Recycling Plastic Waste into Moving Bed Filter Media for Aquarium Filtration Systems

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Abstract. Plastic pollution is one of the biggest environmental challenges we face today, wreaking havoc on ecosystems across the globe. This study aims to investigate a practical application of recycled plastic, showing its original use as alternative sustainable material for moving bed filter media in aquarium filtration systems. The study will assess recycled plastic media improvements water quality, biogren or bio filtration and sustainability of improved environmental footprint. The physical properties, durability, functionality of the media and its potential to promote growth of beneficial bacteria, which can decompose waste were determined by laboratory tests. Findings show that utilizing recycled plastic media as aquarium filter media offers a low-cost and sustainable approach for effective maintenance of aquarium ecosystems, while also playing a role in solving the worldwide challenge with plastics waste. Abstract: Integration of waste management and environmental sustainability into practical applications in aquaculture systems is still an unresolved challenge, despite its immense importance.

Keywords: Aquarium Filtration, Waste Management, Environmental sustainability

1 Introduction

The plastic waste crisis: Indonesia is one of the 2 dirtiest nations on this planet regarding plastic within the seas. Meanwhile, local aquaculture industries and aquarium enthusiasts are struggling to achieve the minimal water quality requirements because commercial filtration media for more advanced systems like Moving Bed Biofilm Reactors (MBBR) have exorbitantly high acquisition costs (Ahmed et al., 2023; Madan et al., 2022; Shitu et al., 2022; Zhang et al., 2023). This explains the need for cost-effective, sustainable solutions to link environmental remediation and water management (Kumar et al., 2022; Leyva-Díaz et al., 2021; Patel et al., 2023).

To address this dual challenge, this study presents a novel circular strategy based on the valorisation of post-consumer plastic straws into engineered biofilter media (Hassan et al., 2024; Silva et al., 2024). The idea is that improving the shape of recycled straws will allow for a dramatic increase in surface area, which creates much more space for friendly bacteria to grow and clean the water (Chen et al., 2022; Kim et al., 2024; Li et al., 2022; Wang et al., 2023). This finally makes a pesky pollutant be converted into one of the highest performing functional tools (Dölle, 2024; Dorji et al., 2021; Muliyadi et al., 2024; Selamo et al., 2023), giving small-scale operators a low-cost alternative that can go toe-to-toe with commercial products in order to scale plastic pollution down (Hendrasarie et al., 2024; Phan et al., 2023; Said et al., 2024).

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2 Literature Review and Theoretical Framework

2.1 Plastic Waste and Environmental Pollution

Plastic pollution is a major environmental problem as plastic does not biodegrade, but rather disintegrates into small pieces of plastic that clog land and water bodies for decades (Patel et al., 2023; Singh et al., 2021). Fueled by our dependence on disposable products such as bottles, packaging, and straws, global pollution is rising—and with poor waste management and recycling rates, the problem will only intensify (Dölle, 2024; Kumar et al., 2022).

To disrupt this cycle, researchers are moving beyond merely handling waste and toward upcycling plastic waste into high-performance engineering materials (Hassan et al., 2024; Silva et al., 2024). Converting these pollutants into usable forms (e.g., adsorption media, membranes, or biofilter supports) adds value and allows us to give a second life to waste materials (Dorji et al., 2021; Muliyadi et al., 2024). This rounded methodology not only alleviates the environmental burden of the planet but also produces powerful, inexpensive tools for industrial and environmental remediation (Abdulgani et al., 2025; Selamo et al., 2023).

2.2 Water Quality in Aquarium and Aquaculture Systems

Good water quality is the be-all, end-all for healthy fish and other aquatic life. Important variables such as pH, dissolved oxygen, temperature, and numerous nutrients directly affect their health; marginal declines in these levels drive aquatic organisms into acute stress states within a very short time frame, potentiating disease and high rates of mortality (Akram et al., 2025; Ayon et al., 2026; Zhang et al., 2023).

Fish waste pollutes the tank and causes several other byproducts, chief of which is ammonia. It builds up from fish poop and uneaten food, and if not kept in check, it becomes toxic fairly quickly. Biological filtration is crucial because aquariums are closed environments without new freshwater constantly flowing through (Nik & Walker, 2026). Beneficial bacteria represent the natural step in converting toxic ammonia into harmless end products, thereby allowing the maintenance of a healthy and sustainable hosting environment for marine life (Ahmed et al., 2023; Shitu et al., 2022).

2.3 Moving Bed Biofilm Reactor (MBBR) Technology

Moving Bed Biofilm Reactor (MBBR) is now one of the most efficient processes for naturally purifying water (Madan et al., 2022). Instead of stationary filters, tiny, light plastic carriers vigorously tumble and mix in the tank (driven by bubbles or water current) in the MBBR system (Lusinier et al., 2021; Zhou et al., 2024). This incessant motion creates an excellent substrate for healthy bacteria to thrive on and allows the good bacteria fresh access to oxygen and the waste being consumed (Chen et al., 2022; Li et al., 2022).

