF) [18]. Combinations of biological and physical treatment methods are easier to control and have higher pollutant removal efficiencies [19].

The MBBR was designed in the early 1990s [20] to utilize the best features of ASP and biofilter processes. In contrast to ASP, MBBR does not require sludge recycling, and has a low head loss. The system depends on plastic carriers for the attachment and growth of biomass. Kaldnes is one of the dominant types of supporting media used in MBBRs [21].

Park et al. [22] carried out a study to find the effectiveness of anaerobic-anaerobic-aerobic (A2O) MBBR for the treatment of colored textile wastewater, and found COD and color removal efficiencies to be 86% and 50%, respectively. Supporting media used in the study was polyurethane (PU) foam, which is an excellent carrier for biomass retention [23]. Shin et al. [24] performed a pilot scaled anaerobic-aerobic-aerobic MBBR with PU-AC as a carrier for biological treatment. MBBR process removed 85% of COD and 70% of color. The biologically treated effluent was further subjected to chemical coagulation, with iron chloride ($FeCl_3$) as a coagulant agent, which removed 97% of color and 95% of COD. The results showed that a combined process of MBBR and chemical coagulation can be used for the treatment of dyed wastewater on a large scale [24].

DAF is a physical and chemical technique for removing impurities from the wastewater with the help of granular filtration media. It is recommended as a post-treatment method to treat industrial effluent from the ASP [25]. The process of floatation with an addition of surfactants is effective for the removal of dye concentration from textile wastewater [26]. A study evaluated the performance of the DAF process for the removal of dye from textile effluents. The results showed more than 97% dye removal efficiency with the addition of the flocculant (polyelectrolyte) and surfactants in DAF process [27]. DAF provides better clarification than sedimentation in removing turbidity and has been improved over the decades to achieve higher efficiencies. The system also reduced the flocculation tank sizes and the overall size of the DAF process due to the higher hydraulic loading rates. Potentially the technology can be used as pre- and post-biological treatment to achieve better quality of the textile effluents [28].

The present study investigates the different biological and physicochemical wastewater treatment technologies and their treatment efficiencies with respect to the textile wastewater. In this research, a combined process of MBBR and DAF was studied for the treatment of textile wastewater. Both of the treatment technologies were evaluated for the removal of BOD, COD, total suspended solids (TSS) and total dissolved solids (TDS). Investigating the operational and management cost of the treatment plant was the second objective of the study.

2. Materials and methods

2.1. Study area

The selected textile company is located 3 km from Lahore at the intersection of Defense and Raiwand road. The textile company is one of the leading manufacturers of denim products in the international market, having customers such as Levi's, Marks and Spencer, H&M and other prominent brands. Overall processes taking place in the company include ball warping, rope dyeing, sizing, weaving, finishing and washing of denim products. Wastewater from the company majorly generates from the fabric dyeing and washing.

2.2. Plant influent design

At the rate of 100–150 m^3/h, the full plant capacity, 2,400–3,600 m^3 of wastewater discharges every 24 h from the company. The average temperature and pH of the wastewater produced in the company are 30.8°C and 7.5, respectively. A treatment plant is typically designed according to the wastewater characteristics. The design value of the WWTP was 250 mg O_2/L for BOD_5; 800 mg O_2/L for COD; 2,600 mg/L for TDS and 700–1,500 mg/L for TSS. Under normal operating conditions, wastewater characteristics do not exceed the design values.

2.3. Wastewater sample collection

Wastewater samples were collected in glass bottles by the grab sampling method from the denim industry located near

Lahore. Samples were collected on four different days over the period of September 2nd to 20th, 2017. Four wastewater samples were collected each day from different points of the effluent treatment plant in order to represent the wastewater characteristics after each treatment step.

An influent sample was obtained from the equalization tank in order to determine the characteristics of untreated wastewater. A second sample was collected from the outflow of the MBBR (aeration tank) in order to analyze the performance of the ASP modified with an MBBR. The third sample was taken from the outflow of the DAF 2. The purpose of analyzing this sample was to measure the coagulation and flocculation performance of DAF 2. Finally, an effluent sample was collected from the outflow of the treatment plant in order to investigate the overall treatment efficiency of the plant, as well as to determine whether the effluent meets the discharge standards.

