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Research article

Investigation of the performance of the combined moving bed bioreactor-membrane bioreactor (MBBR-MBR) for textile wastewater treatment

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ABSTRACT

The present study focused on the investigation of the performance of a Moving Bed Bioreactor coupled with a Membrane Bioreactor (MBBR-MBR) on a small scale for textile wastewater treatment. The parameters examined in this study included the removal efficiency of chemical oxygen demand (COD), biochemical oxygen demand (BOD), total suspended solids (TSS), turbidity, color, and heavy metals (HM). The two reactors were operated consecutively and maintained aerobic conditions. The idea is to reduce the pollutant load significantly through the activity of microorganism attached to the biofilm covered carriers in MBBR and successive membrane filtration. The system demonstrated a favorable outcome even in a smaller hydraulic retention time (HRT) of 1 day, which presents a significant advantage in terms of cost and space saving. The removal effectiveness of COD attained a maximum of 92 %, BOD reached a maximum of 95 %, and the color removal performance obtained a removal efficiency of 87 %. Furthermore, the treatment showed remarkable efficiency in removing up to 100 % of TSS and 96 % of turbidity. Additionally, an evaluation was conducted on the elimination of heavy metals, including Zinc (Zn), Lead (Pb), Chromium (Cr), and Iron (Fe). The efficacy of removing these HMs was found to exceed 85 %. All these favorable outcomes contribute to the improvement of effluent quality, mitigation of contamination hazards, and fouling reduction.

1. Introduction

The issue of limited availability of potable water has emerged as a significant global problem in recent times [1]. The textile industry is a big consumer of water and uses quite large amounts of water throughout manufacturing and processing processes [2]. Because of this, it generates a lot of wastewaters that needs to be treated before being released into the aquatic ecosystem. These effluents contain a variety of contaminants and are distinguished by high levels of pollution indicators such suspended solids, color, toxicity, and turbidity as well as biochemical oxygen demand (BOD) and chemical oxygen demand (COD). Around 10,000 distinct dyes are used in this business, and every year more than 0.7 Mt of these dyes are generated around the world [3]. One of the largest environmental issues of the twenty-first century is the ten to fifteen percent of these dyes that are leaked into the environment. Due to

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the high levels of color and dissolved materials in wastewater, these products seriously harm the ecosystem [4,5]. Because of the challenging biodegradation of hazardous contaminants, the treatment of textile industry effluents, notably color removal, is a problem. The contamination of surface water bodies near industrial areas has emerged as a significant environmental concern [6].

Physical treatment, biological treatment, chemical treatment and combinations of these three treatments are the main categories that make up textile wastewater treatment. Among these, Membrane Bioreactors (MBR) are employed widely for the treatment of industrial and municipal wastewater, including wastewater from textiles. Its usage for the treatment of industrial wastewater has grown due to its inherent advantages over conventional biological treatment. It is an effective method for treating textile effluent [7]. Another rapidly expanding technique for the treatment of wastewater is the moving-bed biofilm reactor (MBBR) [8].

Over the past few decades, MBRs have been used more and more for the treatment of industrial and municipal wastewater. MBRs combine membrane filtration with traditional biological wastewater treatment. The partition of activated sludge and treated effluent is where MBRs vary from conventional biological wastewater treatment methods [9]. MBRs integrate a biological process with a membrane system, providing a special chance to the biocatalyst, which can be an enzyme, an organism, or a plant or animal cell to effectively remove the contaminants from the wastewater. The modeling of such MBR systems might vary significantly depending on the biological process occurring because of the wide diversity of biological responses. MBR systems for textile wastewater recovered more than 80 % of COD and 70 % of color, according to a recent study [10]. However, MBR technology is not free of limitations. The occurrence of membrane fouling is a prevalent issue encountered in the treatment of industrial wastewater. To address this issue, prior research has employed the combination of coagulation and membrane bioreactor, which have demonstrated an improved capacity for controlling membrane fouling. Combining coagulants to the MBR system improved the permeability of the membrane and increase the membrane's operation time [11]. This may be attributed to the tendency of soluble substances, colloids, and foulants to adhere to the mobile carriers. This phenomenon mitigates the occurrence of membrane fouling. The utilization of coagulation in combination with MBRs yielded an 81 % effectiveness in removing COD and a 68 % efficiency in removing color, as reported in Ref. [12]. In another study wastewater generated from textile production underwent treatment processes involving Oxidation treatment and membrane bioreactor. The results of these treatments indicated that the removal efficiency of COD exceeded 83 %, while the removal efficiency of color reached 90 % [13].

