

Performance of Thermophilic Aerobic Membrane Reactor (TAMR) for Carpet Cleaning Wastewater

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ABSTRACT

Managing sewage has become increasingly important at both the national and international levels, largely due to uncertain future options for recovery and disposal. Due to this, it is necessary to develop innovative technology that can reduce pollutants such as surfactants to mitigate the problem at its source. Surfactants are the kind of pollutants that can pose health and environmental risks. This paper aims to study the efficiency of the removal of methylene blue active substances as an anionic surfactant (MBAS) and chemical oxygen demand (COD) from carpet cleaning wastewater using a thermophilic aerobic membrane reactor (TAMR). A laboratory-scale reactor was monitored daily for a month during this study. The removal efficiencies of MBAS and COD were 92 and 95 %, respectively. This study demonstrated that the TAMR process could resist high-stress situations (sudden load peaks) and withstand high surfactant concentrations, making it the ideal pretreatment option. For MBAS removal, the TAR and UF processes combined led to higher removal yields. MBAS was removed almost completely (>92 %) by the TAMR+UF procedure. Moreover, membrane cleaning operations and fouling problems are discussed. Prog. Color Colorants Coat. 16 (2023), 377-385© Institute for Color Science and Technology.

1. Introduction

Chemicals such as dyes, metals, and antibiotic drugs are commonly found in wastewater [1]. These chemicals are known to enter the environment through wastewater and cause profound effects on the environment [2]. While it is widely known that certain chemicals in water are beneficial, they can also threaten human health [3]. Wastewater from washing industries such as laundry, carpet cleaning, and car washing offers combinations of different levels, including suspended solids, turbidity, chemical oxygen demand (COD), and surfactants. In most communities and carpet cleaning situations, wastewater can be discharged by pouring it into a sink, toilet, bathtub, or

other drainage systems as long as it is connected to the municipal sewer infrastructure.

For instance, certain surfactants in high concentrations can cause adverse effects on humans [4]. A surfactant is a substance that has a unique structure that contains both hydrophilic and hydrophobic moieties [5]. It can be used in various industries, such as cleaning and textiles. The cationic surfactants are positively charged, anionic surfactants are negatively charged, and non-ionic surfactants have a non-ionized hydrophilic group [3]. Each type of surfactant is produced differently. For instance, the total production of cationic surfactants is only 10 %. The production of different kinds of surfactants is not the same. For example, the total output of MBAS is 60 %, while the production of

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TAS is 30 % [6]. Due to environmental protection regulations, the use of surfactants has been regulated in many consumer products [7]. However, these chemicals' excessive production and discharge into the environment have continued [8]. Due to the continuous use of surfactants, the environment is still vulnerable to toxicity. Therefore, removing these harmful substances could be challenging [6]. These industrial laundries are mainly responsible for producing wastewater produced by various levels of suspended solids with varying turbidity and COD [9]. The main problem is the removal of dirt from the fabrics [10].

The removal of surfactants involves chemical and electrochemical processes [11], photocatalytic degradation, membrane technology and chemical precipitation [12], adsorption [13], and various biological methods [14]. There are merits and limitations to each approach. Wastewaters containing surfactants are challenging to treat by biological processes, such as activated sludge, because of low degradation kinetics and foam production [15]. Although chemical and physico-chemical treatments are generally considered effective in removing surfactants, they can also cause high operating costs [10]. For illustration, high surfactant concentration can lead to the depletion of adsorbent materials. Biological processes could provide an alternative to conventional waste disposal methods [6, 8, 16]. However, their disadvantages are usually considered when compared to the alternatives.

A thermophilic aerobic membrane reactor (TAMR) was tested in this study to overcome this disadvantage. Thermophilic treatments show low sludge production (0.02-0.1 kgVSS /kgCOD removed). In contrast to mesophilic conditions, WW treatment plants can reduce their total costs by 50 percent due to sludge management costs [17]. Reduced sludge production may be due to increased metabolic activities at higher temperatures rather than reproduction and growth or increased endogenous respiration, which means bacteria consume more COD for maintenance than cellular growth [17]. Furthermore, their biodegradable substrate removal kinetics is around 3-10 times greater than those under mesophilic conditions [18]. By using a UF membrane in conjunction with a thermophilic aerobic reactor (TAR), the biomass is retained at high concentrations (up to 190 kg TSS m⁻³) of total suspended solids (TSS). This concentration can be handled, thus reducing the size of the reactor [1].

