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Original Article

Determination of Suitable Low-Cost Local Media for an MBBR System

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Abstract *- The study aims to identify cost-effective local materials suitable for MBBR media and determine their applicability criteria. Through a lab-scale pilot, four materials—spiral electric hose, modified bottle caps, artificial sponge, and natural loofah—are being assessed alongside standard media. The removal ratios achieved by these media for both BOD (90.5%, 91.1%, 92.0%, and 91.3%) and COD (90.5%, 91.4%, 91.19%, and 91.45%) indicate their potential as effective alternatives to standard media. However, certain constraints need to be considered when considering their use.*

Keywords *- Artificial sponge, Bottle caps, Local media, Low-cost media, MBBR, Wastewater treatment.*

1. Introduction

In Egypt, there were 440 municipal Waste Water Treatment Plants (WWTP) treating an average of 11.76 million cubic meters per day, supported by a 51,000 km sewage network [1]. Recently, rising population growth rates have been related to significant changes in urbanization, community activities, and agro-industrial practices. The increased emissions of wastewater containing pathogenic organisms and various organic and inorganic pollutants can be connected to these recent advancements and developments. To ensure that mechanized wastewater treatment systems comply with rigorous national and international regulations, numerous recommendations are proposed to improve their performance [2].

One of these recommendations involves implementing a hybrid system, which combines Suspended Biomass (AS) and Attached Biomass (biofilm). These systems can be categorized into two types: those with separate reactors for the AS and biofilm systems and those where the biofilm system is integrated into the AS system [3]. The MBBR is the simplest and most effective hybrid system; the main reason it was selected for the study is that it requires no specialized equipment and can be applied locally. The Moving Bed Biofilm Reactor (MBBR) technology is a fixed biomass system that has recently attracted interest in the wastewater treatment industry. The basic concept is that plastic components, which can move freely within the biological reactor, will develop a stable biofilm. These plastic components typically have a diameter of approximately 1-2 cm and a density very close to that of water. The tank is usually filled only to 50-70% capacity with these elements [4]. Various businesses have recently developed carriers in response to the growing use of the MBBR process. Typically, these designs aim to achieve the best treatment results for different scenarios.

These carriers can be adjusted to suit different reactor setups and types of wastewaters because they are available in various sizes and shapes. Consequently, obtaining carriers is considered a crucial step in implementing MBBR technology [5]. Several companies have been manufacturing the MBBR system, each specifying design criteria for its bio-media carriers, as shown in Figure 1 [6].

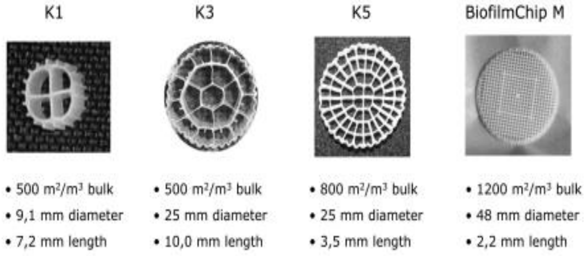

Fig. 1 Most popular carrier types used as the MBBR media [6]

Therefore, finding a low-cost media that meets the same criteria and has the same goal as MBBR media will help lower the system's cost and increase the number of plants that use it. Several studies have explored the potential to improve the biological treatment system by utilizing various types and shapes of media as alternatives to MBBR media. Research was conducted on the MBBR system utilizing the Bio Cube method, which employs free-floating sponge media. The average COD removal efficiency remained at 95%. Nitrification removal efficiency varied from 92% to 100%, averaging 99% [7]. In another study, researchers examined the microbial de nitrification of wastewater using biodegradable Polycaprolactone (PCL) as a carrier for the MBBR system. After 10 weeks, the average removal of Total Nitrogen (TN) exceeded 70%, and PCL exhibited a linear decrease in weight, with approximately 44% weight loss. Despite a reduction in thickness from 0.5 mm to 0.2–0.3 mm, the PCL plate retained its original shape [8].