The moving bed biofilm reactor (MBBR) is another biological treatment procedure that consists of a suspended solid and a biofilm adhered to the carrier. Plastic carriers are used in the wastewater treatment process as a substrate for the growth of biofilms. In a continuously mixed reactor, the reactor uses a significant number of biofilm carriers to enable the development of necessary bacteria. Both aerobic and anoxic processes can use MBBR systems. Chemical oxygen demand removal was 86 % and color reductions were 50 % in the MBBR process, found in previous research [14]. The concentration of biomass in suspension may be kept at levels akin to those in an AS reactor because most of the biomass is attached in the carriers. But one of the biggest issues with MBBR is how poorly biomass pours out when compared to an activated sludge system. If a well-clarified effluent is desired, this frequently necessitates the use of a specific number of coagulant products.

A study was carried out to develop a novel membrane bioreactor that combined an electro bioreactor (EMBR) and MBBR aiming for improving the biological treatment and reducing membrane fouling. The system showed a promising result regarding COD removal (95 %) [15]. However, their system requires more electrical power to supply energy to the EMBR which may lead to an increase in initial and operation costs.

By segregation of the biomass from the wastewater by means of a reactor membrane, a MBBR-MBR system would address the drawback of the poor draining of MBBR systems. However, because the high concentration of biomass is locked to moving bed bioreactor carriers, the oxygen transfer coefficient won't be impacted. The efficacy of an MBBR-MF method in treating wastewater from the food sector was investigated in a previous study that demonstrated that the membrane filtration reduced the MBBR effluent's fluctuating features brought on by variations in influent feed [16].

It would be interesting to combine the two processes (moving bed bioreactor and membrane bioreactor) to increase efficiency and accelerate the degradation of BOD, COD, color, turbidity, TSS and HMs (Zn, Fe, Pb and Cr) from textile wastewater. This would prevent membrane fouling and increase removal efficiency. The major goal of this study is to use an integrated MBBR-MBR technology to treat industrial textile wastewater to reduce its pollutant load and increase its biodegradability.

Table 1
Influent characteristics.

Parameter	Unit	Range
pH	–	7.90-8.98
Conductivity	mS/cm	4.70-5.62
Turbidity	NTU	103–163
Total suspended solids (TSS)	mg/L	206–458
Color	mg Pt-co/L	512–812
Chemical oxygen demand (COD)	mg/L	1225–1935
Biochemical oxygen demand (BOD)	mg/L	907–1466
Zinc (Zn)	mg/L	23–24
Lead (Pb)	mg/L	1.06-1.50
Iron (Fe)	mg/L	82.40–90.88
Chromium (Cr)	mg/L	1.32-1.86

2. Methods

2.1. Characteristics of textile wastewater

This study's textile wastewater came from a knit composite textile factory situated in Tongi BSCIC. Table 1 lists the wastewater's characteristics, including COD, BOD, color, pH, conductivity, turbidity, and TSS and concentrations of HMs (Zn, Fe, Pb and Cr).

2.2. Construction of the reactors

The hybrid reactor is made with enough room for the membrane to be installed correctly and for plastic carriers to move about properly. Fig. 1 depicts the MBBR-MBR reactor's schematic design. Reactors were run in a sequential fashion. Both reactors were operated under aerobic conditions.

The hybrid MBBR-MBR reactor had an effective volume of 130 L and a total volume of 167 L. The membrane tank (41 L) and the MBBR portion (89 L) of the reactor were each given their own compartments. The Kaldnes K1 carriers were introduced to the MBBR tank with a filling ratio of 40 % after taking the potential development rate of the biofilm on the carrier material into account. Although generally 20–30 % filling ratio [17] is sufficient, a high filling ration was used in this experiment to improve the efficient reduction of membrane fouling in the subsequent process. Polyethylene, the material used to create K1 carriers with a diameter of 25 mm, has a specific gravity of 0.96 g/cm^3. The specific surface of the carrier was 590 m^2/m^3. Each carrier weighed 2.1 g.

A single shaft impeller system was used to mix the reactor's contents. The rpm of the system was 150. No mixer was used in the MBBR tank as there were diffusers in place to keep the carriers well fixed and floated in the tank. To maintain the pH between 7.2 and 7.3, an internal pH controller was employed. To adjust pH, H_2SO_4 and NaOH were utilized. A submersible thermostat kept the temperature during the operation at 25 °C. For the wastewater input and intermittent permeate removal, peristaltic pumps were utilized. Diffusers were mounted to the bottom of the reactors; the large bubble diffusers mixed carriers in the MBBR tank while the fine bubble diffusers were used for oxygen diffusion and membrane cleaning in MBR tank. Aeration was done to scour the membrane and provide aerobic bacteria oxygen.

