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Improving the Efficiency of the Biological Treatment of Hospitals' Wastewater by Using MBBR with K1 and K3 Biofilm Carriers

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Abstract: The performance of a moving bed biofilm reactor (MBBR) process was investigated using two different types of plastic carriers: K1 and K3, thereby enhancing the efficacy of biological treatment through biofilm development. The K3 carrier's geometric form was selected to reduce clogging and allow a simpler flow of organic matter and oxygen. Its internal openings are more homogeneous than those of the K1 carrier, and its specific surface area is greater than that. Laboratory-scale moving bed biofilm reactors were constructed from two identical volumes of a split 15L MBBR system. K1 carriers serviced one volume, while K3 carriers serviced the other with a 45% fill rate. A base aeration system provided oxygen, and automated sensors continuously monitored pH and temperature. After a period of acclimation for biofilm development, performance data were quantified and analyzed under standardized methods at steady-state. The results reveal that the K3 conveyor exceeded the K1 in all major performance standards. K3 eliminated 86% of the chemical oxygen demand (COD) and 81% of the biological oxygen demand (BOD), compared to 83% and 74%, respectively, for K1. In addition, K3 eliminated more ammonia (NH_3), 85% compared to K1, 72%, and eliminated 72% of K1 and 82% of all the total suspended solids (TSS). Taking all the parameters into consideration, the heightened efficiency of the K3 conveyor is mainly a result of its enhanced flow dynamics and biofilm adhesion characteristics. These results suggest that K3 can be utilized as a substitute for installed treatment systems or implemented in newly built wastewater treatment plants. Analyzing carrier composition on lifespan and financial efficiency, along with integration of K3 with emerging treatment technologies such as membrane filtration and ultraviolet disinfection, will be beneficial for future research work. This research assists in the development of more sustainable and efficient wastewater treatment processes.

Keywords: Hospital wastewater, MBBR efficiency, Biofilm carriers, K1 and K3, Carrier surface area

Introduction

Many countries around the world, specifically those located in the Middle East, which are afflicted with a lack of freshwater resources, are faced with serious environmental issues, such as limited water availability and declining water quality. Some of the key drivers that have cumulatively increased pressure on surface and groundwater resources include rapid population growth, unplanned urbanization, poor infrastructure, and weak environmental policies (Al-Sulaiman, 2015). Because of its intricate nature, being laden with persistent organic pollutants and pathogenic microorganisms (Ferlici et al., 2010; Santos et al., 2013), hospital wastewater can be classified as one of the most hazardous types of effluent. Hospitals produce more wastewater than normal households (400–1200 l/bed.d vs. 100 l/capita.d) (Ghawi, A. H., 2018). Inadequate handling of this effluent represents significant threats to both public health and aquatic ecosystems (Emmanuel et al., 2009; De Wit and Zhang, 2013). Traditional wastewater treatment methods have been ineffective in addressing the special nature of hospital wastewater challenges. Consequently, more recent efforts have been focused on emerging treatment technologies with the versatility necessary to manage variable flow conditions while sustaining high operational efficiency. The moving bed biofilm reactor (MBBR) is one such innovative technology. It employs suspended plastic carriers to increase the biofilm development and improve the degradation of organic and nitrogenous contaminants (Rusten et al., 2006; Ødegaard et al., 2000).

The MBBR system is of great appropriateness for the treatment of wastewater generated in hospitals since it is effective, has the capacity to absorb organic shock loads, and is compact (Leyva-Díaz et al., 2017). The system has been found through studies to be capable of eliminating various kinds of pollutants, including antibiotics and ammonia (Falas et al., 2012; Di Bella et al., 2013). One crucial measure to avoid surface water body contamination is the purification of sewage water prior to discharge (Hadi, N. H. 2023). In spite of these benefits, substantial knowledge gaps exist regarding how the biofilm carrier's characteristics influence the overall performance of MBBR systems. Biofilm carriers with different shapes, sizes, and capacities are available to perform microbial growth and oxygen transfer. Two of the most common biofilm carriers used in the market are K1 and K3 yet limited comparative efficacy research has been published regarding hospital wastewater treatment.

The objective of this research is to compare and assess the performance of two biofilm carriers, K1 and K3, in an MBBR system for hospital wastewater treatment. The research discusses the performance of different operating conditions in terms of the removal of chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), ammonia (NH_3), and total suspended solids (TSS). Furthermore, the study seeks to offer practical guidelines on the appropriate choice of optimal biofilm carriers for contemporary hospital wastewater treatment plants. The current study will compare the efficiency of two carriers (K1 and K3) in an MBBR system for hospital wastewater contaminant removal based on the removal rate of organic and chemical contaminants.

Care should be taken regarding the influence of chemical and physical parameters on the carriers' properties and how they influence the treatment process and overall performance. Furthermore, the carrier that proved to be the most efficient and best, considering both economic and environmental aspects, was also found to preserve the quality and effectiveness of the treated water.

Study Area Description

The wastewater treatment plant under investigation is situated at the Maternity and Children's Teaching Hospital in the Diwaniyah Governorate Centre, Iraq (long 31.992026478703377, lat 44.91315107631203, Diwaniyah, Al-Qadisiyah Governorate), as shown in Figure 1. The hospital's treatment facility opened in 2014 with a design capacity of 100 cubic meters per day. Sequential batch reactor (SBR) technology is employed. The facility was constructed to treat wastewater from the hospital, which contains a significant amount of organic waste. Over the years, the hospital has expanded significantly, adding more wards as well as a large number of employees and patients. This shows that the plant is currently generating more wastewater than it can handle daily. As a result, the treatment is less effective, and the system has to work harder. Operating and maintaining the SBR has also become more challenging due to its outdated infrastructure, which necessitates sophisticated mechanical and automated systems. According to this study, constructing and operating a pilot treatment unit that makes use of moving bed biofilm reactor (MBBR) technology can resolve these issues. The pilot unit was constructed with the capacity to purify 60 litres of contaminated water per day. Finding out if the moving bed biofilm reactor technology can manage actual hospital waste is the aim.