In 2016, Mozia and colleagues conducted a study on treating and recycling industrial laundry using a hybrid MBBR system. They utilized a pilot-scale Waste Water Treatment Plant (WWTP) with a secondary settling tank and a 1 m3 aerobic bioreactor containing Picobells (PE) carriers. The results showed positive outcomes, with the effluent containing an average of 36 mgO2/L of COD (95%) and 22 mgO2/L of BOD5 (92%) [9]. A study was conducted to enhance the durability of loofah sponges in water solutions. Hideno et al. altered the loofah sponges by acetylating them, turning them into acetylated sponges, to immobilize cellulase-producing microorganisms. They achieved this by soaking the sponges in acetic anhydride solution. Additionally, they treated the loofah sponges with a Ca (OH) 2 solution to improve their endurance in a lab-scale bioreactor. This treatment resulted in an 83% reduction in organic matter and a 71% decrease in total nitrogen [10].

Multiple manufacturers have developed carriers with different shapes and surfaces for use as substrates in the MBBR system, facilitating the growth of biofilms. The efficiency of MBBR processes is influenced by factors such as carrier size, density, shape, accessible surface area, and void volume. Carrier densities are often lower than that of water, allowing them to float in wastewater without requiring vigorous mixing [11].

The research examined the use of a new Sponge Biocarrier (SB) in a Moving Bed Bioreactor (MBBR). Treating wastewater from recirculating aquaculture systems. SB was placed in reactor R1, while K5 plastic carriers were used in R2. Results showed that R1 achieved an 86.67 ± 2.4% ammonia removal efficiency and a nitrification rate of 1.43 mg/L.h while R2 achieved 91.65 ± 1.3% removal efficiency and 1.52 mg/L.h nitrification rate at the same optimal HRT [12]. A new sponge bio carrier infused with NaOH-loaded biochar and nano ferrous oxalate (sponge-C2FeO4@NBC) was developed and assessed for removing nitrogenous compounds from Recirculating Aquaculture Systems (RAS) wastewater. The bioreactor containing sponge-C2FeO4@NBC achieved the highest NH4+-N removal rates, reaching 99.28 ± 1.3%, with no significant nitrite (NO2−-N) accumulation observed in the final phase [13]. The research was done at Egypt's Zenin wastewater treatment facility. Three different biological treatment systems were examined. The results of the study were as follows: In activated sludge systems, the highest removal efficiencies of BOD5, TSS, and NH4-N were 50%, 81.9%, and 82%; in MBBR systems, they were 80%, 81.8%, and 99.3%; and in IFAS systems, they were 62.3%, 86.2%, and 76% [14]. Choosing a carrier that promotes stable biofilm formation is crucial for enhancing the efficiency of the MBBR process. This helps prevent waste particles from overgrowing the biofilm or blocking the void spaces. In selecting media for my study, I have been seeking a well-designed carrier that complements an efficient mixing/aeration process, aiming to achieve outstanding system performance with minimal maintenance requirements.

2. Problem Formulation

Although the MBBR system is highly efficient, it is too difficult to apply in new plants or expand the capacity and efficiency of existing ones because the employed media is expensive. This research studied the various low-cost local media alternatives that can be substituted for MBBR media to upgrade and expand the capacity of an Egyptian conventional activated sludge wastewater treatment plant, all without the need to construct new units—and convert it to an MBBR system using locally available, low-cost media.

3. Materials and Methods

The lab-scale pilot was situated at the Sanitary and Environmental Engineering Laboratory within the Faculty of Engineering at Ain Shams University. Raw sewage was sourced from the ALBERKA WWTP in Egypt, and the analysis was conducted in Ain Shams University's central laboratory. Various doses of Effective Microorganisms (EM) bacteria were tested to determine the optimal dosage for achieving stabilization within one week. Prior to the experiment, 3 milliliters of EM bacteria were applied daily.