The trial lasted for 220 days in total. A lengthy HRT (5 days) was established at the startup phase of 15 days to permit bacteria adaptability and growth. During the first phase, the flow rate was gradually raised from 1.8 L/h to 4.6 L/h to ensure the sludge's stability. On day 45, the membrane was placed. The MBR tank was filled with a hollow fiber membrane module that has a membrane filtering area of 1 m^2. The pore size, the maximum transmembrane pressure, the operating transmembrane pressure and the operating pH range of the operating membrane were 0.03 μm, 80 kPa, 10–60 kPa and 2–13, respectively.

At the base of the MBR, a magnetic stirrer (Mtops MS300HS, Korea) was placed to give the necessary mixing of the sludge liquor. Transmembrane pressure (TMP) was continually monitored using a pressure transmitter (Mesens MPS500), and when the TMP reached 560 mBar, MBR was stopped down and a physical cleaning operation was carried out. With a soft mop and running water, the biomass layer on the membrane surface was gently scraped off to perform physical cleaning. The operation was continued once the contaminated membrane had been washed.

The operation of the reactor was carried out for 220 days. In the MBBR part, the organic loading rate (OLR) gradually increased from 0.33 kg COD/(m^3 d) to 1.12 kg COD/(m^3 d). The flow rate also increased up until day 15th. The hydraulic retention rate was reduced to 2.5 days after the startup phase and to 1 day after the MBR module was installed (day 45th). The membrane was installed when the flow rate was stable at 4.6 L/h and the OLR increased from 1.12 kg COD/(m^3 d) to 1.79 kg COD/(m^3 d).

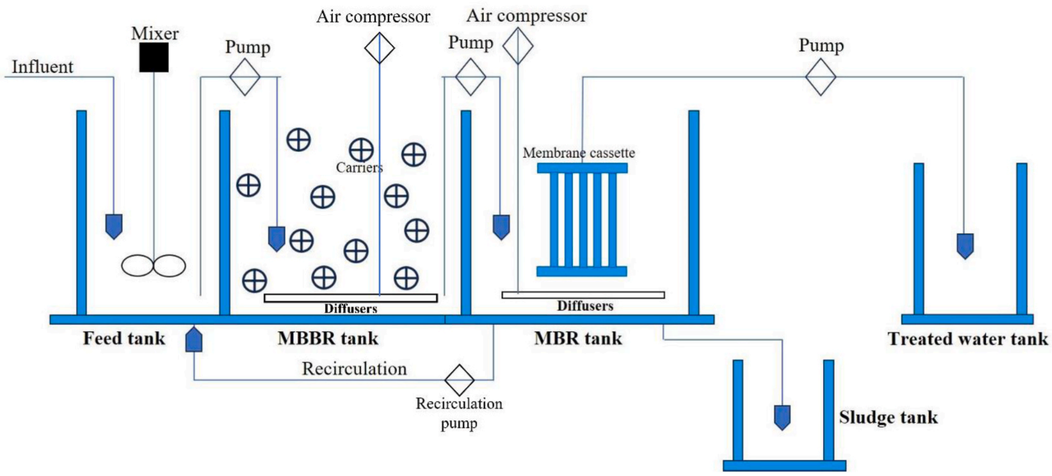

Fig. 1. MBBR-MBR reactor diagram (Recirculation pump, diffusers in MBBR tank needed).

2.3. Analytical methods

2.3.1. Biomass determination

Three carriers from the moving bed bioreactor were collected, properly cleaned in distilled water, and then dried for 24 h at 70 °C in an oven. The dried carriers were weighed before the acid treatment. One liter of 0.5 M hydrochloric acid (HCl) solution was prepared. To dissolve the attached biomass, the dried carriers were immersed in this solution for a whole day. Following the removal of the carriers, 0.5 M NaOH was added to the solution to neutralize it. The dissolved biomass was separated by filtering the neutralized solution. To concentrate biomass, the filtered solution was moved to an evaporation dish and allowed to evaporate. The final weight of the dish with the concentrated biomass was collected to calculate the biomass concentration.