Figure 1. Overview of the maternity and children's teaching hospital

Hospital Wastewater Sources

Medical and Civil Wastewater

Numerous human activities and events occurring in hospitals lead to the generation of medical and civil waste. The various corridors, operating rooms, and laboratories within the hospital are significant sources of this waste (Khan, 2021). This waste is known to contain many toxic compounds resulting from the chemicals used in the hospital. The presence of these toxic compounds necessitates a treatment facility capable of managing these quantities of chemicals.

Rainwater

This water is collected in a separate network within the hospital and is drained into the city's rainwater system. It cannot enter the hospital's treatment plant to ensure the plant's performance is maintained.

Materials and Methods

The Pilot Plants

In July 2024, a prototype of the station was constructed. The schematic diagram of the wastewater route to the pilot station units is shown in Figure 2. The raw wastewater was collected from the Primary treatment tank of the children's hospital, about 80 liters. The effluent of wastewater was transferred from the feed tank to the pilot plant (MBBR).

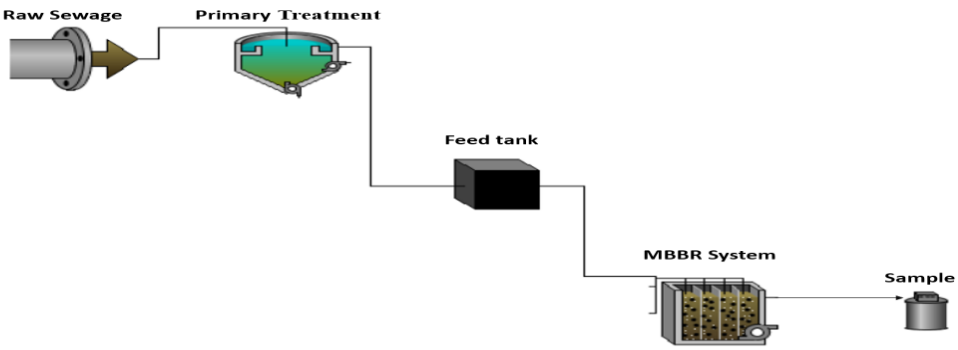

Figure 2. Schematic diagram of the MBBR experimental.

Collection Tank

The collection tank represents the first stage in the wastewater treatment plant. The tank is designed from high-strength plastic with dimensions of 40 cm in diameter and 70 cm in height, to be a corrosion-resistant tank that collects and temporarily keeps raw sewage before it leaves for the next treatment step. The tank has a manual control valve, which is used to control the flow of water to the next stage and ensure the smooth operation of the plant.

The MBBR Reactors

The treatment tank represents the main stage in the wastewater treatment plant using the MBBR technology (Ødegaard, 2016). The tank is made of glass with dimensions of 10 x 30 x 50 cm, as shown in Figure 3. Allowing visual monitoring of the treatment process. Water quality testing samples are gathered from the tank using a manual discharge switch, which also tracks system performance. Biofilm carriers, materials designed for plastic packaging with a lot of surface area to let microorganisms flourish on, abound in the tank. This makes the contaminated biological degradation of water more effective. Apart from a mixer to ensure consistent air distribution and carrier movement inside the tank, it also features an air compressor to supply the oxygen needed for microorganism activity.

Figure 3. Photo of the MBBR tank.

Aeration System

The tank is constantly aerated by a compressor, which promotes aerobic microorganisms growing on the biofilm carriers. The efficient digestion of organic contaminants (BOD and COD) in the wastewater depends on the dissolved oxygen produced by the compressor. The constant flow of air also aids in the water cycle within the tank, preventing sedimentation and advancing homogeneous microorganism distribution. The compressor is essential for guaranteeing high degradation efficiency and short degradation time of organic pollutants, so enabling the system to be sustainable and ecologically friendly.

Mixing Unit

Inside the treatment tank, the mixer is a tool meant to guarantee a homogeneous distribution of water, microorganisms, and biofilm carriers. Its main goal is to improve the interaction between pollutants and active microorganisms, so raising the effectiveness of the biological treatment method. By means of a continuous circular motion in the tank, the mixer helps to prevent the settling of carrier or organic sediments at the bottom. It also guarantees that oxygen reaches all sides of the tank efficiently by helping the air compressor produce dissolved oxygen distribution, as shown in Figure 4. This homogeneous distribution improves the performance of the system, allowing better standards of wastewater treatment in lower running times and with more efficiency.