2.4. Chemical analysis of wastewater samples

The collected samples were tested for pH and temperature on site, and for TSS, TDS, COD and BOD in the laboratory. All the laboratory tests were performed according to the procedure in Standard Methods for the Examination of Water and Wastewater [29].

Influent from the industry had a dark blue color, which gradually decreased in aeration tank and then DAF tank. The samples collected from the outlet of DAF and the final discharge from the WWTP were very clear, as shown in Fig. 1(d).

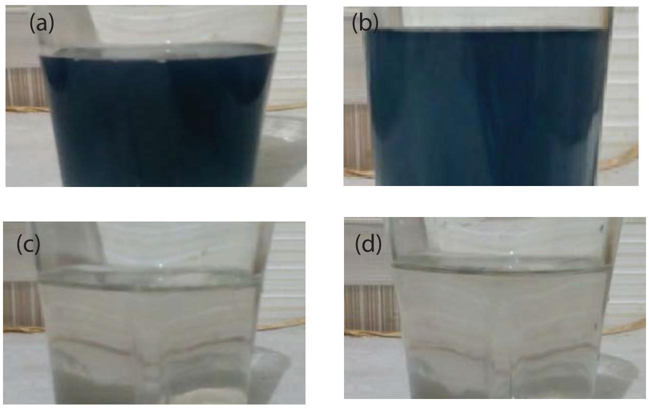

Fig. 1. Gradual color removal from influent to final effluent.

2.5. Operational and design study of the plant

A block-flow diagram of the (wastewater treatment plant) WWTP of the textile company is shown in Fig. 2.

The wastewater treatment plant in the company is designed to operate at the maximum flow rate of 150 m^3/h. The layout of the effluent treatment plant of the company is shown in Fig. 3.

A sump pit collects the wastewater coming from the main industrial unit through an underground pipe system. The plant includes a sump pit, four pumps and a drainage line. Out of the four sump pumps two are submersible and two are centrifugal. Two pumps are in working condition while the other two are for back-up in case of an emergency.

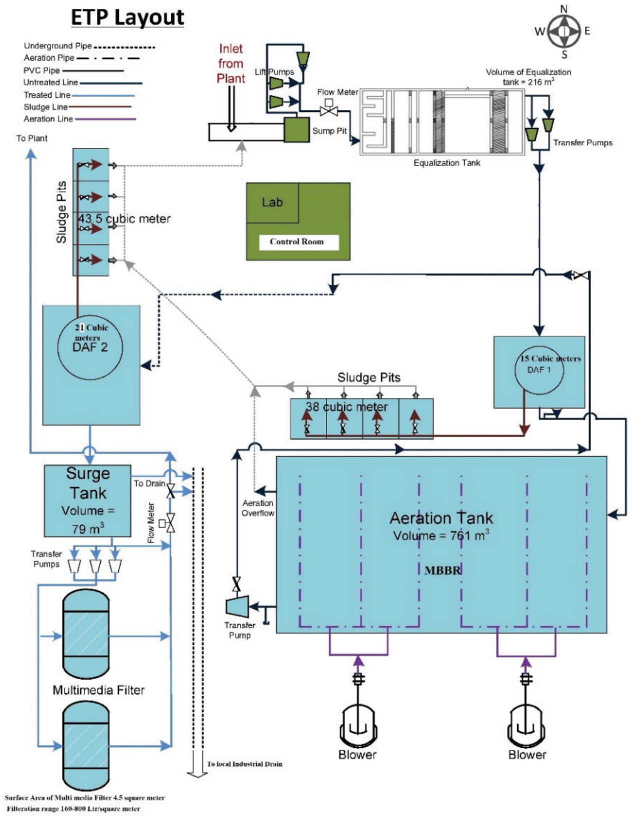

Fig. 3. Layout of the wastewater treatment plant of the company.