2.3.2. Determination of BOD, COD, color, TSS and HM concentration

The standard dilution method described in APHA standard methods for the examination of water and wastewater was employed for the BOD analysis (APHA 5210.B). The dichromate reflux method (APHA 5220.B) was applied to determine the COD. Color analysis was performed using a UV–Vis spectrophotometer (Thermo Scientific Orion AquaMate 8100) to measure the absorbance of light passing through the samples at 450 nm wavelengths and by comparing the resultant value to the calibration curves. A turbidimeter (OAKTON turbidity meter, model: 35635-10) was used to measure turbidity in NTU unit. The TSS determination process (APHA 2540.D) entailed filtering samples through a pre-weighed filter paper, drying and weighing the filter paper containing the solids that were retained, and calculating the mg/L concentration of suspended solids.

The water samples were analyzed using an atomic absorption spectrophotometer (AAS) with an air/acetylene flame to determine the concentrations of Cr, Zn, Fe, and Pb. Hollow cathode lamps were used to examine the samples. There was a 5.0 mA of light current. The instrument's detection limit for Cr was 0.01 mg/L, for Zn was 0.04 mg/L, for Fe was 0.10 mg/L, and for Pb was 0.02 mg/L.

3. Results and discussion

3.1. Evaluation of the performance of the MBBR-MBR system

In the initial phase of the investigation, the process of establishing a resilient biofilm on the carrier surface involved the introduction of a little amount of sludge into the bioreactor from a running ETP plant. The duration of the starting phase spanned a period of 15 days. The attainment of a stable attached biomass concentration required around 15 days. The production of biofilm in the surface of the carriers of MBBR was limited at this period. The hydraulic retention rate was 5 days during the starting phase. HRT was then modified to 2.5 days from 5 days during the period spanning days 16–45, then further reduced to 1 day from days 46–220. This alteration in HRT regimen revealed a discernible linear development pattern, indicative of the proliferation of biofilm. The concentration of the biofilm ranged from 1330 to 2230 mg/L. The biomass content in MBBR systems typically falls between 2000 and 8000 mg/L [18]. In MBBR carriers, the process of biofilm formation is intricate. Biofilm formation usually occurs through several stages. Microorganisms in wastewater initially cling to carrier media surfaces via physicochemical interactions [19]. Extracellular polymeric substances (EPS) are produced to aid the creation of an initial biofilm layer, which is followed by microbial colonization. Microbial communities go through metabolic processes as the biofilm ages, which results in the formation of intricate, multi-layered structures [20]. Biofilms are cohesive, but they undergo constant turnover because of shear stresses and aging processes that cause biomass to separate and peel off.

According to the data presented in Fig. 2, there was a consistent increase in the concentration of mixed liquid suspended solids (MLSS) following the installation of the membrane on the 45th day. Before MBR, the MLSS was between 872 and 2106 mg/L and after installation it was between 2012 and 4998 mg/L. The filtering process effectively hindered the passage of suspended particles, hence ensuring a consistent rise in the concentration of mixed liquor suspended solids (MLSS). Additionally, the filtration process resulted in a reduction of MLSS loss through the effluent. This finding further validates the efficacy of combining Moving Bed Biofilm Reactor (MBBR) with Membrane Bioreactor (MBR) in addressing the issue of inadequate decantation in MBBR systems.

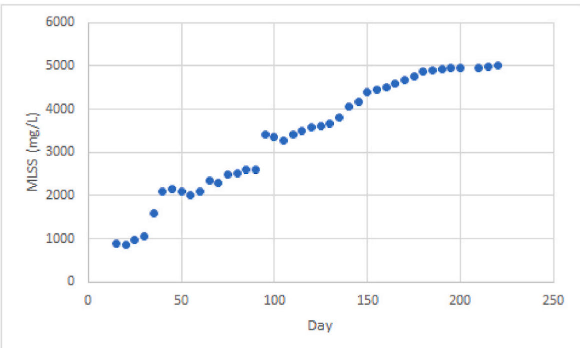

Fig. 2. MLSS in the reactor setup.