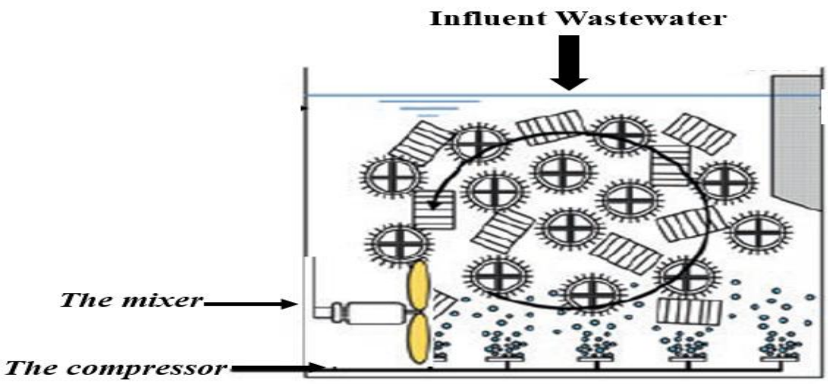

Figure 4. Photo and schematic diagram of the MBBR tank.

Biofilm Carriers

The carrier used in the treatment tank is of the K1 and K3 types, which are plastic packing media specially designed for the suspended bed bioreactor (MBBR) technology. Both types feature an effective surface for the growth of aerobic microorganisms that degrade organic pollutants (Ødegaard, H. 2023). Table 1 represents some characteristics of the carriers.

Table 1. Characteristics of the carrier used

Limitations	K1carrier	K3 carrier
Specific Gravity g/cm³	0.96	>0.96
Efficient surface m²/m³	500	>500
Temperature °C	35-65	35-65
Packing number	365400	135256
Life span (Year)	>10	>10

MBBR Plant Unit

The design criteria of the MBBR, as obtained from reviewing the previous studies, are presented in Table 2. These criteria include HRT, volume, and filling ratio. The values of these criteria were the guide in designing the experiment for the MBBR used in this study to treat the Hospital WasteWater.

Table 2. Specification of MBR units

Criterion	Range of values	Ref.
HRT	6 h	S A. Al-Khafaji 2024
Volume	15 L	
Filling ratio	45%	Majmudar et al.
Daily Consumption	60L	
Flow direction	Up-flow	

Operation Conditions

Sewage was discharged after initial treatment. Employing a suction pump to ensure the preservation of its physical and chemical qualities, to a collection tank that is designed to avoid unnecessary reaction or secondary contamination, the wastewater was released from the collection tank to the treatment tank through a specific discharge valve to regulate the flow rate. In two independent experiments, the treatment tank was charged with bio-carriers K1 and K3, respectively. As shown in Figures 5 and 6, the experimental unit was run at a hydraulic Retention time (HRT) of 6 hours to complete the biological treatment process. Such operations were for the comparison of the performance of the two types of wastewater treatment under controlled conditions.

Figure 5. Treatment with K1

Figure 6. Treatment with K3

Results and Discussions

Characteristics of Raw Wastewater Source

Hospital raw wastewater is the most sophisticated form of polluted water, containing chemical and biological contaminants as a by-product of medical care (Verstraete, 2006). It contains drug residues, chemicals used in sterilization and diagnosis, and organic and biological pollutants from human excreta. Raw wastewater is typified by high TSS, COD, and BOD_5, alongside high heavy metal and pathogenic bacteria counts. The water must be efficiently treated to mitigate its adverse environmental and public health impacts. The physical, chemical, and biological analysis results of the raw wastewater obtained from the hospital are presented in Table 3.

Table 3. Characteristics of raw wastewater samples during the study period

Parameter	Unit	Minimum Value	Maximum Value	Average Value	Iraqi guidelines limitations
PH	-	7.5	8.2	8	6 – 9.5
TURB	NTU	143.2	180.2	162.68	
EC	µs/cm	2968.8	3140.0	3052.63	
COD	mg/l	620.2	698.4	655.4	<100
BOD_5	mg/l	294.2	344.2	315.8	<40
NH3	mg/l	13.4	18.3	16.19	<10
DO	mg/l	0.3	0.9	0.57	
TSS	mg/l	478.8	502.6	489.23	<60
TDS	mg/l	1993.7	2190.4	2090.5	

Note: This information was obtained from the Maternity and Children's Teaching Hospital Engineering Division.

Effect of the Sedimentation Tank

Primary sedimentation removes suspended solids (TSS), which serves to improve the quality of treated water before it is discharged into the secondary treatment stages. The removal efficiency reached 38%, 10.2 %, 11.3 %, and 38.4% for the TSS, COD, BOD_5, and Turbidity, respectively. The reduction of pollution parameters is Table 4. The resulting water still contains high concentrations, which requires secondary treatment (such as biological treatment) to achieve environmental standards. Some parameters are not affected by primary treatment because they are dissolved and cannot be removed by sedimentation.

Table 4. Primary treatment results

Parameter	Unit	Average Raw Value	Average Sedimentation Value	Removal efficiency
PH	-	8	7.8	-
TURB	NTU	162.68	112.2	38.4%
EC	µs/cm	3052	3018	-
COD	mg/l	655.4	600.8	10.2%
BOD_5	mg/l	315.8	280.2	11.3%
NH_3	mg/l	16.2	15.2	6.2%
DO	mg/l	0.5	0.66	-
TSS	mg/l	489.2	324.6	33.7%
TDS	mg/l	2090.5	2084	0.2%

Calculate the Removal Efficiency

Equation (1) calculates the removal efficiency, where Ci and Cf represent the initial and final concentrations, respectively. Goodland (1995).

$$\text{Removal efficiency} = \frac{\mathbf{Ci - Cf}}{\text{Ci}} * 100\%$$

Treatment of Wastewater by MBBR System

When the wastewater effluent from the sedimentation tank was directed to the MBBR system, a noticeable improvement in the removal of pollution parameters was observed. The final concentrations of TSS, COD, BOD_5, and ammonia-N in the treated effluent showed a significant decrease compared to their initial values. The experimental setup involved the use of two types of bio-carriers, K1 and K3, to evaluate their impact on treatment efficiency.