EM bacteria were employed to accelerate the biological action velocity, aiming to achieve stabilization in less than one week, as opposed to the usual four weeks under normal operation without EM. The lab-scale pilot was constructed using glass and consisted of four parallel streams. Each stream was divided into three units to simulate the primary sedimentation tank, aeration tank, and final sedimentation tank. Figure 2 shows the schematic diagram of the pilot, while Figure 3 illustrates its final design. Wastewater was supplied to the pilot system from a feeding tank with a capacity of 200 liters. To ensure stable flow distribution, a constant head tank was utilized after the feeding tank, compensating for fixed head loss. Connecting pipes with a diameter of 50 mm were used to transfer wastewater to the primary sedimentation tank, with flow control for each stream achieved through valves. The study employed five types of MBBR media, each with a filling ratio of 40%.

The first type is a standard MBBR media commonly used in Egypt, while the remaining four were sourced from inexpensive materials available in the local market, suitable for MBBR media based on their properties. The first type used is the Al Andalus Bio Media 800, made from VIRGIN HDPE and locally manufactured by Al Andalus BIMEX. It has dimensions of 16.75 mm outer diameter and 5 mm depth, with a bulk surface area of 48.66 cm2 and a void ratio of approximately 63% [15].

The remaining types of media used are:

a) Common water bottle covers with the closing surface removed, leaving only the ring with dimensions of 2.8 cm for outer diameter and 1 cm for ring height. Its outer and inner surface area is approximately 25 cm2.
b) Small pieces of corrugated spiral electric hose with dimensions of 1.1 cm for outer diameter and 1 cm for height. Its outer and inner surface area is about 14 cm2.
c) Cubic-shaped sponges with dimensions of 1.5 cm in width, 1.5 cm in length, and 1 cm in height. Its outer surface area is approximately 45 cm2, and its void ratio is about 83%.
d) Pieces of a natural loofah with an outer surface area of about 35 cm2 and a void ratio of approximately 90%.

The program consists of three stages:

1. Preparation Period: This phase ensures the stability of the pilot system by simulating its performance and efficiency under consistent hydraulic and organic loads. It aims to establish stability before proceeding further.
2. Run 1 Period: During this stage, four parallel streams are operated. The first stream simulates a conventional activated sludge system, while the second, third, and fourth streams apply the MBBR system with different types of media in each stream. The second stream uses standard manufactured MBBR plastic media, the third stream uses modified bottle caps plastic media, and the fourth stream uses pieces of spiral plastic electric hose media.
3. Run 2 Period: In this phase, three parallel streams are operated. Like Run 1, the first stream simulates a conventional activated sludge system, while the second and third streams apply the MBBR system with different types of media. The second stream uses natural loofah media, and the third stream uses artificial sponge media. Throughout these stages, EM bacteria are utilized to accelerate biological action velocity, aiming to achieve stabilization in less than one week, compared to the typical four weeks required under normal operation without EM. unit in every stream during each run to monitor changes in Dissolved Oxygen (DO), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), and Biochemical Oxygen Demand (BOD). Sampling was conducted twice: the first set of samples was taken in the morning at the inlet, and the second set was collected after 8 hours at the outlet to verify the effectiveness of the treatment process.