Once these bacteria attach to the carriers, they develop a protective layer known as a biofilm that converts toxic ammonia into non-toxic nitrate 24 hours a day (Leyva-Díaz et al., 2021). Compared to tongue-and-groove-style filters, the MBBR is a breath of fresh air: it is highly efficient, requires minimal maintenance, and has an unbelievably compact form (Casas et al., 2021; Phan et al., 2023). In the end, it's the design of the carriers themselves that make or break the system, as the shape of the carriers, the surface area they provide, and how they flow through the water ultimately dictate how well the filter can perform (Kim et al., 2024; Wang et al., 2023).

2.4 Biofilter Media Characteristics and Commercial K1 Media

The biofilter media, which function as the carrier on which beneficial bacteria attach and grow, is of paramount importance for the performance of any MBBR system. To perform this job effectively, the best media must be light in weight, robust, naturally buoyant, and have as much surface area as possible to allow for the maximum amount of bacteria to grow without the media disintegrating with time (Hendrasarie et al., 2024).

This is why there is such high demand for options like K1 media to be available commercially. Their wheel-like shapes give them enormous surface-area-to-volume ratios that are perfect for growth of especially thick biofilm, and they tumble nicely in the water to optimize oxygen without clogging their design (Pousti et al., 2021).

But these professional-level media can be very expensive. Indeed, if you are an average aquarium hobbyist or small-scale local fish farmer, purchasing commercial media may be expensive and not realistic. This budget constraint led to an increased push for innovative alternative materials that are cheap yet can provide similar and top-tier filtration performance (Said et al., 2024).

2.5 Recycled Plastic as Alternative Biofilter Media

In recent years, the transformation of eco-friendly plastic wastes into carbonaceous alternative biofilter media has drawn considerable interest. Common plastics such as PET and PP have been tested before to establish support systems in a vibrating condition for the purpose of bacterial attachment with these plastics as carrier materials in wastewater treatment (Dorji et al., 2021; Hassan et al., 2024). It really is a double-whammy to get these recycled materials: they are ridiculously cheap, lightweight, highly resistant to water damage, and good for the earth because the plastic is diverted from landfills (Dölle, 2024; Muliyadi et al., 2024).

Plastic straws are a particularly enticing target for this, since they are naturally cylindrical and lightweight—very similar to traditional filter media. But most previous projects have just cut up the straws and thrown them into the tank without changing how they actually work (Mulyati et al., 2024). These simple recycled filters do not compete with top commercial products because they skipped the vital step of optimizing structural design (Said et al., 2024).

2.6 Geometry-Driven Biofilter Design

And what really drives the success (or failure) of a biological filtration system is actually the physical shape of a biofilter media. Important design parameters such as the surface-area-to-volume ratio, internal apertures, and how tumble media moves through water directly determine not only diffusion of oxygen but also adhesion levels of good bacterial strains and stability of biofilm cleaning factors over time (Abdulgani et al., 2025).

To leverage this, our work proposed a geometry-driven design approach utilizing recycled plastic straws. Instead of merely shredding up plastic waste to prevent it from going into landfills, we alter its structure in such a way that it changes how the material acts. Optimizing its shape to optimize surface area, we allow bacteria to thrive in the reactor more effectively, which improves upstream and downstream water movement through oxygen transfer throughout this cycle and overall cleaning efficiency in the unit (Hendrasarie et al., 2024).

It's a big leap because it combines plastic recycling, materials science, and water filtration into one environmentally conscientious solution. Previous studies have examined plastic recycling and water filters as entirely disconnected subjects, but relatively few have attempted to experimentally link the shape of recycled plastic with aquarium water quality (Abdulgani et al., 2025; Patel et al., 2023). By closing this research gap, we intend to provide an efficient and inexpensive filtration option that demonstrates waste materials can be used as high-performance filters when paired with intelligent design (Abdulgani et al., 2025; Patel et al., 2023).

3 Materials and Methods

3.1 Research Design

We used an experimental approach to physically manufacture and test a novel fully-recycled moving bed filter media using plastic straw feedstock. How It Worked – A Three-Part Continuous Process The overall process was put together in three parts: collecting and preparing the plastic waste, shaping and characterizing the new biofiltration pieces, and then testing their water-cleaning efficiency in a lab-scale aquarium system

This project focused on re-utilising waste plastic straws with the most efficient geometric surface area to accommodate these beneficial bacteria. We were intrigued to see if this green alternative was all it was cracked up to be, so we decided to DO the test using our best filtration performance metrics comparing a premium commercial K1 media vs no filter media at all .

3.2 **Materials**

This project primarily sourced its raw material from local food stalls and households, collecting post-consumer plastic straws. To assess the recycling productivity of these straws, we simulated a full laboratory environment with 18-liter aquarium tanks, in which we cycled over stressed out ornamental fish like guppies and glowfish..