Table 5. MBBR results (K1 , K3)

Items	pH (–)	TURB NTU	COD mg/l	BOD_5 mg/l	NH_3 mg/l	DO mg/l	TSS mg/l	TDS mg/l	EC µs/cm
Average influent	7.8	112.2	600.8	280.2	15.2	0.66	324.6	2084	3018
Average effluent [K1]	7.53	43.96	98.14	75.23	4.5	5.41	87.405	2064.78	3038.0
Average effluent [K3]	7.47	38.65	84.45	55.13	2.465	5.32	60.220	2064.78	3038.0

Impact of the System MBBR on PH

pH was recorded once daily throughout the trial operation by the bulk analysis (loading) method for a representative average of the system, as shown in Figure 7. The abbreviation (inf.) refers to the concentration of contaminants in the inlet water to the MBBR system, while (eff.k1) refers to the concentration of the effluent after treatment with the K1 biocarrier within the MBBR system. (eff.k3) refers to the concentration of the effluent after treatment with the K3 biocarrier, allowing for a comparative evaluation of the two types of carriers in terms of treatment efficiency.

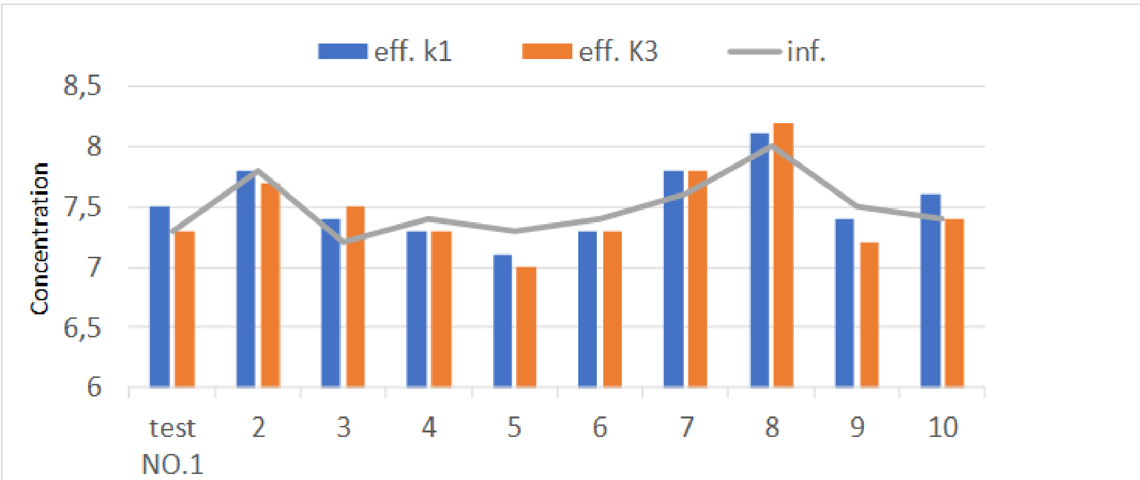

Figure7. pH results after MBBR system (K1, K3) carrier

PH trends during operation

- The raw water pH at the start of the experiment was as expected for hospital wastewater and was in the range of 6.5 to 9.5.
- When the system started up and the biological activity was established, there were a few slight changes in pH observed due to the biological reactions in the reactor.
- pH was kept within the range ideal for the activity of the microorganisms that carry out biodegradation, i.e., 6.5 - 8.5.
- The system did not show any sharp changes in pH, indicating a stable treatment environment during the trial operation.
- There was no significant effect of the type of carrier, K1 or K3, on pH, except for some minor differences that may be due to the difference in the growth of the biological film on each type of carrier.
- The values recorded were consistent with environmental standards, proving the efficiency of the system in maintaining the balance of biological processes.

Impact of Using MBBR System on Turbidity

The data show that the MBBR system significantly reduced turbidity. Turbidity values in the effluent water decreased compared to the influent water in all tests, as shown in Figure 8. For example, in the first test, turbidity decreased from 100.24 NTU in the influent water to 38.6 NTU in the efferent water from K1 and to 32.6 NTU in the efferent water from K3. Overall, K3 performed slightly better than K1 in most tests for reducing turbidity.