The study was conducted on a bench-scale

wastewater reactor with TAR+ ultrafiltration (UF). The reactor was monitored for over one month by using real wastewater has been characterized. Moreover, information on membrane cleaning operations and fouling problems is obtainable. The current study aimed to study and reveal that TAMR may be utilized as a pretreatment to reduce the concentration of MBAS and takes advantage of its stability by using UF for polishing.

2. Experimental

2.1. Carpet cleaning wastewater

The wastewater samples were collected from a carpet cleaning plant in Al Najaf, Iraq. The characterization of the wastewater used in our experimental study is given in Table 1.

Shakeri et al. [19] stated the wastewater characteristics from hospital laundry as surfactant and COD ranged between 3.19-6.48 mg/L and 650-1,080 mg/L, respectively. Changanani et al. [6] also detected that the wastewater from the carpet cleaning industry's average effluent characteristics was a detergent of 55.51 mg/L and COD of 367.4 mg/L. Furthermore, MBAS, COD, turbidity, electrical conductivity, and pH were detected as 353-25 mg/L, 229-1446 mg/L, 137-2250 NTU, 250-1,890 μ S/cm, and 7.7-8.2, respectively, of wastewater from car wash station [20]. Table 1 shows concentrations of all contaminants measured in the current study were within the range stated in the significant literature and relevant. The effluent analyses were performed on a sample withdrawn from the supernatant. COD was analyzed using a digestion reactor (LT200, Hach, USA) and spectrophotometer (DR 5000 UV-Vis, Hach, Germany). Water and

Table 1: The characterization of the wastewater used in the experimental study.

Parameter	Unit	Concentration
COD	mg/L	499-650
Turbidity	NTU	100-133
MBAS	mg/L	17.8-20.2
Conductivity	mS/m	0.77-0.88
pH	-	8.5-9.1

Wastewater Standard Methods have been used to quantify COD in raw influent WW (APHA, 2012) [21]. MBAS was measured with a spectrophotometer (DR 3900 UV-Vis, Hach, Germany) according to the method suggested by Chitikela et al. [22]. The nephelometric method [21] was used to analyze turbidity using a spectrophotometer (2100 AN, Hach, Germany). The MBAS, COD, and turbidities removal efficiency (R) (%) was calculated using the formula shown in Eq. 1. The MBAS content was determined after filtration with UF membranes. Other parameters were determined for effluent as obtained.

$$\text{Surfactants removal (\%)} = \frac{C_{in} - C_{out}}{C_{in}} \times 100 \quad (1)$$

Where C_{in} and C_{out} are the concentration of Influent and Effluent wastewater.

A pH meter and thermometer (model SenTix® 940, WTW-IDS) were used in the TAMR reactor for simultaneous pH and temperature measurement. A probe model TetraCon® 925 was used to measure electrical conductivity.

2.2. Bioreactor configuration

Aerobic conditions were imposed upon the TAMR bioreactor made of Plexiglas and having a volume of 10 L. There were two sampling ports on the reactor body, each at a different height, as shown in the schematic diagram Figure 1). There were two main sections in this apparatus: the main one was where wastewater and activated sludge met, and the second section was where UF membranes were sited. A compressor, air diffuser, and O₂ from the oxygen cylinder provided aeration from the bottom of the column. A peristaltic pump was used to pump continuous wastewater into the system from the feed tank. The treated wastewater was also discharged from the upper part of the reactor into UF membranes. At different temperatures, the lab-scale bioreactor was operated with a programmable logic controller for different cycle times: 30 minutes for aeration, 10 minutes for settling, and 2 minutes for effluent withdrawal.