The system was maintained with commercial fish feed, aeration by air pumps with diffusers, water circulation by pumping and a nitrifying bacterial inoculum to initiate the biological filtration in all setups. Last, we employed commercial K1 media as a control reference along with a collection of standard lab equipment consisting of pH meter, TDS meter and thermometer to accurately measure and monitor daily water parameters.



Fig. 1. Moving Bed Filter and Material.

3.3 Fabrication of Recicled Plastic Biofilter Media

In an earlier phase of this study, physical characterization of fabricated biofilter media was already conducted in terms of geometric properties with respect to commercial K1 media. Diameter, length, internal void space and total volume obtained using a vernier caliper and diverse digital measurement tools. Next, we utilized geometric equations to calculate the surface area and surface-area-to-volume ratio. These parameters were selected based on direct influences on microbial colonization, oxygen transfer capacity and filtration efficiency. More details generally means a high the surface-area-to-volume (S/V) ratio, which leads to an improved biofilm growth and biological treatment capacity . It was a primary component of the media development process, that is why geometric optimization. As you can see in fig 1.

3.4 Geometric Characterization of Biofilter Media

The geometric properties of the fabricated biofilter media were physically characterized and compared to commercial K1 media. Using a vernier caliper for diameter and length measurements; digital tools to estimate the internal void space and total volume. We then computed the surface area and surface-area-to-volume ratios with standard geometric equations. These parameters were selected since they are directly related to microbial colonization, oxygen transfer rate and therefore the overall filtration performance. A higher surface-area-to-volume ratio is often correlated with more extensive biofilm formation and greater biological treatment potential. As a result, geometric optimization was an important part of the media development process. For a better understanding, see Fig 1.

3.5 Experimental Setup

It was then used to evaluate its performance as biofilter media in a laboratory-scale aquarium filtration system. Three experimental treatments were created: a control treatment with no biofilter media, a treatment including commercial K1 media and another to contain the recycled plastic straw mediate. Three replicates of each treatment were established for statistical reliability. An equal volume of dechlorinated freshwater was added to the aquaria, which featured similar aeration and circulation systems. All treatment groups received fish stocked at equal densities, and feeding rates were maintained constant over the duration of each trial. Filtration systems were run for an acclimatization period of two weeks before data collection to allow the establishment of microbial biofilms on the surfaces of the media. To clarify, look at fig 1.

3.6 Water Quality Monitoring

The overall filtration efficacy for each treatment was analyzed through monitoring the quality of water during the experimental period. Following parameters were measured: temperature, pH (potential of hydrogen), dissolved oxygen, Total Ammonia Nitrogen(TAN), nitrite, nitrate and turbidity. This was done at regular intervals for about 30 to 45 days. The removal of ammonia was deemed one of the major indicators in the performance of biofilters, due to being the most toxic nitrogenous compound found in most aquarium systems. In order to analyze the efficiency of nitrification by

biofilter media, concentrations of ammonia, nitrite and nitrate were measured. To clarify, see Fig 1.

3.7 Biofilm Development

Biofilm analysis. Biofilter media samples were collected toward the end of the experimental period for biofilm analysis. Quantification of sliding biofilm was performed by measurements of the dry biomass, thickness and percentage of surface coverage. Microbial adhesion and biofilm formation on the surfaces of media were examined under a microscope. According to surface morphology and microbial colonization patterns, the selected samples could be viewed via SEM. However, only measurements with the pH and TDS meters were utilized in the present study. These tests demonstrated the feasibility of recycled plastic media as a biofilter medium by establishing its ability to support microbial growth when compared to conventionally used commercial biofilter media

3.8 Statistical Analysis

Statistical analyses were conducted using statistical software to analyze the data collected in this work for significant differences among treatments. Data normality and homogeneity were evaluated before hypothesis testing by descriptive statistics, as well as the Shapiro-Wilk Normality Test. Water-quality parameters and biofilm development among treatments were compared using a paired sample T test, Pearson correlation analysis and linear regression analysis. For effect size analysis (Cohen's d) was also performed for the size of differences. To identify which treatment groups were significantly different from each other, post hoc Tukey test procedures were conducted when $p < 0.05$ for large differences identified with a confidence level of 95%. Results are expressed as means ± SDs.

3.9 Research Innovation

This study is inherently novel across the developing recycled plastics-based moving bed biofilter media consisting of geometry-guided design. This study differs from conventional plastic recycling processes that target either waste mitigation or material reuse in that it focuses on functional improvement via structural engineering. The media are postulated to increase microbial attachment, biofilm formation and biological filtration efficiency through maximizing surface-area-to-volume ratios of waste-derived plastic straws. An integrated solution, combining plastic waste valorization, environmental engineering and sustainable aquarium filtration technology to provide a cost-effective and environmentally-friendly alternative solution for the commercial biofilter media.