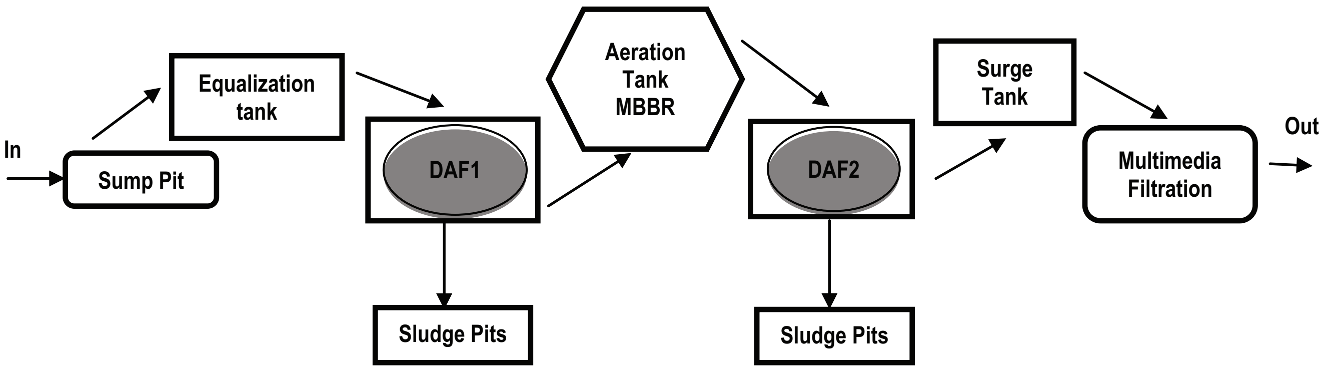

Fig. 2. Block-flow diagram of effluent treatment plant in the company.

The sump pumps lift the wastewater from the industry into an equalization tank.

The volume of equalization tank is about 240 m^3. The flow rate of the wastewater coming from the sump pit widely fluctuates. The purpose of equalization is to transfer the wastewater into further effluent treatment plant units at a steady flow rate. There are two centrifugal transfer pumps at the outlet of the equalization tank, which transfer water into the DAF 1.

Pre-treatment in DAF 1 is carried out to reduce the pollutant load on the upstream biological treatment unit. DAF 1 has a capacity of 15 m^3 and removes suspended particles in particular from the wastewater. The retention time of this unit is about 6 min. Excessive sludge produced in DAF 1 goes into the sludge pits. There are four small units for the sludge storage with an overall capacity of 38 m^3. 360 g/m^3 alum and 8 g/m^3 polyelectrolyte (polyacrylamide [PAM]) are used as coagulant and flocculant agents respectively, in DAF units.

The volume of the aeration tank of the plant is 761 m^3. The ASP is enhanced with an MBBR. The wastewater in the aeration tank is continuously aerated by the blowers. In the plant, about 90 m^3 of Kaldnes K1 type media is used for the growth of bacteria. This media provides support to bacterial growth, offering a protected surface area of multiple cells for the rapid growth of microorganisms. Bacteria grow on every surface of the media. Biofilm on the surface of the aeration tank improves the treatment efficiency of the ASP. Chemicals used in aeration tank to enhance the bacterial activity include DAP and urea.

An excessive amount of sludge produced in the aeration tank is sent to the sludge pits, otherwise, the treatment efficiency of the tank would be compromised. The total BOD load in 24 h of operation is about 1,000 kg. Hydraulic retention time (HRT) at full plant capacity of 150 m^3/h is about 5 h in aeration tank.

The purpose of DAF 2 is to further polish the effluent from biological treatment. After 5 h of aeration in MBBR, the effluent moves to the DAF 2 via the application of a transfer pump. The volume of DAF 2 tank is 21 m^3 where aerated water is subjected to the action of coagulants and flocculants for 8 min. About 360 g/m^3 of alum is used in the tank as a coagulating agent and 8 g/m^3 of PAM is added to the DAF 2 as a flocculating agent. This properly monitored amount of coagulant and flocculant is added to the DAF 2 to achieve optimal pollutant removal efficiency.