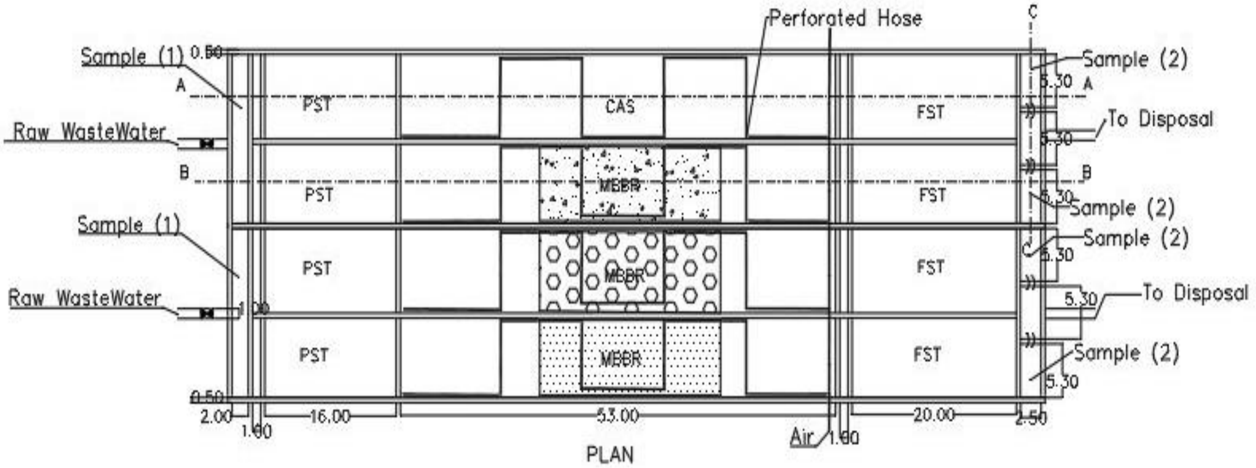

Fig. 2 Schematic diagram of the pilot

Fig. 3 The final shape of the lab-scale pilot

4. Results

Each run spanned four weeks. Tables 1 through 5 present the analysis of all samples collected during the first run of the pilot study.

Tables 6 through 9 showcase the analysis of all samples collected during the second run of the pilot study.

Table 1. Applied wastewater for the first run

Applied Waste Water				
Date	**BOD (mg/l)**	**COD (mg/l)**	**TSS (mg/l)**	**DO (mg/l)**
29/7/2023	210	385	280	0.51
5/8/2023	149	272	220	0.6
12/8/2023	155	259	180	0.54
19/8/2023	240	420	290	0.40

Table 2. CAS results

CAS				
Date	**BOD (mg/l)**	**COD (mg/l)**	**TSS (mg/l)**	**DO (mg/l)**
30/7/2023	28	50	59	1.7
31/7/2023	26	47	57	2.57
1/8/2023	26	47	58	2.60
2/8/2023	26	46	55	2.62
6/8/2023	23	40	44	1.50
7/8/2023	23	40	44	1.50
8/8/2023	20	35	42	1.13
9/8/2023	20	35	42	1.23
13/8/2023	25	42	43	2.20
14/8/2023	23	37	43	2.17
15/8/2023	23	37	42	2.48
16/8/2023	21	35	42	2.48
20/8/2023	26	50	58	2.17
21/8/2023	26	50	56	2.17
22/8/2023	22	46	56	2.48
23/8/2023	22	46	55	2.48

Table 3. Standard MBBR media results

Standard MBBR Media				
Date	**BOD (mg/l)**	**COD (mg/l)**	**TSS (mg/l)**	**DO (mg/l)**
30/7/2023	21	37	30	2.36
31/7/2023	19	35	29	2.52
1/8/2023	18	33	27	2.6
2/8/2023	18	33	27	2.62
6/8/2023	15	26	23	1.50
7/8/2023	14	24	22	1.60
8/8/2023	13	22	20	1.25
9/8/2023	13	22	19	1.05
13/8/2023	12	20	19	2.33
14/8/2023	12	20	18	2.35
15/8/2023	10	17	16	2.55
16/8/2023	10	17	16	2.55
20/8/2023	17	33	28	2.35
21/8/2023	17	33	28	2.35
22/8/2023	15	31	26	2.50
23/8/2023	13	28	26	2.55

Table 4. Modified Bottle Caps media results

Modified Bottle Caps				
Date	**BOD (mg/l)**	**COD (mg/l)**	**TSS (mg/l)**	**DO (mg/l)**
30/7/2023	24	43	46	1.6
31/7/2023	22	39	41	2.66
1/8/2023	21	38	40	2.70
2/8/2023	21	38	40	2.70

6/8/2023	16	28	38	1.20
7/8/2023	15	26	37	1.19
8/8/2023	15	26	37	1.19
9/8/2023	14	24	37	1.17
13/8/2023	16	25	30	2.43
14/8/2023	16	25	30	2.43
15/8/2023	15	24	28	2.67
16/8/2023	15	24	28	2.67
20/8/2023	22	42	43	2.35
21/8/2023	22	41	42	2.35
22/8/2023	21	40	40	2.67
23/8/2023	21	40	40	2.67