After the successful implementation of the membrane, it was observed that the average clearance rate of COD ranged from 89 % to 93 %. Prior to then, the rate of removal was recorded to be between 82 % and 85 %. The concentrations of COD in the incoming wastewater on days 15, 20, 30, and 40 were measured to be 1225.00, 1378.23, 1376.11, and 1518.29 mg/L, respectively. In contrast, the effluent exhibited COD concentrations of 224.10, 218.16, 216.48, and 228.36 mg/L (as shown in Fig. 3). These values indicate a higher COD removal rate compared to the traditional biological treatment method, as reported in a previous study [21]. The concentrations of COD in the influent ranged from 1302.05 to 1671.11 mg/L, while in the effluent, the COD levels ranged from 140.97 to 182.31 mg/L following the installation of the membrane bioreactor (MBR), as seen in Fig. 3. The results suggest a notable enhancement in the efficacy of COD removal subsequent to the implementation of a membrane bioreactor (MBR), leading to the effective elimination of COD by as much as 92 %. The rate of removal remained consistent despite significant fluctuations in the COD values of the influent. The stability of the COD removal rate can be attributed to the robustness of the MBBR system in withstanding high levels of organic loading [22]. According to the Environment Conservation Rules, Bangladesh, 1997, which govern the criteria for discharged water, the prescribed upper threshold for COD is 200 mg/L [23]. The water subjected to treatment by the MBBR-MBR system exhibited a decreased COD value in comparison to the upper limit.

A previous study on an Anaerobic Moving Bed Biofilm Reactor (AnMBBR) experiment to treat household wastewater reported a COD removal efficiency ranging from 80 % to 92 % [24]. Another study achieved marginally superior outcomes in contrast to our investigation. The results could be attributable to their use of synthetic wastewater [25]. In a previous study, a Moving Bed Biofilm Reactor (MBBR), loaded with bio carriers that contained zinc nanoparticles, and the filling ratio was set at 40 %, was employed for the treatment of textile wastewater that showed a COD removal efficiency of 70 % [26]. A similar result (93 % COD removal) to this study was reported by Yang et al. (2021) [27]. They used an AnMBBR-AeMBR treatment method. In a study conducted by a group of researchers on the azo dye Reactive Orange 16 (RO16) using a combination of ozonation and biological treatment in a moving-bed biofilm reactor (MBBR), achieved a 90 % removal of COD [25].

Fig. 4 presents the levels of BOD in both the influent and effluent. The influent's greatest BOD prior to the installation of the MBR was observed on day 40, measuring 867.59 mg/L. Conversely, the minimum BOD was recorded on day 10, measuring 707.41 mg/L. The MBBR effectively decreased the BOD levels in the effluent to a range of 95.78–112.95 mg/L. Following the completion of the