A surge tank collects and drains the treated water. The volume of the surge tank is 79 m^3. One outlet from the surge tank directs the treated water to the local industrial drainage system. There are three transfer pumps after the surge tank, which are used to transfer the treated water into the multimedia filter. There are two multimedia filters with surface areas of 2.25 m^2 and 4.5 m^2. The filtration range of these multimedia filters is 160–800 L/m^2. Two filters can manage the maximum flow of 3.6 m^3/min. A treated line carries filtered water from this point and takes it to the plant for the purpose of reuse.

3. Results and discussion

An MBBR in combination with a DAF was studied for the treatment of denim industry wastewater. pH, temperature, COD, BOD, TSS and TDS were tested to investigate the removal efficiencies (%) of MBBR and DAF.

Influent of the company had a pH value of 7.4 ± 0.3, which was within the limits required for biological growth. pH value in all four tanks remained in the range of 6.9 to 7.4, which was appropriate for the removal of pollutants. As bacteria require neutral pH for their growth to remove pollutants from the wastewater, pH should not be below 6 or above 9.5 in the aeration tank [30]. The temperature remained in the range of 32°C to 34°C in all treatment units of the WWTP.

All results obtained from the experimentation are shown in Table 1.

The BOD of the influent was 200.2 ± 11.1 mg O_2/L. In an ASP with an MBBR, 75.7% ± 2.0% of the BOD was removed, achieving 48.5 ± 2.1 mg O_2/L. Normally average BOD removal rate in an ASP is considered 61% [31]. The aeration tank, supported by the bacterial growth from Kaldnes media achieved 75.7% ± 2.0% BOD removal rate.

After DAF tank, the value for BOD was 27.5 mg O_2/L, dropped from 48.5 mg O_2/L. The combination of MBBR and DAF achieved a BOD removal efficiency of 86.24% ± 1.7%. The sample obtained from the surge tank after final multimedia filtration showed the results of 24.2 ± 2.6 mg O_2/L for BOD, and overall achieved a removal efficiency of 87.87% ± 1.2%. Removal efficiencies were calculated for ASP, both ASP and DAF, and effluent, as shown in Table 2.

The COD of the influent from the company was 761.2 ± 15.8 mg O_2/L. The aeration tank removed 80.5% ± 1.2% of COD. The combined effect of the MBBR system and DAF on COD removal was quite satisfactory, obtaining 85.5 ± 4.2 mg O_2/L of COD value and 88.77% ± 0.4% removal efficiency. The effluent value and removal efficiency for COD after the final filtration process were 79.7 ± 3.7 mg O_2/L and 89.52% ± 0.5%, respectively. The MBBR system has a higher

Table 1
Concentrations of different pollutants at different treatment stages

Quality indicator	Mean value ± standard deviation			
	Influent	Out ASP	Out DAF	Treated effluent
pH	7.4 ± 0.3	7.1 ± 0.2	7 ± 0.4	6.97 ± 0.2
Temperature, °C	32.6 ± 1.5	32.5 ± 2.6	31.9 ± 2.6	33.6 ± 2.5
BOD, mg O_2/L	200.2 ± 11.1	48.5 ± 2.1	27.5 ± 3.8	24.2 ± 2.6
COD, mg O_2/L	761.2 ± 15.8	148.5 ± 13.0	85.5 ± 4.2	79.7 ± 3.7
TDS, mg/L	1,397.5 ± 27.5	1,386.2 ± 14.9	1,311.2 ± 27.8	1,268.7 ± 43.3
TSS, mg/L	409 ± 12.4	131 ± 5.6	22.2 ± 8.7	15.5 ± 8.8

Table 2
Removal efficiencies of BOD, COD, TDS and TSS at different stages

Quality indicator	ASP removal (%)	ASP + DAF removal (%)	Overall WWTP efficiency (%)
BOD	75.7 ± 2.0	86.24 ± 1.7	87.87 ± 1.2
COD	80.5 ± 1.2	88.77 ± 0.4	89.52 ± 0.5
TDS	0.78 ± 1.8	6.12 ± 3.2	9.16 ± 3.9
TSS	67.9 ± 1.5	94.55 ± 1.9	96.19 ± 1.9

COD and BOD removal rate due to the large amount of active biomass attached to the Kaldnes media.