Table 5. Pieces of spiral Electric Hose media results

Pieces of Spiral Electric Hose				
Date	**BOD (mg/l)**	**COD (mg/l)**	**TSS (mg/l)**	**DO (mg/l)**
30/7/2023	21	37	42	2.44
31/7/2023	20	36	40	2.65
1/8/2023	19	34	37	2.75
2/8/2023	19	34	37	2.77
6/8/2023	15	26	37	1.41
7/8/2023	14	25	35	1.40
8/8/2023	14	24	30	1.23
9/8/2023	13	22	30	1.20
13/8/2023	16	26	21	2.44
14/8/2023	15	24	21	2.59
15/8/2023	13	21	19	2.60
16/8/2023	13	21	19	2.60
20/8/2023	23	39	37	2.20
21/8/2023	22	37	35	2.45
22/8/2023	20	35	30	2.56
23/8/2023	19	33	30	2.60

Table 6. Applied wastewater for the second run

Applied Waste Water				
Date	**BOD (mg/l)**	**COD (mg/l)**	**TSS (mg/l)**	**DO (mg/l)**
9/9/2023	324	460	320	0.5
16/9/2023	246	350	300	0.34
23/9/2023	243	345	270	0.4
30/9//2023	282	400	240	0.55

Table 7. CAS results

CAS				
Date	**BOD (mg/l)**	**COD (mg/l)**	**TSS (mg/l)**	**DO (mg/l)**
10/9/2023	63	90	68	2.4
10/9/2023	62	88	64	2.57
11/90/2023	59	84	64	2.6
12/9/2023	59	84	60	2.62
17/9/2023	46	65	65	2.30
18/9/2023	43	61	60	2.35
19/9/2023	40	58	58	2.55
20/9/2023	40	58	58	2.55
24/9/2023	49	71	70	2.10
25/9/2023	48	68	65	2.4

26/9/2023	48	68	57	2.4
27/9/2023	43	60	55	2.45
1/10/2023	54	78	55	2.4
2/10/2023	51	74	53	2.55
3/10/2023	48	70	48	2.6
4/10/2023	48	70	48	2.6

Table 8. Artificial sponge media results

Artificial Sponge Media				
Date	**BOD (mg/l)**	**COD (mg/l)**	**TSS (mg/l)**	**DO (mg/l)**
10/9/2023	30	43	35	2.4
10/9/2023	28	40	30	2.36
11/90/2023	26	37	25	2.55
12/9/2023	26	37	25	2.55
17/9/2023	23	32	28	2.17
18/9/2023	21	30	27	2.20
19/9/2023	19	27	23	2.4
20/9/2023	19	27	23	2.4
24/9/2023	20	28	27	2.00
25/9/2023	19	28	25	2.2
26/9/2023	18	26	23	2.35
27/9/2023	18	26	23	2.35
1/10/2023	24	35	26	2.3
2/10/2023	24	35	25	2.43
3/10/2023	21	30	24	2.5
4/10/2023	21	30	18	2.5

Table 9. Natural Loofah media results

Natural Loofah				
Date	**BOD (mg/l)**	**COD (mg/l)**	**TSS (mg/l)**	**DO (mg/l)**
10/9/2023	33	47	33	2.3
10/9/2023	32	45	32	2.43
11/90/2023	27	42	32	2.45
12/9/2023	28	39	30	2.5
17/9/2023	24	34	29	2.35
18/9/2023	23	32	28	2.43
19/9/2023	23	32	26	2.5
20/9/2023	21	30	26	2.55
24/9/2023	22	31	29	2.20
25/9/2023	21	29	27	2.35
26/9/2023	21	29	27	2.35
27/9/2023	20	28	25	2.4
1/10/2023	26	37	25	2.2
2/10/2023	25	35	25	2.45
3/10/2023	23	33	22	2.56
4/10/2023	23	33	21	2.56

Table 10. Removal ratio of BOD result

Periodical AVERAGE	**Removal Ratio of TSS (%)**					
	CAS	**Standard Media**	**Modified Bottle Caps**	**Pieces of Spiral Electric Hose**	**Artificial Sponge**	**Natural Loofah**
Week 1	79.7	89.9	85.1	86.1	91.0	90.1
Week 2	80.2	90.5	83.1	85.0	91.6	90.9
Week 3	76.8	90.4	83.9	88.6	90.9	90.0
Week 4	79.7	90.7	85.8	88.3	90.3	90.3