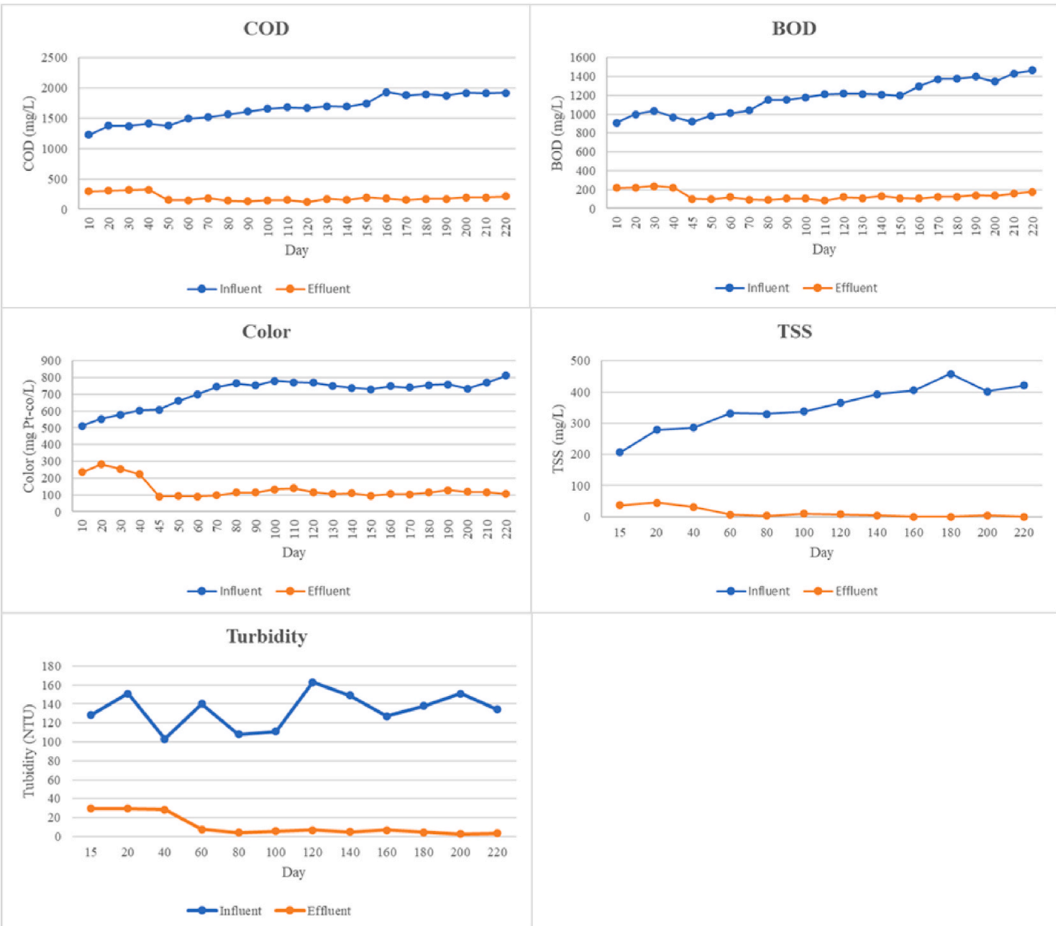

Fig. 3. COD, BOD, Color, TSS and Turbidity of influent and effluent.

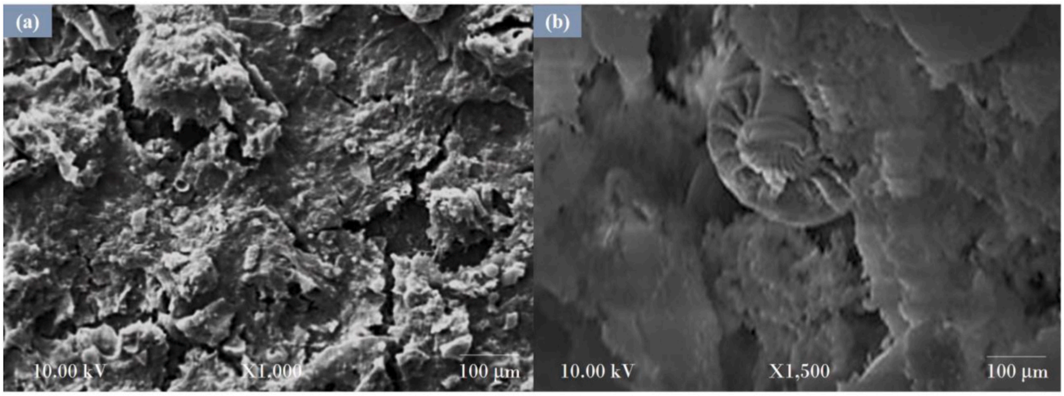

Fig. 4. SEM images of biofilm attached to (a) the membrane module and (b) K1 carrier.

membrane installation, the effluent's BOD came down to 39.78–65.95 mg/L while the influent's BOD was between 709.10 and 974.43 mg/L. In the specific operational framework of a single MBBR, it was noted that the rate of removal for BOD achieved a maximum of 76 %. However, with the installation of a Membrane Biofilm Reactor (MBR), this removal rate saw a significant increase, ranging from 80 % to 95 %. The water treated by the MBBR-MBR system showed a lower BOD value in comparison to the upper limit of the Bangladeshi standard for discharged water (50 mg/L) [23].

The conventional activated sludge system is widely employed in actual textile businesses as a prevalent approach for the treatment of their effluent. While the system demonstrated efficacy in reducing organic contaminants, it did not fulfill the necessary criteria for wastewater color removal. Satisfactory removal of color necessitates the implementation of a tertiary treatment method, such as chemical coagulation. Nevertheless, the use of tertiary treatment methods leads to an escalation in expenses and the production of additional byproducts, such as depleted activated carbon and chemical sludge [28,29]. Throughout the course of the trials, the concentration of color in the influent exhibited a range of 512–812 mg Pt-co/L. Fig. 3 illustrates the color present in the influent and effluent before and after the MBBR-MBR treatment. During the operation of the Moving Bed Biofilm Reactor (MBBR), until day 45, the maximum and the minimum color in the influent were 603 and 512 mg Pt-co/L, respectively. In the effluent, the colors were found to be between 223.11 and 282.54 mg Pt-co/L. The effectiveness of color removal was 49–63 %. However, this efficiency significantly improved to 83–87 % following the installation of the membrane. The effluent color was between 91.13 and 138.96 mg Pt-co/L while the influent color was between 608 and 812 mg Pt-co/L. A previous study revealed that the color removal efficiency in the pilot-scale MBBR systems was 50 %, which is comparatively lower than the findings of our own study [14]. A combined process of MBBR and chemical coagulation for dyeing wastewater treatment reported a 97.4 % efficiency for color removal [30].