3. Results and Discussion

3.1. Characterization of the wastewater

Although the characteristics of carpet cleaning wastewater can vary, the variation can be observed due

to the various procedures utilized. The carpet-cleaning wastewater influent was treated with a pilot-scale treatment system. The results revealed that the high concentration of multiple surfactants and COD allowed the wastewater to achieve high electrical conductivity and pH. The results showed that the conductivity reported between 0.77-0.88 and pH was 8.5–9.1, respectively, as shown in Table 1. The concentration of the surfactants was within the range obtained by literature reports. pH values were lower than those seen in other tests as well. WW had the same electrical conductivity as Collivignarelli et al. [23] but a higher one than Ciabattia et al. [24].

3.2. The overall removal efficiency of organic matter and surfactant wastes

The average output and input concentrations of COD were 100 and 561 mg/L. Removal efficiency for COD was estimated between 70.55-94.99 %. Figure 3 shows that the process stability is still good despite the increase in COD value. A high level of process and quality stability was also observed during the experiments.

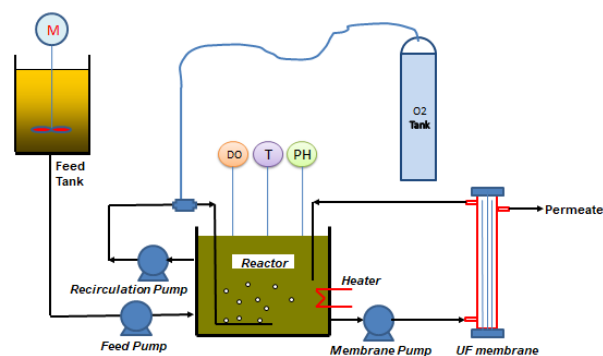


Figure 1: Experimental setup of TAMR.



Figure 2: The TAMR bench scale.

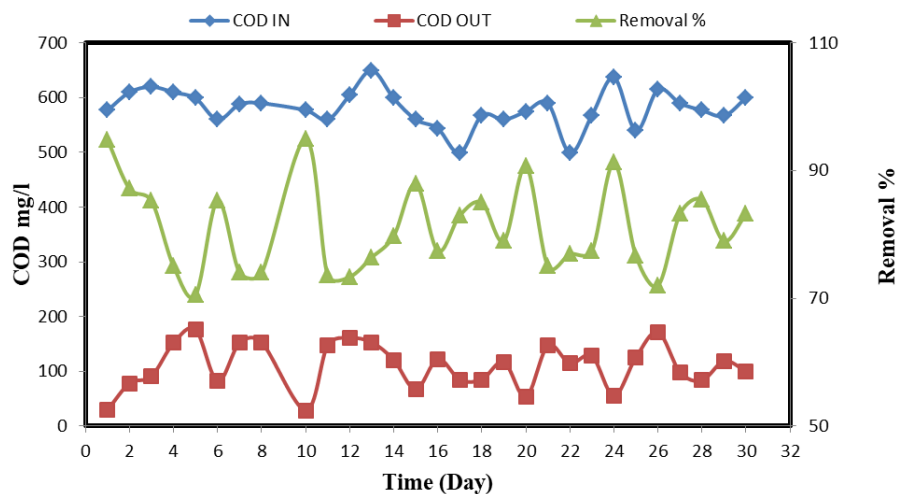


Figure 3: Concentrations of COD input and output and removal efficiency.

Figure 4 shows concentrations of anionic surfactants (MBAS). The MBAS average removal efficiencies were between 70.1 and 90.1 %, respectively, so the effluent concentration was between 1.465 and 5.44 mg/L. Despite high COD and MBAS, the TAMR process performed exceptionally well with 94.99 and 90.1% removal yields for COD and MBAS, respectively.

The TAMR reactor is an effective and valid process for removing MBAS and is the novelty of this research. There is a great deal of variability in the data obtained in this study compared to some provided by the literature. In our test, the removal efficiency of

surfactant concentration was 90.1 %, which agrees with that reported by Collivignarelli et al. [23, 25, 26] but significantly higher than that reported by Ciabattia et al. [24] and one order of magnitude higher than Ostar-Turk et al. [27] even COD removal.

Figure 5 shows concentrations of biological oxygen demand (BOD). The BOD average removal efficiencies were 82 and 94 %, respectively, so the effluent concentration was consistently between 34 and 14 mg/L. Even with high BOD, the TAMR process performed exceptionally well with a 94.99 % removal yield for BOD.