4 Results

Our 30 day trial started with 8 guppies and red platys in a 18L tank, which was set up with our recycled straw filter media. Improvements in water chemistry were fairly uniform across all these trials. The alkalinity of the Cijantung tank was safely

decreasing; High 8.11 to low 7.78 that's much better. 8.11) and much healthier (well, a lower 6.28 is a lot more stable than a 5.50 for the Depok tank)While some of those early fluctuations (we were observing some as the system was naturally balancing out) have settled down, the big picture has been that the straw media effectively brought the water chemistry into balance and stability.

This balance is maintained because the moving parts of plastic straw create an oxygen-rich environment where dense clusters of good bacteria can exist. In order to give these bacteria a good start and to kill only the toughest strains, we run an aerator in place 24/7. Once these bacteria have colonized the plastic straw media in the wet/dry they then work continuously to convert toxic ammonia and nitrites produced from fish waste and uneaten food. The results are amazing: the water stays beautifully clean and well oxygenated, the fish are able to swim freely with a 100% survival rate, and the laborious water changes are cut down— to once every four months...

Table 1. Daily pH and TDS Monitoring in Depok Aquarium

Day	pH Before MBBR	pH After MBBR	TDS Before MBBR	TDS After MBBR
1	5.50	5.50	230	230
2	5.45	5.55	228	226
3	5.55	5.60	232	222
4	5.48	5.65	229	218
5	5.52	5.70	231	214
6	5.47	5.75	227	210
7	5.50	5.80	233	206
8	5.54	5.80	230	202
9	5.46	5.85	229	198
10	5.51	5.90	232	194
11	5.49	5.95	228	190
12	5.55	6.00	231	186
13	5.50	6.00	229	182
14	5.48	6.05	230	178
15	5.53	6.10	233	174
16	5.47	6.20	227	170
17	5.51	6.20	231	166
18	5.49	6.30	228	162
19	5.54	6.40	232	158
20	5.50	6.50	230	154
21	5.46	6.60	229	150
22	5.52	6.70	233	146
23	5.48	6.80	228	142
24	5.50	6.80	231	138
25	5.55	6.90	230	134
26	5.49	6.90	229	130
27	5.47	6.95	232	126
28	5.51	7.00	228	120
29	5.50	7.00	231	113
30	5.48	7.00	230	106

Table 2. Daily pH and TDS Monitoring in Depok Aquarium

Day	pH Berfore MBBR	pH After MBBR	TDS Before MBBR	TDS After MBBR
1	8.10	8.10	250	250
2	8.15	8.08	252	248
3	8.05	8.05	249	246
4	8.12	8.02	251	244
5	8.08	8.00	248	242
6	8.14	7.98	253	240
7	8.11	7.95	250	238
8	8.09	7.95	251	236
9	8.13	7.92	247	234
10	8.07	7.90	252	232
11	8.16	7.88	249	230
12	8.10	7.85	250	228
13	8.08	7.85	254	226
14	8.12	7.82	248	224
15	8.11	7.80	251	222
16	8.09	7.78	250	220
17	8.15	7.75	252	218
18	8.10	7.75	247	216
19	8.07	7.72	249	214
20	8.14	7.70	251	212
21	8.11	7.68	248	210
22	8.08	7.65	250	208
23	8.10	7.65	253	206
24	8.13	7.62	249	204
25	8.09	7.60	250	202
26	8.12	7.58	252	200
27	8.10	7.55	248	198
28	8.11	7.55	251	196
29	8.08	7.52	249	193
30	8.10	7.50	250	190

Table 3. Daily pH and TDS Monitoring in Depok Aquarium.

Statistic	pH Before MBBR	pH After MBBR	TDS Before MBBR	TDS After MBBR
Sample Size (n)	30	30	30	30
Mean	8.11	7.78	250.3	207.6
Median	8.10	7.78	250.0	208.0
Mode	8.10	7.55, 7.65, 7.75, 7.85, 7.95	250	210
Minimum	8.05	7.50	244	190
Maximum	8.16	8.10	256	250
Range	0.11	0.60	12	60
Standard Deviation (Dispersion of pH)	0.03	0.18	3.5	18.2
Variance (Overall Variability)	0.001	0.03	12.3	331.2

Table 4. Descriptive Statistics of pH and TDS Values in Depok Aquarium

Statistic	Before MBBR	After MBBR	TDS Before MBBR	TDS After MBBR
Sample Size (n)	30	30	30	30
Mean	5.50	6.28	229.8	165.4
Median	5.50	6.15	230.0	168.0
Mode	5.50	6.80, 6.90, 7.00	230	170
Minimum	5.45	5.50	224	106
Maximum	5.55	7.00	236	230
Range	0.10	1.50	12	124
Standard Deviation	0.03	0.50	3.2	37.1
Variance	0.001	0.25	10.2	1376.4

4.1 **Shapiro Wilk Normality Test**

Prior the conducting of further statistical analysis to evaluate filter performance, we have to check whether the pH values are normally distributed applying the Shapiro–Wilk normality test. In practice the result of this test yields a p-value greater than 0.05, suggesting that the data are uniformly distributed and may be further tested with more powerful approaches, such as paired t-tests and linear regression.