Fig. 3 depicts the levels of TSS, and turbidity observed in both the influent and effluent water samples. The rates of removal for TSS and turbidity displayed a comparable trend. During the operational period of the MBBR exclusively, the clearance rate consistently fell within the range of 82 %–89 %. The TSS exhibited a notable decrease, with levels ranging from 31 to 45 mg/L, as compared to the initial range of 206–286 mg/L. Subsequent to the implementation of the membrane, the removal efficiencies exhibited a substantial enhancement, with TSS achieving a maximum removal rate of 100 %. Following the completion of the installation process, TSS concentration in the effluent was observed to range from 0 to 10.11 mg/L.

When it comes to turbidity, it was noted that the installation of the membrane resulted in a removal efficiency of 96 %. Prior to day 45, the turbidity of the effluent was recorded as 29.50 NTU on day 15, 29.63 NTU on day 20, and 28.34 NTU on day 40. The recorded turbidity levels were 128, 151, and 103 NTU on days 15, 20, and 40, respectively, in the inlet water. Upon the installation of MBR, the turbidity levels experienced a notable decrease, with the effluent measuring between 2 and 7 NTU, in contrast to the influent range of 108–163 NTU. The MBR process could produce a considerably clarified effluent without the requirement of adding coagulation agents, a necessity frequently noticed in conventional MBBR systems.

3.2. Transmembrane pressure (TMP) in the MBBR-MBR system and microbial community

A comprehensive evaluation of the transmembrane pressure (TMP) was conducted. The MBR demonstrated effective operation for a duration of 143 days at a HRT of 1 day, without the need for chemical or manual cleaning. Following the observed increase in the TMP value to 560 mBar, the MBR system underwent some physical cleaning which was conducted at a frequency of once every 21 days.

The scanning electron microscopy (SEM) investigations were conducted on the biofilms present on Kaldnes K1 in the MBBR and MBR, as shown in Fig. 4. The parameters of biofilm thickness and biomass concentration hold significant importance in biofilm cultivation systems. In the present investigation, a fine but condensed biofilm layer on the plastic carrier, measuring around 120–130 μm in thickness was observed (Fig. 4 b). The membrane had a condensed biofilm of 145–165 μm (Fig. 4 a). The biofilms in both MBBR and MBR grew in aerobic conditions. Aerobic biofilm systems have the capability to develop thicker biofilms, with a thickness ranging between 100 and 200 μm [31,32].

3.3. Removal of heavy metals

Textile effluent is known to include a diverse range of pollutants, including heavy metals. The prevalence of diverse heavy metals is on the rise due to population development and advancements in technology. While some metals are essential for the well-being of people, aquatic ecosystems, and microbes, excessive concentrations of these metals can pose significant risks to their respective surroundings. The efficacy of metal removal using the MBBR-MBR system in wastewater treatment has been assessed, and the corresponding outcomes are depicted in Table 2. Four different heavy metals, specifically Zn, Fe, Pb and Cr, were quantified on four distinct days: the 50th, 100th, 150th, and 200th days. Table 2 presents the recorded amounts of Zn in the input water, which were consistently measured at 24 mg/L for three instances and 23 mg/L for one instance. The concentration of zinc in the effluent was measured to be 0.99, 0.97, 0.96, and 0.92 mg/L. The efficacy of removal was found to be 96 %. The Cr removal effectiveness ranged from 84 % to 85 %. The highest and lowest concentrations of Cr in the influent were observed on day 50, with a value of 1.86 mg/L, and on day 200, with a value of 1.32 mg/L, respectively. The concentration of the outlet water was measured to be 0.28, 0.24, 0.25, and 0.20 mg/L on the 50th, 100th, 150th, and 200th days, respectively. The concentrations of Pb in the feed water were measured to be 1.50 mg/L on day 50, 1.17 mg/L on day 100, 1.06 mg/L on day 150, and 1.33 mg/L on day 200. Similarly, the concentrations of Fe in the feed water were found to be 82.40 mg/L on day 50, 88.85 mg/L on day 100, 90.88 mg/L on day 150, and 85.23 mg/L on day 200. The concentrations of Pb and Fe decreased to 0.12 mg/L (on day 50th), 0.11 mg/L (on day 100th), 0.09 mg/L (on day 150th), and 0.14 mg/L (on day 200th) for Pb, and 10.25 mg/L (on day 50th), 12.51 mg/L (on day 100th), 11.36 mg/L (on day 150th), and 10.04 mg/L (on day 200th) for Fe, following the treatment. The study detected an approximate effectiveness of 92 % for the removal of Pb and 88 % for the removal of Fe. The standard limits for Zn, Fe, Pb and Cr in wastewater discharged in water bodies in Bangladesh are 5 mg/L, 2 mg/L, 0.1 mg/L and 0.5 mg/L respectively [23]. Wastewater treated by the MBBR-MBR system had a lower Cr and Zn concentration than the standard. Concentration of Pb slightly exceeded the limit. However, the Fe concentration in the effluent surpassed the maximum limit for water discharged in water bodies. The observed high efficiency can be attributed to the concurrent occurrence of adsorption, precipitation, filtration, and biological processes. Comparing our findings with other research is challenging due to the absence, to the best of our knowledge, of any existing MBBR-MBR studies specifically focused on heavy metal removal. According to previous studies using MBR for HMs removal, the efficiency was around 70 % for Cr [33], 77 % for Zn [34], and for 98.3 % Pb [35]. Granular activated carbon added to the MBR in combination with the low influent concentration (0.2 mg/L) might have contributed to the higher Pb removal efficiency. However, in our investigation, the Pb content was as high as 1.5 mg/L.