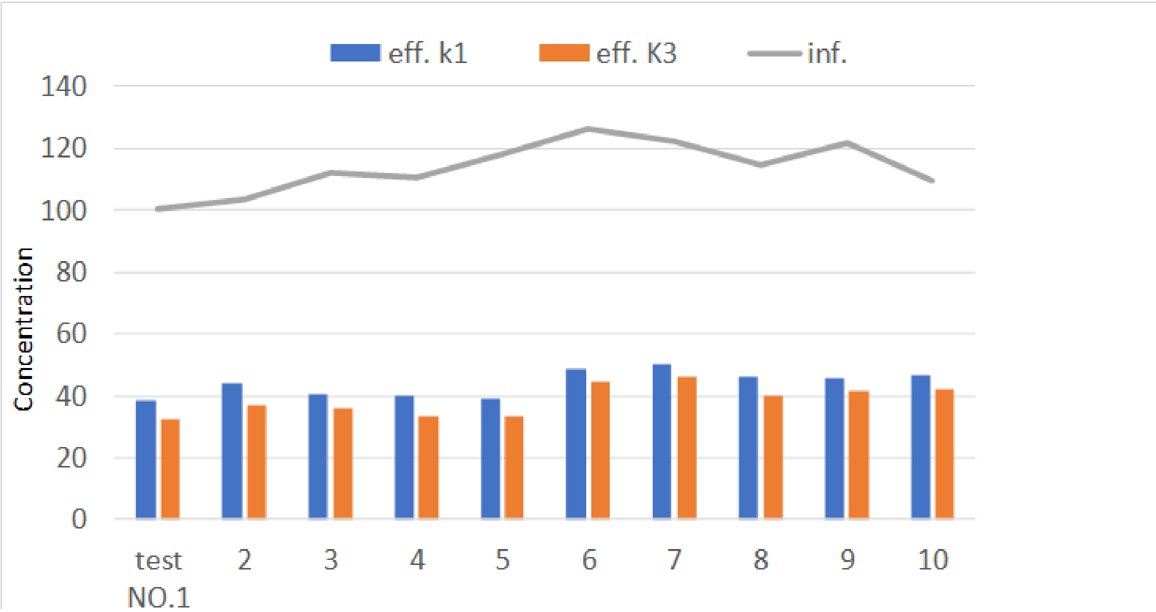

Figure 8. Turbidity results after MBBR system (K1, K3) carrier

Impact of the System MBBR on COD

Figure 9 shows the COD concentrations entering and exiting the MBBR reactors. It can be shown that the waste concentrations in the reactors were acceptable according to the Iraqi specifications, except sometimes when the COD values exceeded 100 mg/L. Despite the high removal efficiency, this is due to the high concentrations of the COD parameters that do not match the concentrations of homes but are higher, which requires achieving better removal rates or adding a treatment unit to achieve the required concentrations.

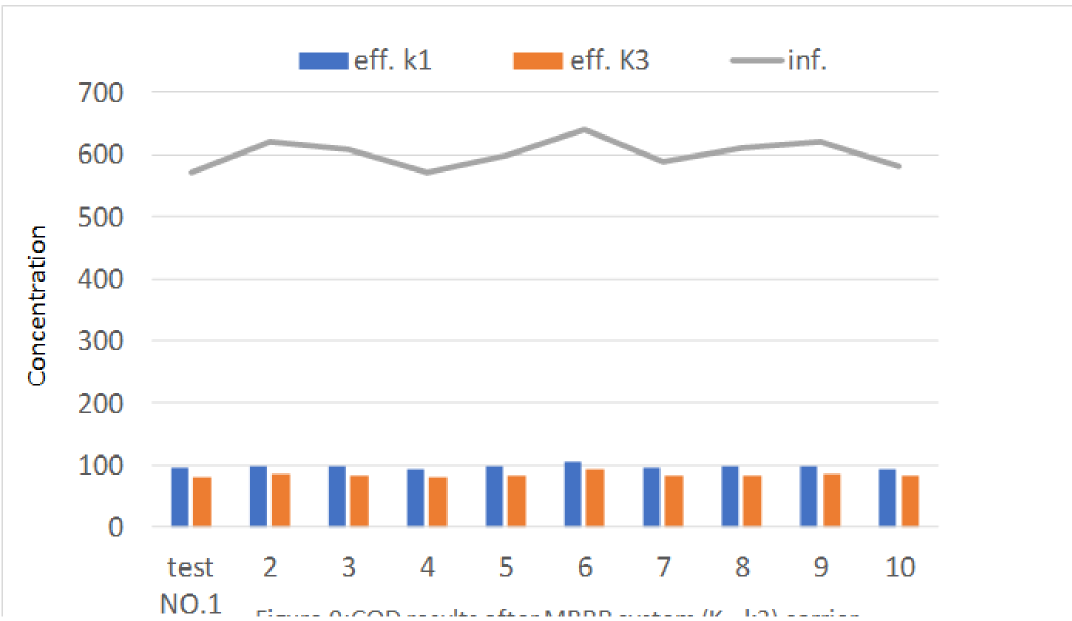

Figure 9. COD results after MBBR system (K1, K3) carrier

Impact of the System MBBR on BOD_5

Figure 10 presents the measured values of the biochemical oxygen demand (BOD_5) of inlet and outlet water after treatment using biocarriers K1 and K3. The figure indicates the magnitude of BOD_5 concentration reduction after treatment. It can be demonstrated that the concentrations of waste in the reactors were above the Iraqi-specified concentration of BOD_5, 40 mg/L. This is because the concentrations of the BOD_5 parameters were high, even though it has a high removal efficiency. Performance and removal efficiency analysis.

- The BOD_5 concentration in the outlet water:
- Carrier K1 reduced BOD_5 levels to an average of 66 - 79.7 mg/L.
- Carrier K3 lowered BOD_5 levels to a mean of 46 - 58 mg/L.
- These findings show that K3 was more effective in eliminating organic matter, having lower values than K1

Percentage removal:

- K1 carrier: The Removal rate ranges from 74%.
- K3 carrier: The Removal rate ranges from 81%.

The higher performance of the K3 carrier compared to K1 for BOD removal can be explained by the greater specific surface area of K3, which supports much denser development and maintenance of biofilm. Higher surface area provides more sites for microbial populations to attach, hence facilitating improved biodegradation efficiency due to higher biomass concentration and greater substrate contact. Madan et al. (2022) highlighted that MBBR process efficiency is greatly dependent on the active biofilm surface area, where a larger carrier surface improves microbial activity and facilitates the removal of organic pollutants.