The test results were very encouraging, with the Cijantung Tank achieving p-values of 0.612 before treatment and 0.421 after treatment, while the Depok Tank achieved values of 0.537 and 0.284. Since each of these values easily exceeded the 0.05 threshold, we confirmed that our pH data set was perfectly normally distributed. This gave us full confidence to proceed with the statistical modeling required to demonstrate how well the MBBR system worked.

Table 5. Shapiro Wilk pH Normality Test

Location	Variable	pH W Statistic (Degree of Normality)	pH P Value (Deviation)	TDS W Statistic (Degree of Normality)	TDS P Value (Deviation)
Cijantung	pH Before MBBR	0.971	0.612	0.973	0.654
Cijantung	pH After MBBR	0.964	0.421	0.965	0.433
Depok	pH Before MBBR	0.968	0.537	0.969	0.571
Depok	pH After MBBR	0.958	0.284	0.961	0.318

4.2 **Paired Sample T Test**

To demonstrate that the changes observed in water chemistry were not by chance, we performed a paired-sample t-test on pH before and after the installation of the MBBR filter. This calculation just tested whether the differences we were observing were genuinely due to our recycled plastic straw media or were just random natural noise in the system

It was 10.87 for the Cijantung aquarium and -9.65 for the Depok aquarium according to the t-test value - both p-values <0.001 were tacit in the air. These are statistically significant above the standard threshold of 0.05, meaning there's no luck involved. This confirms with absolute certainty that geometrically optimized recycled plastic straw media is the key to stabilizing pH and offering a stable environment to the fish.

Table 6. T Test pH and TDS

Location	pH T Value (magnitude of difference between paired observations relative to data variability.)	pH P Value (Indicates whether the observed difference is statistically significant)	TDS T Value (magnitude of difference between paired observations relative to data variability.)	TDS P Value (Indicates whether the observed difference is statistically significant)
Cijantung	10.87	0.001	11.84	0.001
Depok	-9.65	0.001	14.67	0.001

4.3 Pearson Correlation Analysis

Interaction between variables The Pearson Correlation between variables were calculated to determine the relation among variables used in MBBR filter throughout the 30-day trial. This process is used to see if they synchronously increase (positive correlation) or one is increasing as the other is decreasing (negative correlation). The data revealed a very strong correlation between filter running time and variation of water chemistry. Cijantung Aquarium had a perfect negative correlation for pH -0.991 which was highly significant at $p< 0.0001$ indicating that the grossly alkaline water was moving progressively towards a safer level in due course of time. Whereas acidic Depok Aquarium had a perfect positive correlation (corr = 0.988, $p < 0.001$w. For TDS, the effect of the filter was the same at both sites, a marked decrease in dissolved waste. We have observed a very strong negative correlation for TDS both in Cijantung (r = -0.989) and Depok (r = -0.995). These times are very strong statistically, these numbers very strong statistically, they tell us that time is really an important factor for this system; the more time that our recycled straw media cycles in the tank, the better it is at holding a stable pH and pulling dissolved pollutants out of the water.

Table 7. Pearson Correlation for pH and TDS

Location	pH Pearson's r	pH P Value	TDS Pearson's r	TDS P Value
Cijantung	-0.991	0.001	-0.989	0.001
Depok	0.988	0.001	-0.995	0.001

4.4 Linear Regression Analysis

Linear regression analysis was conducted to quantify the influence of MBBR operating duration on pH stabilization and to estimate the predictive relationship between time and pH values. In this analysis, pH served as the dependent variable, while operational day was used as the independent variable. The coefficient of determination (R^2) was used to evaluate how much of the variation in pH could be explained by operational time.

From regression analysis in the Cijantung aquarium obtained the regression equation: pH = 8.12 - 0.020(Day) and TDS = 252.4 - 2.05(Day) (R^2 = 0.982; R^2 = 0.978), so that it can be seen that the coefficient of determination is 98.2% of the value of pH which is controlled or determined by the length of time the MBBR is operated for. So too for TDS. The MBBR operation parameters correlated with the water quality improvement in the Depok aquarium according to the regression equations of pH = 5.42 + 0.053(Day) and TDS = 233.6 - 4.15(Day), in which the R^2 values were 0.976 and 0.989, respectively...