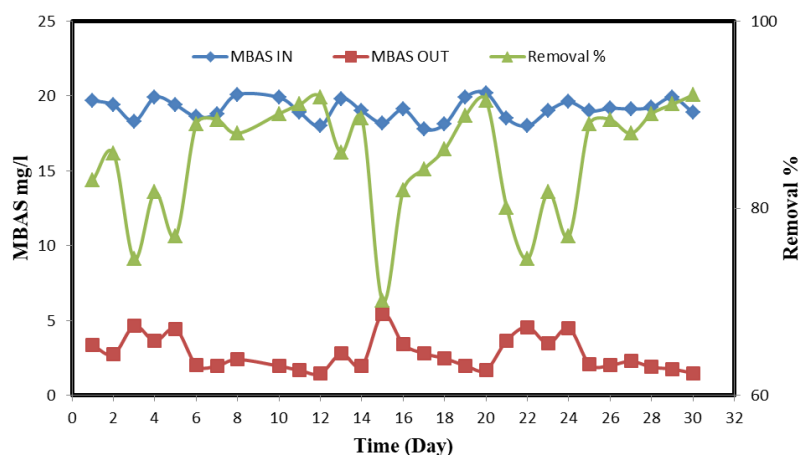


Figure 4: MBAS concentrations and removal yields of the TAMR experiment.

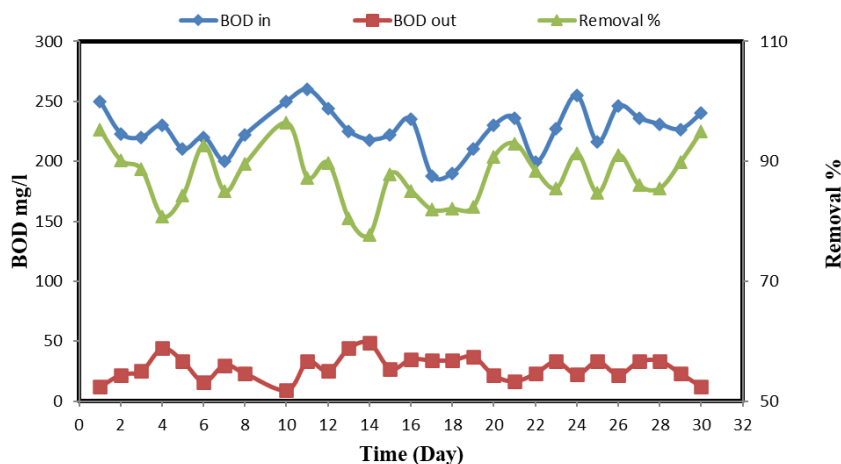


Figure 5: Concentrations of BOD input and output and removal efficiency.

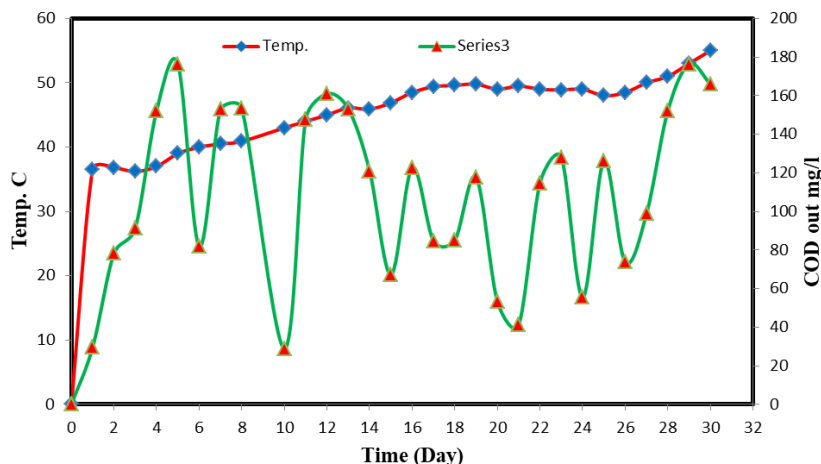


Figure 6: Effect of temp. on COD concentration.