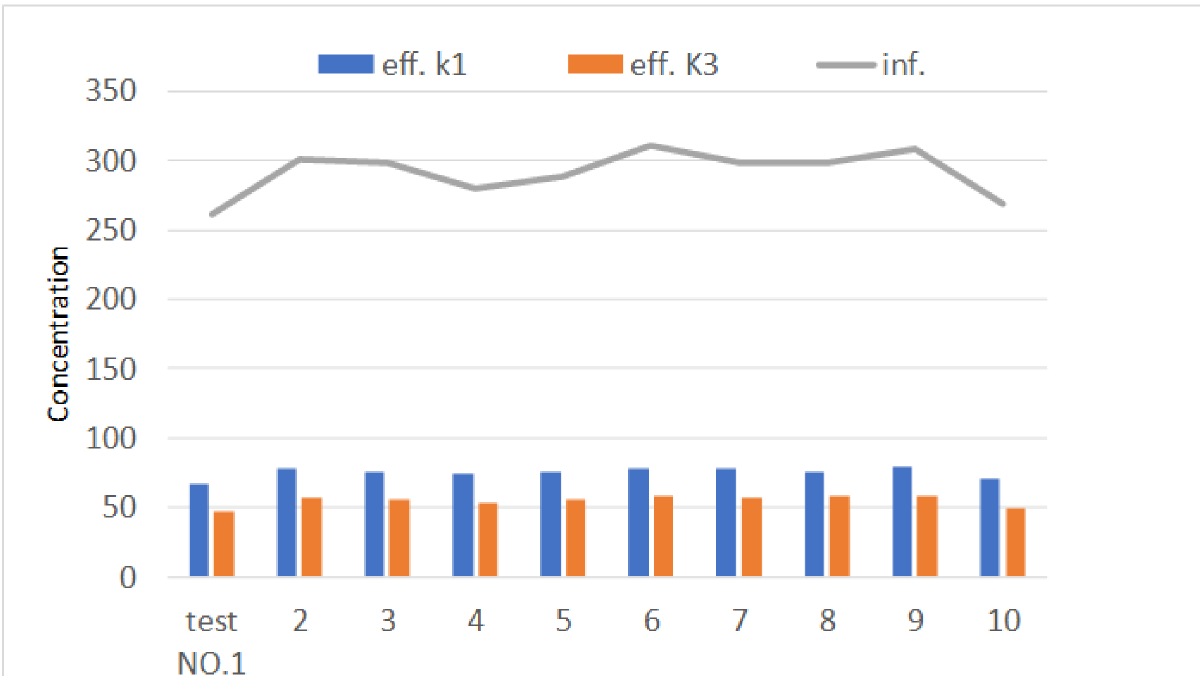

Figure 10. BOD results after MBBR system (K1, K3) carrier

Impact of the System MBBR on NH3-N

The concentration of NH_3-N in influent and treated effluents for carriers K1 and K3
Performance of carrier K1: As in Figure 11

- Average ammonia removal efficiency ≈ 72%, which is satisfactory but less than that of K3.
- End NH_3-N concentrations were 4 – 5 mg/L, indicating good removal efficiency.

Performance of carrier K3:

- Average removal efficiency of ammonia ≈ 85%, having higher NH_3-N removal efficiency than K1.
- Terminal concentration of NH_3-N was 2-2.8 mg/L, showing a considerable decrease compared to K1, having higher efficiency.

The higher efficiency of K3 can be explained by the presence of a greater surface area, so it will be able to offer a denser population of nitrifying bacteria and, thus, more efficient ammonia removal.

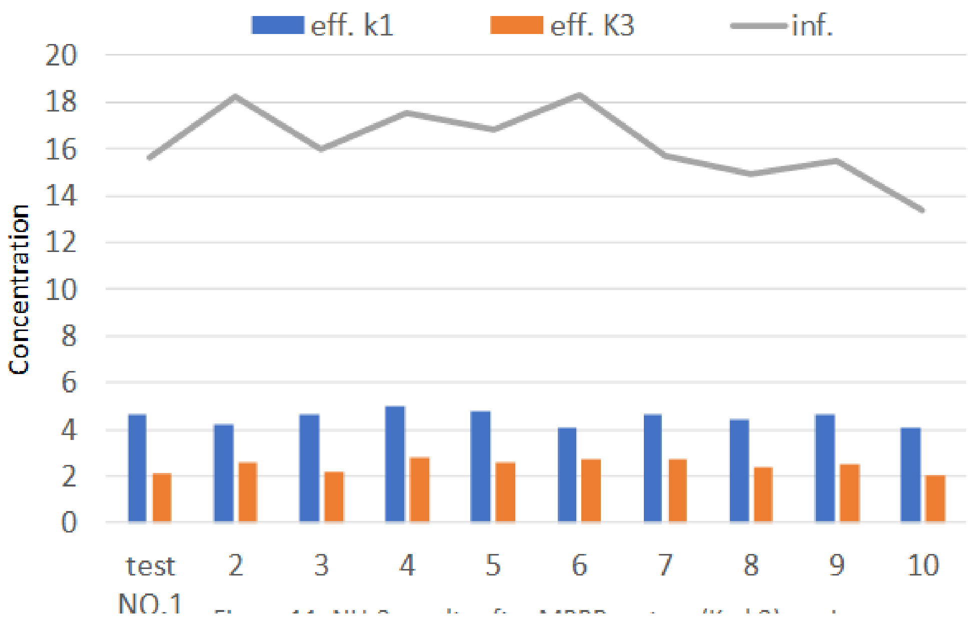

Figure 11. NH-3 results after MBBR system (K1, K3) carrier

Impact of MBBR System on Total Suspended Solids

According to Figure 12, the removal efficiency of the K1 carrier was 72%, while the K3 carrier was 85%. The K3 carriers provide higher efficiency than the K1 carriers due to their advanced design and ability to support denser and more stable biofilms.