TDS are usually difficult to remove from the wastewater. A typical activated sludge treatment plant can achieve TDS removal efficiency of about 29% at 12 d of retention time [32]. In this WWTP, there was no dosage of alum in the aeration tank. Moreover, the retention time was 5 h, which was the reason no significant TDS removal rate was observed at this stage. A DAF tank removed 6.12% ± 3.2% of TDS at a retention time of 6 min. Overall, the WWTP removed 9.16% ± 3.9% TDS and achieved the value of 1,268.7 ± 43.3 mg/L in the final effluent.

Suspended solids are typically removed by the coagulation process or primary settlement. However, in the treatment plant under study, there was no coagulation taking place before aeration. The aeration tank removed 67.9% ± 1.5% of TSS and dropped the value from 409 to 131 mg/L. DAF, which is a typical method to remove suspended solids, further removed the TSS and achieved the value of 22.2 ± 8.7 mg/L. Combined efficiency of MBBR and DAF for the removal of TSS was 94.55% ± 1.9%. The TSS value in the final effluent was found to be 15.5 ± 8.8 mg/L, and overall plant efficiency to remove TSS was 96.19% ± 1.9% on average.

Any treatment method either physicochemical or biological alone hardly achieved satisfactory results, however, combinations of two or more process have resulted in above 90% removal efficiencies of COD, BOD and color in most of the studies. A series of three physicochemical processes which included chemical coagulation, electrocoagulation and adsorption were investigated in a lab-scale experiment. The overall results showed 98%, 94% and 99% removal rates of COD, BOD and color, respectively [33].

Several pilot and lab-scale experiments of physical, chemical, biological treatment methods and their combinations have achieved up to 99% of COD and BOD removal efficiencies, but these results may vary when implemented on a full-scale process [34,35]. In the full-scaled WWTP study, this research found the combined process of MBBR and DAF to be highly effective for the removal of pollutants and color. Overall, the process removed 88% of BOD, 90% of COD and 96% of TSS from the denim wastewater, where the HRT in aeration tank and DAF was only 5 h and 8 min, respectively.

Physicochemical methods or only advanced oxidation can be used as a pre-treatment or post-treatment approach, depending upon the characteristics of the textile denim wastewater in a series with biological treatment method [14]. However, combination of two different treatment methods should be chosen very carefully according to the target pollutants, because an unstable sequence can alter the characteristics of the original wastewater, producing non-biodegradelable compounds [36].

Table 3
Comparison of effluent quality with PEQs, NEQs and Levi's standards

Quality indicator	Effluent quality	PEQs	NEQs	Standards by Levi's
Temperature (°C)	33.6 ± 2.5	≤40		≤37
pH	6.97 ± 0.2	6–9	6–9	–6–9
BOD_5 (mg O_2/L)	24.2 ± 2.6	80	80	≤30
COD (mg O_2/L)	79.7 ± 3.7	150	150	≤200
TDS (mg/L)	1,268.7 ± 43.3	3,500	3,500	–
TSS (mg/L)	15.5 ± 8.8	200	150	≤30

A comparison of the effluent quality from the company with Punjab Environmental Quality Standards (PEQs), National Environmental Quality Standards (NEQs) and Levi's standards are given in Table 3.

PEQs and NEQs are not difficult to meet for industrial discharge. However, Levi's (a major client of the industry) has set very strict standards for treating industrial effluent. As shown in Table 3, the temperature of the effluent should not be greater than 37°C (which is Levi's standard) and effluent discharged from the industry has a temperature of 33.6°C ± 2.5°C. pH of the effluent also lies within the range given by Levi's standards. Levi's Standards for BOD_5 (≤30 mg O_2/L) and COD (≤200 mg O_2/ L) are also met by the WWTP, releasing the effluent with a BOD_5 of 24.2 ± 2.6 mg O_2/L and COD of 79.7 ± 3.7 mg O_2/L.