Table 11. Removal Ratio of COD Results

Periodical Average	Removal Ratio of COD (%)				
	CAS	**Modified Bottle Caps**	**Pieces of Spiral Electric Hose**	**Artificial Sponge**	**Natural Loofah**
Week 1	84.4	89.7	90.8	91.5	90.6
Week 2	84.5	90.4	91.1	91.7	90.9
Week 3	83.0	90.5	91.1	92.2	91.5
Week 4	85.2	90.5	91.4	91.9	91.4

Table 12. Removal Ratio of TSS Results

Periodical Average	Removal Ratio of BOD (%)					
	CAS	**Standard Media**	**Modified Bottle Caps**	**Pieces of Spiral Electric Hose**	**Artificial Sponge**	**Natural Loofah**
Week 1	84.3	90.9	89.6	90.7	91.5	90.7
Week 2	84.2	91.0	90.0	90.7	91.8	90.8
Week 3	83.0	92.8	90.4	91.0	92.2	91.5
Week 4	86.1	93.5	91.1	91.3	92.0	91.3

5. Discussion

5.1. Technical Comparison

The technical comparison encompasses discussions of all measurements obtained during the experimental phases on the pilot, highlighting the impact of each applied media on parameters such as removal efficiency, media durability, availability, and virtual age. Hereafter, the presentation of these discussions and analyses will be provided.

5.1.1. Parameters Results' Discussion

The experimental results were acquired by operating the pilot for four weeks per run, with data collected based on the stability of the results over one week. The illustration below presents all the measurements taken during each week of the study period. In general, all applied media achieved the desired BOD removal goal, surpassing CAS by 5-11%. The standard media exhibited the highest efficiency due to its large surface area and void ratio.

Conversely, the artificial sponge media performed similarly to the standard media in terms of performance and efficiency, attributed to its voids that facilitate bacterial growth. However, the accumulation of microorganisms within these small voids limited the effective surface area available for bacterial activity over time, leading to a decline in efficiency and potentially reversing the treatment process.

The efficiency of natural loofah is indeed lower compared to that of artificial sponge and standard media, primarily due to its smaller void ratio. Additionally, over time, the natural loofah tends to soften, leading to a reduction in voids. Consequently, there is less surface area available for bacteria to grow on, resulting in a decrease in efficiency over time. The efficiency of the spiral electric hose and modified bottle caps has shown an increase in the last two weeks, with a slight difference between them. Despite their smaller surface area compared to artificial sponges and natural loofahs, their efficiency has improved because they have larger holes, preventing bacterial clogging over time and allowing for bacterial growth across their entire surface area.

5.1.2. Availability of Media

Indeed, natural loofahs, artificial sponges, and electric hoses are commonly accessible materials, making them successful choices for achieving treatment goals. Additionally, modified bottle caps, being leftover products, are easily obtainable from water bottles or similar sources.

While these media may require some modification before use, such as cutting into small pieces, the process is relatively straightforward compared to producing standard media. For instance, modifying bottle caps may involve drilling a hole in the middle, which adds more effort but is still less complex than manufacturing standard media.

Overall, the accessibility and simplicity of preparation make these alternative media viable options for treatment applications.

5.1.3. Durability of Media

Durability is indeed a crucial characteristic for chosen media in wastewater treatment, as it ensures that the media remains effective despite exposure to wastewater and organic matter. Figures 4, 5, and 6 illustrate the results for the removal ratio of BOD, COD, and TSS from the five pilot streamlines for each week. These figures showcase the progress of the removal ratio for each media over time, providing insight into their performance and durability throughout the study period.