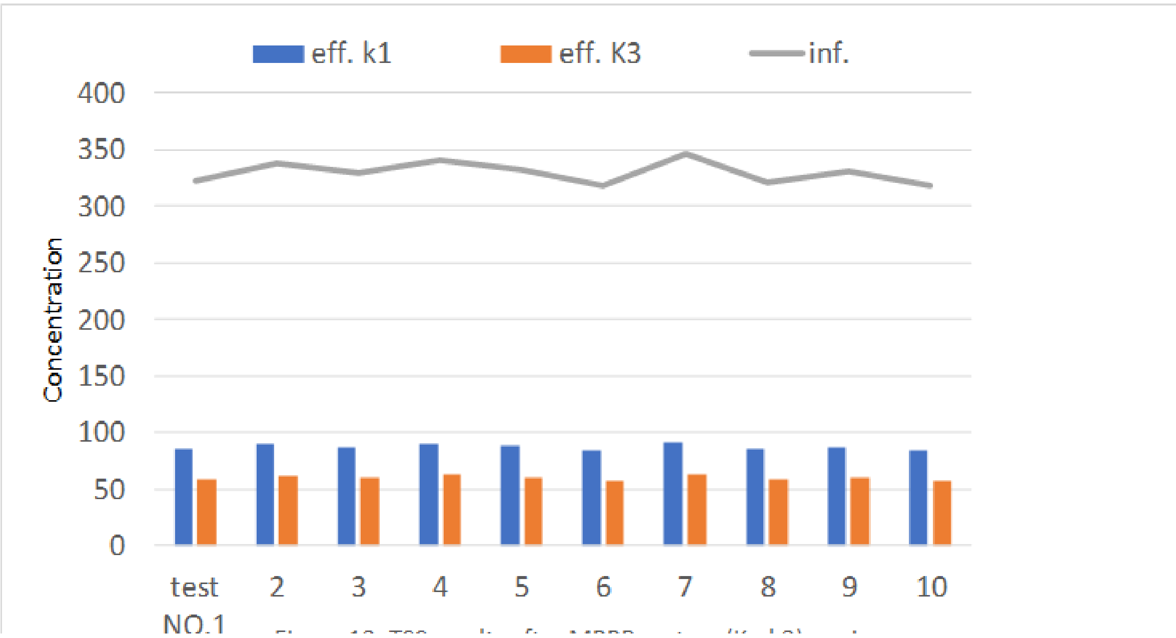

Figure 12. TSS results after MBBR system (K1, K3) carrier

Impact of MBBR System on Total Dissolved Solids and Electrical Conductivity

This MBBR system, using K1 and K3 carriers, is ineffective in removing TDS and EC Paudel, S. R. (2024). To reduce TDS and EC, other technologies such as reverse osmosis (RO) or ion exchange should be used. Slight variations in TDS and EC are due to other factors not directly related to the MBBR system or the type of carriers used.

Impact of the System MBBR on Dissolved Oxygen

DO was measured daily. The observation was as follows:

- DO levels were 1.5 - 2.5 mg/L at the start of the operation, a moderate level that indicates the initiation of the stabilization of the biological system.
- As the operation proceeded and the biofilm developed on the carriers, there was a gradual increase in oxygen consumption owing to enhanced biological activity.
- Towards the end of the experiment, the DO levels stabilized to the range of 4 – 6.5 mg/L, which meant that equilibrium between oxygen demand and supply in the system had been established.
- The carrier type did not have a profound impact on the DO levels, although a reduction was brought about by K3 owing to its greater biological activity than K1.
- DO levels stabilized in the optimum range, showing a good balance between oxygen supply and consumption in the system

Statistical Analysis

Used independent and paired T-tests to determine the effectiveness of the MBBR system in reducing pollutant concentrations in four parameters: BOD, COD, NH_3, and TSS. The independent T-test established the performance of each carrier, and the paired T-test compared the influent and effluent concentration differences for each type of media (K1 and K3). The mean Biochemical Oxygen Demand (BOD) concentration reduced greatly from 291.26 mg/L before treatment to 75.23 mg/L after K1 treatment and further to 55.13 mg/L after K3 treatment. K3 performed much better compared to K1 ($p = 1.51 \times 10^{-9}$), and both treatments showed statistically significant reductions ($p < 0.001$). It was, however, only K3 that managed to reduce BOD below the Iraqi discharge level of 40 mg/L. For Chemical Oxygen Demand (COD), the concentrations were lowered from a mean of 593.62 mg/L with K1 to 96.24 mg/L, and 84.16 mg/L with K3. Both decreases were statistically significant ($p < 0.001$), with K3 being significantly superior to K1 ($p = 1.61 \times 10^{-7}$). Of note is that both measurements were below the Iraqi discharge standard of 100 mg/L.