Effluent from the company also meets the PEQs and NEQs for TDS, which allows 3,500 mg/L TDS. According to Levi's standards, TSS value should not be more than 30 mg/L and the effluent results obtained from the experimentation showed the values for TSS (15.5 ± 8.8 mg/L) as remaining within the company's limits.

3.1. Operational cost of the WWTP

The overall cost of the WWTP depends upon several factors. The space required for the plant installation is one of the factors determining the cost [37]. Compact treatment options are more preferred, which is why biofilm systems are becoming more popular as compared with the activated sludge systems. Energy consumption is another critical factor determining the operational cost of the plant, which is also a recurring expense [38]. In the United States, more than 4% of electrical energy is consumed by water and wastewater treatment plants, which indicates that WWTPs require a considerable amount of electricity for their operations. Due to the continuous aeration process, a biological unit of the WWTP requires the largest proportion of the energy, which could be between 30% and 60% of the plant usage [39].

It was important to determine the operational cost of the treatment plant to understand how affordable it can be for small to large textile companies. One month's expense on operating and maintaining the wastewater treatment plant was determined when the plant worked for 26 d. About 2,400 m^3 of treated effluent leaves the plant every day, which makes 62,400 m^3 of treated water for a month.

Table 4
Chemical cost of operating WWTP for a month

Chemicals	Unit price (USD)	Chemical use/d (kg)	kg used in 26 d	Cost (USD)	Cost/m^3 (USD)
Alum	0.19	1296	33,696	6418	0.1029
Polyacrylamide (PAM)	0.48	29	754	359	0.0058
DAP	0.74	4	104	77.3	0.0012
Urea	0.38	4	104	39.6	0.0006
Total chemical cost (USD/month)				6,894.2	
Total chemical cost/m^3 (USD/m^3)					0.110

Labor cost/d (USD)	Labor cost/month (USD)	No. of labors	Cost/month (USD)	Cost/m^3 (USD)
5.5	142.86	3	428.57	0.006

Function	Cost/month (USD)	Cost/m^3 (USD)
Sludge cleaning	333.3	0.005

Electricity consumption kWh/month	Price/kWh (USD)	Cost/month (USD)	Cost/m^3 (USD)
60,000	0.133	8,000	0.128

The cost of the chemicals required to treat 62,400 m^3 of water was 6,894.2 USD. Thus, every cubic metre of the water required 0.1029 USD for the chemical usage. Though alum is not an expensive chemical, a large quantity is used in the DAFs of the treatment plant, which requires 6,418.3 USD every month.

In order to manage operation and working of the WWTP, the textile company needs three full-time labors every month. Each labor in the WWTP is paid 143 USD, which makes the labor cost 429 USD per month. Therefore, each cubic metre of the wastewater requires 0.01 USD for the manpower, as indicated in Table 4. The monthly expense of sludge cleaning was around 333.3 USD.

The industry utilizes the electricity provided by the Water and Power Development Authority (WAPDA), as well as electricity produced by the power generators installed on site. Table 4 shows the electricity cost of treating 62,400 m^3 of wastewater every month.

The operations of this WWTP consume 60,000 kWh energy every month. At the rate of dollar 0.13/kWh, the textile company spends 8,000 USD for the electricity usage every month.

It was found that overall 51% of the operational and maintenance cost is consumed by electricity, while 44% of the total cost is attributed to chemical use in the WWTP.

4. Conclusion

The study findings indicate that a combination of two or more treatment technologies can achieve higher removal efficiencies of pollutants. It was found that an MBBR, followed by the use of DAF can achieve satisfactory results for the removal of COD, BOD and TSS. It was found that it costs roughly 15,656 USD every month to properly operate and maintain the WWTP. The studied treatment technology, due to its satisfactory results, could be one of the preferred options for the large textile companies in Pakistan. Further research is recommended to study the complete expense of a well-performing treatment plant and methods to reduce the overall operational cost without compromising treatment efficiency. Moreover, further studies can compare the activated sludge treatment plant system with an MBBR, in terms of treatment efficiency and overall cost in Pakistan's context.

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