There could be two possible processes for the removal of heavy metals in MBR: adsorption and membrane filtration. Zn, Fe, Pb, and Cr were successfully eliminated from the treated wastewater by membrane filtering in the MBR. As physical barriers, the semi-permeable membranes kept bigger particles, including the HMs, within the bioreactor while permitting water molecules to flow through. Moreover, HMs might get adsorbed onto the sludge and biomass flocs in the MBR. The sludge particles' and microbial biomass's large surface area and adsorptive qualities made it easier for HM ions to bind.

4. Conclusion

This study highlighted the efficacy of the hybrid MBBR-MBR system in the treatment of actual textile effluent. The combination of MBBR and MBR showed a high level of effectiveness in removing COD by up to 93 %, BOD by up to 92 %, color by up to 87 %, turbidity by up to 96 % and TSS by up to 100 %. The potential of implementing lower HRT in realistic scenarios holds promise for the textile sector, since it may lead to significant benefits such as space and energy conservation. The greatest COD removal achievable by biological wastewater treatment is around 93 %. This limitation arises from the fact that the water is not entirely biodegradable, owing to the presence of resistant substances, particularly colors, in textile wastewater. The removal of 87 % of color without the need for tertiary treatment is a viable and appealing approach for the treatment of textile wastewater, considering its positive implications on

Table 2
Concentration of heavy metals in inlet and outlet water.

Heavy metal	Day	Influent (mg/L)	Effluent (mg/L)	Maximum limit in Bangladesh for discharged wastewater (mg/L) [6,36]
Cr	50	1.86	0.28	0.5
	100	1.53	0.24	
	150	1.66	0.25	
	200	1.32	0.20	
Zn	50	24.00	0.99	5
	100	24.00	0.97	
	150	24.00	0.96	
	200	23.00	0.92	
Fe	50	82.40	10.25	13
	100	88.85	12.51	
	150	90.88	11.36	
	200	85.23	10.04	
Pb	50	1.50	0.12	0.1
	100	1.17	0.11	
	150	1.06	0.09	
	200	1.33	0.14	

both economic and environmental aspects. In addition, the use of the MBBR-MBR treatment system has been found to enhance the efficiency of heavy metals elimination from wastewater. The elimination effectiveness of Zn, Fe, Pb and Cr was determined to be greater than 85 %. The aforementioned findings together contribute to the enhancement of water quality, mitigation of contamination risks, reduction in membrane fouling, decreased presence of hazardous sludge deposits, and overall improvement in the operation of treatment plants.

This study is not devoid of drawbacks. The textile wastewater contains other heavy metals, such as copper and cadmium, which were not included in the experimental setup to assess the system's potential capabilities. Additional research is necessary to provide a more comprehensive understanding of the efficacy of this treatment approach in eliminating possible heavy metals. The duration of the treatment setup trial was limited to a period of 220 days. Extending the period may yield a greater outcome.

Data availability report

The data that support the findings of the study are available in the article.

CRediT authorship contribution statement

Mohsin Uddin: Writing – review & editing, Writing – original draft, Investigation, Formal analysis, Conceptualization. **Md Khayrul Islam:** Writing – review & editing, Investigation. **Shubra Dev:** Writing – review & editing.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used QuillBot to improve language and readability. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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