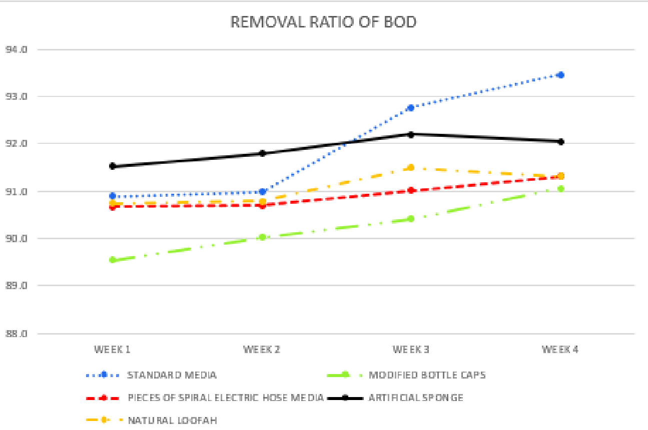

Fig. 4 Progress for BOD removal ratio through four weeks

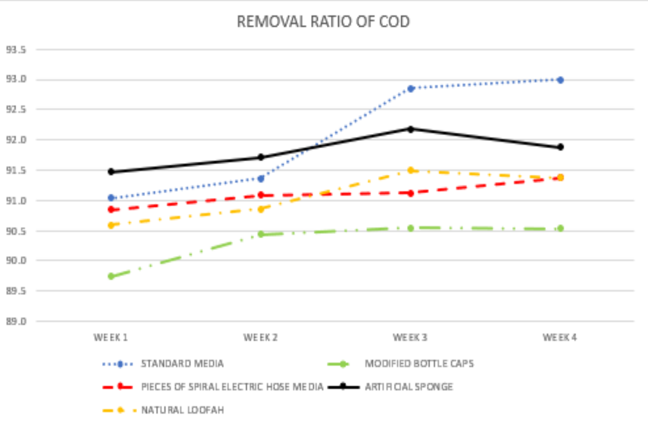

Fig. 5 Progress for COD removal ratio through four weeks

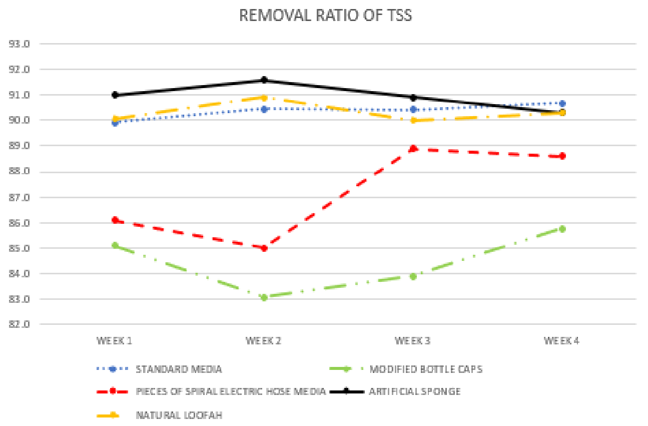

Fig. 6 Progress for TSS removal ratio through four weeks

From the previous Figures 4, 5, and 6, it is evident that the sponge and loofah initially exhibited higher removal ratios, but these efficiencies gradually decreased over the operating period. This decline highlights the effect of both media deterioration and void clogging. On the other hand, the bottle caps and spiral hose pieces achieved better efficiency over time and did not experience deformations or void clogging during operation. This durability makes them more resilient compared to the other two media types. Figures 7, 8, 9, and 10 depict each applied local media before and after the four-week test period, demonstrating the impact of the application on the media and its virtual age. These images effectively showcase the suitability of the media as MBBR media. The photos reveal the success of the two plastic media types, while both the sponge and loofah media fail due to significant deformation in their construction. This deformation led to a gradual decrease in the system's removal efficiency for BOD and COD.


(a) **(b)**

Fig. 7 Pieces of spiral electric hose (a) Before using it, and (b) After the operation period.


(a) **(b)**

Fig. 8 Modified Bottle Caps (a) Before using it, and (b) After the operation period.

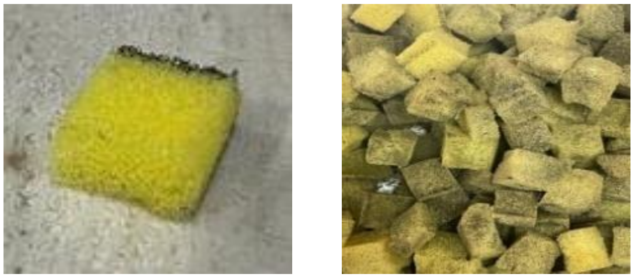
(a) **(b)**

Fig. 9 Artificial sponge (a) Before using it, and (b) After the operation period.