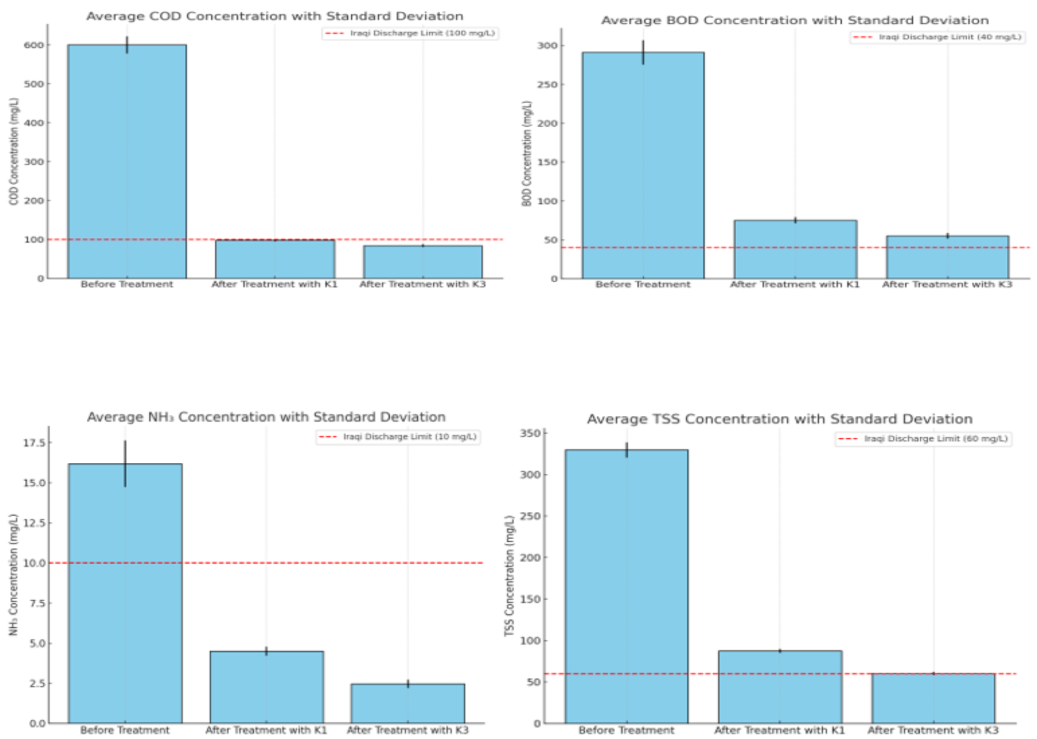

Figure 13. Average concentrations of COD, BOD, NH_3, and TSS in hospital wastewater before treatment and after treatment using K1 and K3 carriers, with standard deviation bars, compared to the Iraqi environmental discharge limits.

In the case of Ammonia (NH_3), the influent mean value of 16.29 mg/L was reduced to 4.56 mg/L using K1 and to 2.52 mg/L using K3. Both were significantly different ($p < 0.001$), and K3 medium was significantly better than K1 significantly ($p = 5.30 \times 10^{-12}$). Both the effluent values were within the Iraqi standard of 10 mg/L. In terms of Total Suspended Solids (TSS), the initial mean concentration of 329.71 mg/L was reduced to 86.91 mg/L when treated with K1 and further reduced to 60.23 mg/L with K3. K3 had a highly significant difference ($p = 5.08 \times 10^{-16}$), and both resulting reductions were very significantly different ($p < 0.001$). The TSS levels were slightly less than the Iraqi standard of 60 mg/L under K3 treatment.

These statistic-based results depict that both K1 and K3 carriers have a positive role in the removal of pollutants from hospital wastewater treatment, although K3 was always better than K1 in all parameters tested. In addition, K3-treated effluents alone achieved or exceeded all Iraqi environmental discharge standards.

Comparison Between Two Carriers in the MBBR System for Choosing the Optimal

In an MBBR wastewater treatment process, the type of carrier selection is a crucial step in achieving high-level biological performance. The study demonstrated that the K3 carrier is superior to the K1, as shown in Table 6. This is founded on several aspects. The geometrical shape provides a larger surface area, stabilizing a greater number of microorganisms responsible for pollutant degradation, thus enhancing the effectiveness of biochemical reactions within the reactor. In addition, the new geometry maximizes water and oxygen flow distribution around the carrier, enhancing biological oxidation processes and reducing sediment deposition, hence enabling long-term sustained performance. The final answer is that these advantages render the K3 carrier as the ideal choice for achieving higher percentages of pollutant removal and greater operating efficiency in MBBR wastewater treatment systems.

Table 6. Efficiency of removing K1 and K3 carriers for the MBBR system

Parameter	MBBR System (K1)	MBBR System (K3)
COD	83%	86%
BOD	74%	81%
NH3-N	72%	85%
TSS	72%	85%

Conclusions

From the results of this research, the following can be concluded:

- Raw hospital wastewater characteristics:
  Analysis indicated that raw hospital wastewater contains a high concentration of pollutants (chemical and biological), twice that of domestic wastewater, making it an environmental and health problem that requires specialized and effective treatment.
- MBBR Pilot System:
  When utilizing the moving bed bioreactor (MBBR) system in an application using biocarriers (K1 and K3), K3 carriers exhibited a clear superiority in performance compared to the K1 carriers. The reason for this lies in the K3's more geometric design and higher surface area for the stabilization of biomass, which enhances the efficiency of pollutant biodegradation.
- MBBR system and other technologies: They complement the quality of treated water through combining the MBBR system with membrane separation technologies to upgrade the removal efficiency of fine solids and toxic microorganisms. State-of-the-art technologies: To oxidize recalcitrant pollutants (e.g., pharmaceuticals and pharmaceutical residues) by using ozone or ultraviolet light

Scientific Ethics Declaration

* The authors declares that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Conflict of Interest

* The authors declare that they have no conflicts of interest

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