3.3. The effect of temperature on performance removal of COD and surfactant wastes

The experimental performance improved over time due to installing a heater for temperature control (between 45 and 48 °C). When the temperature is higher than 50°C, COD removal yields are significantly reduced, as shown in (Figures 6 and 7). The high removal rate of biodegradable substrates (up to 10 times higher than those measured in mesophilic conditions [28]), is mainly due to the fast hydrolysis of the organic substance at thermophilic temperature. That allows substrate solubilization and its availability for oxidation.

3.4. UF investigations during experimental setup

3.4.1. NTU investigations

Turbidity rejection was not disturbed in all cases and

always maintained $\geq 98-99\%$, as shown in Figure 8.

3.4.2. Flux investigations for short term

The correlation of flux decline with time was conducted to obtain preliminary information about the fouling tendency of the membrane. The behavior of the permeate flux as a function of the operation time was studied quickly. Figure 9 shows that the UF permeate flux appears very stable with the operating time, indicating that fouling is not a problem on the UF system during 150 min operation. During the UF, the temperature increased again (54 ± 2 °C) due to the working conditions. Therefore, more favorable permeation rates can be achieved due to decreased viscosity [29]. Permeate flux was expressed as volume per unit membrane area per unit time, e.g., $\text{Lm}^{-2} \text{h}^{-1}$ (LMH).

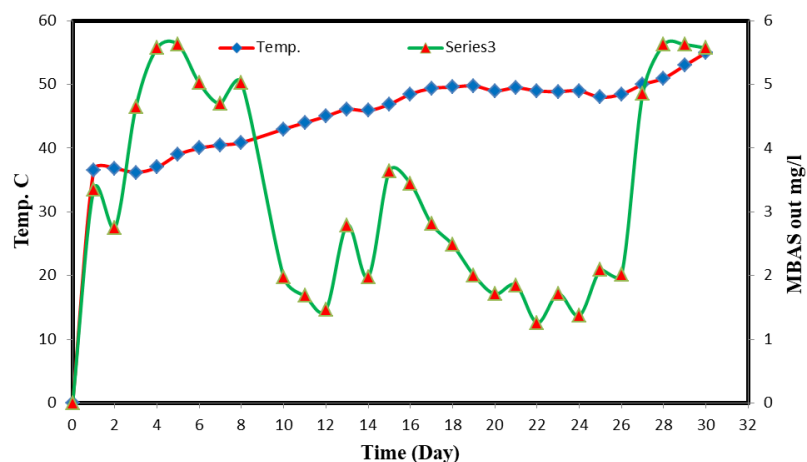


Figure 7: Effect of temp. on MBAS concentration.

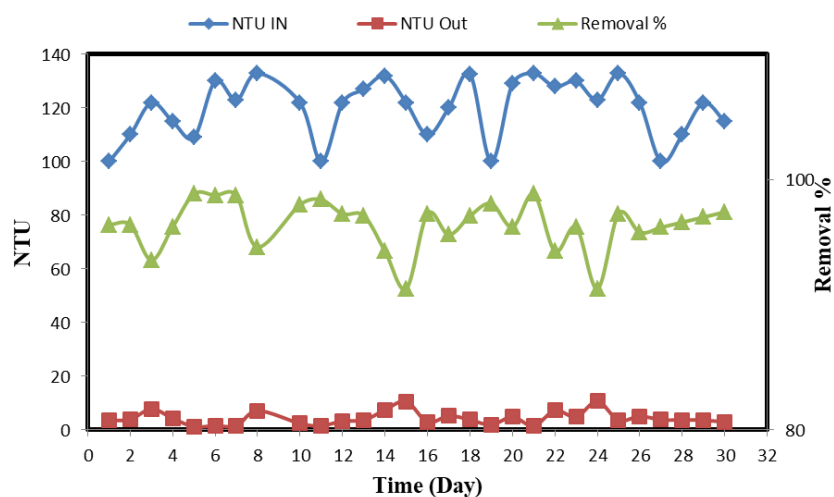


Figure 8: Concentrations of NTU input and output and removal efficiency.