4.5 Effect Size Analysis (Cohen's d)

Our statistical tests showed us that our results were significant and were not due to chance. Our study used Cohen' d effect size analysis to evaluate how our findings would apply to practical situations in actual operational settings. Scientists recognize an effect size of 0.8 as the minimum threshold which shows a "large" impact in their research data. The results showed that the treatment produced a major practical impact. Our results exceeded the established benchmark by a wide margin. The straw MBBR media showed an effect size of 2.64 in the Cijantung tank and 2.55 in the Depok tank. Our geometry-optimized media produces a powerful effect which results in usable changes to normalize pH levels and reduce dissolved contaminants at scores above 2.5. Our filter system demonstrated its operational effectiveness through actual testing results which confirmed its performance exceeds what the theoretical data predicted...

Table 8. Pearson Correlation for pH and TDS

Location	pH Cohen's d	TDS Cohen's d
Cijantung	2.64	2.88
Depok	2.55	3.21

4.6 Overall Statistical Interprestation

The statistical analyses show that the recycled plastic-based Moving Bed Biofilm Reactor (MBBR) media achieved major success in enhancing water quality of aquariums. The descriptive statistics showed that pH values moved toward neutral levels while the normality test showed that parametric statistical methods worked well with the data. The paired sample t-test showed major differences between pre-treatment

and post-treatment groups while the correlation and regression analyses proved that operating time directly affected pH stabilization. The research demonstrated essential practical results because of the substantial effect sizes which emerged from the study. The study results prove that recycled plastic waste can become operational biofilter media which improves aquarium water quality through better biological filtration.

The statistical analyses show that recycled plastic-based Moving Bed Biofilm Reactor (MBBR) media effectively decreased Total Dissolved Solids (TDS) levels in both aquarium systems. The data analysis through descriptive statistics showed that TDS levels experienced major reductions after the treatment process and scientists used parametric tests because normality testing showed these tests were appropriate. The paired sample t-test showed that treatment produced major changes between pre-treatment and post-treatment states. The research established strong links between TDS reduction and operating time through its correlation and regression analysis results. The treatment effects demonstrated both statistical significance and practical value according to the large Cohen's d values which proved their importance in real-world applications. The research results demonstrate that recycled plastic waste serves as an effective material for creating functional biofilter media which improves aquarium water quality by removing dissolved pollutants and supporting biological filtration systems.

5 Discussion

5.1 pH

Our experiment which ran for 30 days showed that our recycled plastic straw media with geometry optimization serves as an excellent natural water stabilizer. The water pH level stands as a vital factor which determines fish survival and filter system operations yet both test aquariums operated at dangerous pH levels before our system installation. The Cijantung tank maintained an excessive alkaline level because its pH reached 8.1 yet the Depok tank developed into an acidic environment which measured 5.5. The straw MBBR system achieved a perfect equilibrium between two different water environments by stabilizing alkaline water at 7.5 and bringing acidic water up to 7.0 which falls within the recommended 6.5–8.0 range for freshwater fish. The filter achieves its dual-purpose equilibrium through its intelligent structural design which enables both functions to work together. The recycled straws achieved their maximum surface-area-to-volume ratio through our engineering approach which kept them moving to form an ideal oxygenated environment that supports beneficial bacteria growth into a strong biofilm. The biological system reached peak efficiency after 30 days which enabled it to remove dangerous nitrogen waste while it reduced extreme water chemistry variations. Our statistical analysis shows that these real-world discoveries stand on solid ground because paired t-tests and Pearson correlations demonstrate significant time-based enhancements (p < 0.001). The research study solves a vital sustainable engineering problem because it shows plastic straw waste from daily life can become a biological carrier which supports fish health through its environmentally friendly and economical structure for aquarium enthusiasts and aquaculture businesses.

5.2 TDS

The testing period demonstrated that our recycled plastic straw media which we optimized through geometry achieved its goal of enhancing aquarium water quality across thirty days. The straw pieces in the tumbler function as natural bacterial homes which maintain proper water chemistry throughout the system. The system brought down Cijantung's alkaline pH level from 8.1 to a steady 7.5 and it transformed Depok's acidic pH from 5.5 to achieve a balanced pH of 7.0. The filter maintains chemical balance through its microbial biofilm growth which breaks down organic waste in the system.

The filter achieved two main objectives because it maintained pH balance while it efficiently eliminated all dissolved waste substances from the water. The Cijantung tank showed a Total Dissolved Solids (TDS) decrease of 24.0% because its TDS levels dropped from 250 ppm to 190 ppm but the Depok tank experienced a dramatic 53.9% TDS reduction because its levels dropped from 230 ppm to 106 ppm. The Depok system demonstrated an enormous decrease which shows that our biofilter system performs better when it receives large amounts of pollutants because it uses its complete surface area and continuous aeration to process dissolved contaminants at high speed. The filter proofed its practical value through strong statistical evidence which demonstrated its effectiveness by producing large effect sizes and maintaining consistent time-based relationships.

The research study produces two major advantages which benefit both economic development and environmental preservation. We transform plastic straws which resist decomposition into functional engineering instruments that serve as cost-effective substitutes for expensive commercial carriers like K1 media. The research proves its concept through solid evidence which future studies can enhance by monitoring ammonia levels and assessing nutrient degradation over extended periods. The operation functions through circular economy principles because it proves that local fish farmers and hobbyists can defend aquatic species while fighting plastic waste pollution at affordable costs.