(a) **(b)**

Fig. 10 Natural Loofah (a) Before using it, and (b) After the operation period.

5.1.4. Media Virtual Age

The virtual age of media refers to the duration for which a media can be used before it requires replacement due to shape deformation and changes in properties such as void ratio and surface area. Electric hoses remain in good condition even after prolonged use and can be utilized for an extended period, like standard media, as they are both made of plastic. Similarly, modified bottle caps can also be used for an extended period with only the need for washing and reuse.

However, artificial sponges will need replacement after a certain period, typically three to five weeks, as suspended solids and microorganisms clog their voids, reducing efficiency. Likewise, the natural loofah will require replacement approximately every three weeks due to softening and reduction of voids caused by wastewater exposure, thereby maintaining efficiency.

5.2. Financial Comparison

This financial study encompasses the cost of the media and materials, labor costs for preparation, preparation location, time spent preparing the media in the tank, and the cost of transporting the media to the plant site. It serves to complete the feasibility study for the applied media to be used as MBBR media in the biological aeration reactor. Since larger quantities of media are typically less expensive than smaller ones, the comparison assumed that a plant would require 1000 m3 of media, with the cost of 1 m3 of media being as follows.

Table 13. Financial comparison between different used media

Cost Item (L.E.)	Standard Media	Modified Bottle Caps	Spiral Electric Hose	Artificial Sponge	Natual Loofah
Initial	22000	2750	3100	3750	8100
Labour	3000	2200	2400	3000	3300
Trans.	500	500	500	500	500
Total	25500	5450	6000	7250	12200

Table 13 presents the total cost, including the following components: the initial cost of the media, sourced from the factory or supplier; labor costs, comprising salaries for workers involved in media preparation; and transportation costs from the media source to the plant location.

These costs were determined through consultations with specialists in wastewater treatment and MBBR systems, as well as managers of factories manufacturing the media used. The prices listed are based on July 2023 rates. Based on the data from Table 13, the total cost of local media is typically less than half that of standard media.

Moreover, these local media options are readily available in any quantity throughout the year in the local market. Furthermore, the modified bottle caps exhibit cost savings of approximately 25% compared to standard media, making them a more economical choice.

The slight difference in cost between modified bottle caps and spiral electric hose pieces is negligible when compared to the other two local media options. This highlights the value of their application, given their good removal efficiency and close resemblance to standard media. Additionally, the absence of clogging or deformation during operation enhances their virtual age and durability, further justifying their use.

6. Conclusion

Based on the study results and the conducted data, the following conclusions can be drawn:

1. The four applied local MBBR media achieved high removal efficiency ratios for BOD, COD, and TSS, closely resembling those of standard media.
2. While the artificial sponge media initially performed similarly to standard media, its efficiency gradually decreased over time due to the accumulation of microorganisms in its small voids. Regular replacement or cleaning with acid is necessary every 3-5 weeks to maintain effectiveness, which may increase running costs and defeat the purpose of its application.
3. Natural loofah exhibited lower efficiency compared to artificial sponge and standard media due to its lower void ratio. Its effectiveness diminishes over time due to deterioration and reduced voids, requiring replacement every 3 weeks or when clogged with solids.
4. Both spiral electric hose pieces and modified bottle caps initially had lower efficiency compared to standard media, but their efficiency slightly increased over time. There is a slight difference between them due to their similar surface areas. Additionally, it was neither deformed nor clogged by wastewater.
5. Despite having less surface area and void ratio than an artificial sponge and natural loofah, spiral electric hose pieces and modified bottle caps became more efficient over time due to their large holes, allowing bacteria to grow across their entire surface area without clogging.
6. The modified bottle caps achieved the lowest cost, followed by the pieces of spiral electric hose, saving approximately 70-75% of the locally manufactured standard media cost and 90-93% of the exported standard media cost.

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