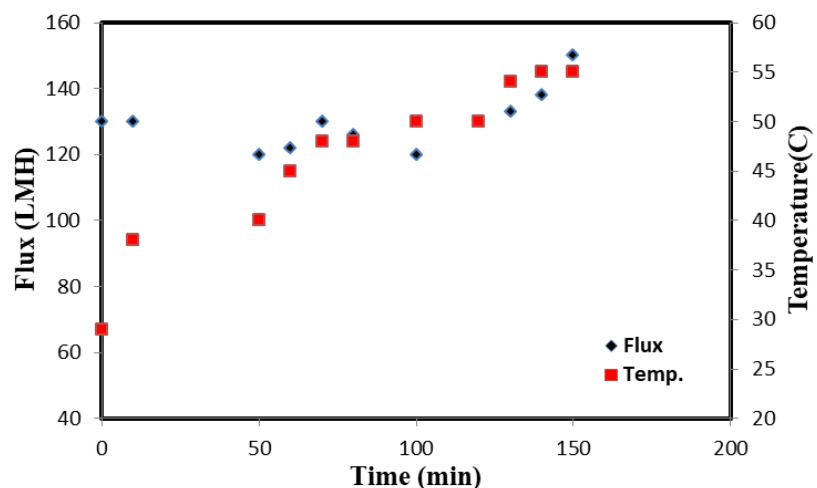


Figure 9: The behavior of the permeate flux as a function of the operation time and temperature.

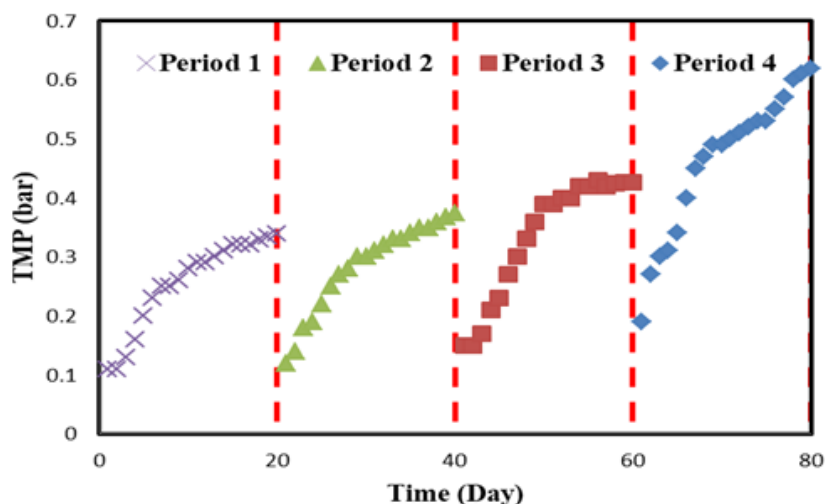


Figure 10: Transmembrane pressure (TMP) change in the UF process.

3.4.3. Membranes: fouling and cleaning for long term

As part of this study, the feed, retentate, and permeate pressures in the vessel were measured, further more transmembrane pressure was calculated as described in Eq. 2.:

$$\text{TMP (bar)} = \frac{P_F - P_R}{2} - P_P \quad (2)$$

Where P_F , P_R , and P_P represent the feed, retention, and permeate pressures.

Figure 10 shows that the transmembrane pressure increased significantly in the long term. It was observed that the membranes were being subjected to organic fouling and the presence of inorganic precipitates. The membrane cleaning was not different between the lines. The process consisted of four passages, and each was carried out at the highest temperature permitted by the membranes. pH levels are brought nearer to neutral by rinsing with demineralized water. The cleaning operations for the membranes were performed at various times. These tests revealed that the membranes did not exhibit organic fouling problems. Since cleaning the

membranes is essential to reduce the formation of inorganic fouling, they are regularly washed at least once in a 60-minute operation.

4. Conclusions

The study results revealed that combining the TAMR+UF process can achieve an optimal removal of MBAS and COD was 92.15 to 95%, respectively, with a different OLR. The colored wastes did not cause inhibition of the thermophilic biomass; surfactants were removed up to efficiencies as high as 92.1 %, even at the highest OLR values. The plant was fully monitored for more than one month to confirm the presence of certain surfactants in the wastewater. The TAMR+UF combination has the potential to provide an excellent polishing treatment. Moreover, membrane cleaning operations and fouling problems are discussed.

Acknowledgments

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