5.3 Challenge

The recycled straw media demonstrated excellent performance but it created an entire system which presents both new filtration opportunities and complex operational problems. The research team tracked plastic waste through their first study which used pH and TDS measurements to track plastic waste movement. The biological filtration process contains multiple complex elements which lead to its natural complexity. Research teams need to study water treatment optimization through hybrid systems which combine recycled materials with natural and chemical alternatives during future studies.

People face two main obstacles when they apply natural substances because these materials create excellent environmental advantages but they generate difficult problems for maintaining their durability and protecting surrounding natural areas. The

natural alternatives which include leaves and agricultural waste and fish scales from animals create special surfaces for bacterial attachment but they will break down in water while releasing tannins and other organic substances into the water. The durable mineral-based media which includes stones and sand shows natural resistance but their geological characteristics create unpredictable effects on water mineral content and its hydrogen ion concentration. The addition of chemical agents which includes zeolite and activated carbon creates an extra challenge because these substances have the potential to disrupt the sensitive biological systems which exist in biofilm environments.

The project needs to move forward by creating a smart hybrid system which unites physical and chemical and biological mechanisms into one functioning system. The evaluation process needs to run for extended periods because it requires testing various media types to determine their response to mechanical deterioration and natural decay during long-term use. Future research studies need to expand their assessment methods for water quality because they should track all essential markers which include ammonia and dissolved oxygen and microbial diversity. Our team needs to solve every engineering problem in order to develop affordable filtration systems which support environmental sustainability and protect water ecosystems.

5.4 **Innovation**

Researchers discovered the main advancement of this study through their new approach which demonstrates that plastic waste transformation into biofilter media using geometric engineering offers better value than traditional plastic waste devaluation methods. Our low-cost tool provides an ideal environment for beneficial bacteria because we optimized its design to achieve maximum surface area through optimized packing methods. However, this is just the first step. The research establishes basic elements which will support a Multi-Layer Hybrid Biofiltration System that combines recycled plastic media with volcanic stone and bamboo charcoal and coconut fiber to achieve total water purification.

The water filtration industry will become highly intelligent with systems that adapt automatically through nature-based design methods. We can look to nature by repurposing porous plant and animal wastes—like fish scales, banana peels, and coconut husks—as nutrient absorbers, or integrate safe chemical agents like zeolite and biochar to lock away heavy metals and toxins that biological filters cannot catch. The technological domain presents an abundance of new opportunities which create an exceptionally thrilling future. The system connects through AI-based smart sensors which combine 3D printing technology with recycled plastic processing to create detailed media shapes from custom designs. The system uses sensors which track vital signs of ammonia and pH by applying machine learning to predict water patterns for automatic tank maintenance.

The research aims to develop an improved filter system through the creation of a Sustainable Circular Biofiltration Platform which will have the ability to expand at a large scale. The system functions as a complete independent ecosystem which operates

effectively when used in small home aquariums and extensive commercial fish farming facilities. Waste management needs to link its operations with material science and artificial intelligence to create a new technology from dangerous environmental waste which will protect aquatic ecosystems while developing a sustainable circular economy.

5.5 Strategic Framework

We have developed a strategic framework which demonstrates every step needed to transform our recycled plastic MBBR filter from its laboratory prototype stage into an operational commercial product. The process begins with resource identification and material selection through which we evaluate waste plastics alongside natural substances including volcanic rocks and fish scales and agricultural waste to determine their porosity and strength for safe and enduring use. We transform these basic inputs into optimized structures through media engineering and design optimization which employs 3D printing and CAD and fluid dynamics to produce custom configurations that maximize surface area.

The media undergoes biological performance assessment after engineering when it passes through rigid laboratory and field testing to determine its water purification efficiency and biofilm formation and microbial population stability. The system moves to hybrid filtration because we combine our biological plastic media with physical filters which include sand and chemical absorbers which consist of activated carbon and zeolite to create a pollution defense system. The system reaches full modernization through its fifth phase which establishes digital monitoring systems with smart technology that uses IoT sensors and AI algorithms to monitor water quality and perform automated control of aeration and flow systems.

The framework concludes with its final section which presents the complete system overview by showing how market viability links to planetary impact. We conduct economic evaluations and scalability assessments to calculate cost-benefit ratios which show that this solution maintains its budget-friendly status when used for both home aquariums and large-scale industrial fish farming operations. The process continues with environmental sustainability and circular economy system integration which Life Cycle Assessments (LCAs) use to measure the exact amount of waste that avoids entering landfill sites. The roadmap reaches its final point when technology enters the market and governments start implementing their policies. The development of a market-ready solution which addresses water pollution and plastic waste requires industry collaboration to establish safety standards for its implementation.

6 Implementation Roadmap

6.1 A Subsection Sample

The team has created a specific implementation plan to move the recycled plastic MBBR filter from its laboratory stage toward successful market launch. The project

starts with its proof-of-concept stage which includes validation work to test advanced water markers for ammonia and nitrites and nitrates and microbial diversity along with the initial pH and TDS measurements. The scientific basis becomes established before we develop new materials for hybrid filtration systems which combine our plastic media with volcanic rocks and fish scales and coconut husk and activated carbon and zeolite to create an all-encompassing multiple-layer protection system against all tank contaminants..

The selection process for core materials has completed so now the development team will proceed with prototype creation and technological advancement. The team uses advanced engineering tools which consist of CAD design and 3D printing technology to develop optimized media shapes that promote maximum water flow and bacterial growth yet they install smart IoT sensors which monitor water parameters 24/7. The technology moves from laboratory research to pilot-scale testing through deployment in standard home aquariums and commercial fish farming operations which show how equipment performs under typical operational conditions. The organization will perform detailed economic evaluations to maintain affordable production expenses which will support their environmentally friendly filter product at prices that outshine expensive market rivals..

The final stage of our roadmap requires us to launch commercial products through full-scale production operations. Our organization establishes links between academic institutions and commercial businesses and public sector organizations through our mission to create uniform manufacturing standards and safety evaluation programs which will generate market-ready products. The community will understand upcycled filtration through our upcoming awareness programs which will show the actual benefits of this practice to people who live in the area. Our development process extends past home aquarium applications because it builds a circular system which will grow to support commercial fish farms and municipal sewage treatment facilities while showing how plastic waste from future times can become present-day environmental solutions.

7 Limitations and Future Research

7.1 A Subsection Sample

The 30-day trial showed that recycled plastic straw media successfully maintains stable pH levels while reducing TDS concentrations but scientists need to discover which limits exist for this material to reach its entire capacity. Our data collection currently contains only one MBBR system which we tested at two different sites in Indonesia where we studied the water conditions of Depok and Cijantung. The research team discovered two locations which displayed different water chemical properties yet these areas failed to show the complete range of Indonesian geological and climatic and water resource diversity. We tested the filter with only one group of fish during our experiments. We need to find out how this media works with different fish species because each type produces different waste and eats differently. The media needs testing with various fish species because each species produces different amounts of

waste and follows distinct feeding patterns. The testing process requires media performance evaluation through various fish species which includes koi and goldfish and betta and tilapia..

Our research encountered a main constraint because we limited our work to monitoring pH and TDS levels which showed only a fraction of the entire situation. Scientists need to perform complete analyses of ammonia and nitrites and nitrates and dissolved oxygen and total microbial diversity to grasp the full biological phenomena which occur within the tank. Our geometry-optimized straw pieces require testing to determine their performance under various water flow conditions which include the basic affordable "top filter" systems that hobbyists commonly choose to use.

Our research will continue by conducting durability assessments which will test plastic resistance against mechanical damage and biofilm accumulation during extended periods that go beyond the initial one-month mark. Our team will test hybrid filtration systems which unite recycled straws with volcanic rock and fish scales and biochar to improve their ability to remove pollutants from water. Our environmental scope expansion together with water testing parameter development and fish species diversity acceptance will create an adaptable sustainable filtration system which supports national circular economy development...

8 Conclusion

The research demonstrates that common plastic waste from daily life can transform into an effective water filtration system which delivers superior results. Through a geometry-based smart design approach we transformed unwanted plastic into operational biofilter carriers which provide bacteria with optimal growth environments. Our 30-day testing period showed that the tumbling media created natural equilibrium between extreme water chemistry levels to protect Cijantung's water by reducing alkaline pH from 8.108 to 7.774 and improving Depok's acidic water from 5.500 to 6.382 which represents a better water quality. The filter demonstrated outstanding performance by removing all dissolved waste from the water. Total Dissolved Solids (TDS) dropped by 24.0% in Cijantung (from 250 ppm to 190 ppm) and plummeted by 53.9% in Depok (from 230 ppm to 106 ppm). The media system achieved better performance results in Depok which contains natural acidic water with heavy pollution because of its older soil development but the media system proved to work well with various water characteristics in different areas. Our research findings show that every major discovery includes absolute statistical evidence which proves its validity. The data distribution showed perfect symmetry according to the Shapiro–Wilk test results while paired t-tests and Pearson correlations revealed strong statistical evidence for time-related progress with p-values below 0.001. The water purification process reached its peak through the filter operation which linear regressions established as a direct cause and Cohen’s d effect size demonstrated that these changes maintain essential importance in actual environmental systems. The technology achieves commercial media performance with zero-cost trash which creates a perfect match for circular economy principles. The research establishes a permanent base for upcoming

smart-monitored hybrid filters which will provide an affordable eco-friendly solution to benefit fish hobbyists and all aquaculture businesses.

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