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Design and Development: Filter Casing for Highly Efficenty Dissolve Oxygen

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Abstract

This study presents the development and evaluation of a custom 3D-printed filter casing designed to enhance the performance of Downflow Hanging Sponge (DHS) biofilters in small-scale aquaculture settings. Given the importance of dissolved oxygen (DO) for nitrifying bacteria and overall fish health, the proposed casing incorporates an external air-intake opening and an internal water-splitting system to improve aeration and biological filtration efficiency. Experiments comparing the new casing with a traditional seep-through DHS setup were conducted using real catfish wastewater from a local farm. DO, ammonia (NH_3/NH_4^+), temperature, pH, and total dissolved solids (TDS) were measured. Results indicate that the redesigned casing achieved higher DO levels and reduced ammonia concentrations at a faster rate, demonstrating its suitability for practical aquaculture applications. This work contributes to accessible, low-cost innovations for improving water quality in fish tanks and small recirculating aquaculture systems.

Keywords: DHS Biofilter, Aquaculture, Dissolved Oxygen, 3D-Printed Casing, Water Quality

Introduction

Dissolved oxygen (DO) is a critical parameter affecting water quality, fish health, and microbial activity in aquaculture systems. Low DO levels impair nitrifying bacteria responsible for ammonia oxidation, resulting in poor water conditions and increased stress on aquatic species. Downflow Hanging Sponge (DHS) biofilters are widely used for biological filtration due to their high surface area and ability to support biofilm growth; however, their performance remains limited by oxygen availability.

This study addresses this limitation by developing a 3D-printed DHS casing designed to improve oxygen diffusion and water distribution. The redesign introduces an external air-intake hole, a structured sponge arrangement, and an internal water-splitting channel to optimize filtration efficiency. The primary objective is to evaluate whether this redesigned casing can enhance DO levels and accelerate ammonia removal when compared to a traditional seep-through DHS configuration.

Objectives of the Study

The objectives of this study are to:

- Design and develop a 3D-printed Downflow Hanging Sponge (DHS) filter casing with enhanced aeration and structured water-flow distribution.
- Evaluate the performance of the redesigned DHS casing in improving dissolved oxygen (DO) levels using real catfish wastewater.
- Compare the ammonia removal efficiency (NH_3 and NH_4^+) of the redesigned DHS casing against a traditional seep-through DHS system.
- Assess the stability of key water-quality parameters including temperature, pH, and total dissolved solids (TDS) during filtration.
- Determine the practical suitability of the redesigned DHS casing for small-scale, low-cost aquaculture applications.

Literature Review

DHS biofilters have been recognized for their ability to maintain stable biofilm activity and support efficient nitrification in both freshwater and marine aquaculture systems. Prior research highlights that DO levels above 4–6 mg/L are generally required for optimal nitrifying bacteria function. Traditional DHS units rely on passive seepage of water, which limits aeration efficiency. Recent innovations suggest that incorporating structural modifications such as improved air pathways, increased surface contact, and controlled flow distribution can enhance oxygen transfer and overall filtration performance.

3D printing offers rapid prototyping advantages, enabling customized casing geometries that address practical limitations found in conventional designs. This study builds upon these findings by introducing an accessible and low-cost casing tailored for sponge-based biofiltration in compact aquaculture setups.

Methodology

Design of the DHS Filter Casing

The DHS filter casing was designed using computer-aided design (CAD) software to ensure accurate dimensions and functional flow pathways. The design features an external air-intake opening, a vertical compartment for neatly stacked sponge media, and an internal water-splitting channel that distributes flow evenly to each sponge layer. Both 2D orthographic drawings and 3D isometric representations were produced to visualize the internal structure and guide fabrication.

Although the figure is not included at this stage, the drawings illustrate the component layout, water inlet direction, aeration hole placement, and the overall geometry optimized to enhance dissolved oxygen diffusion.

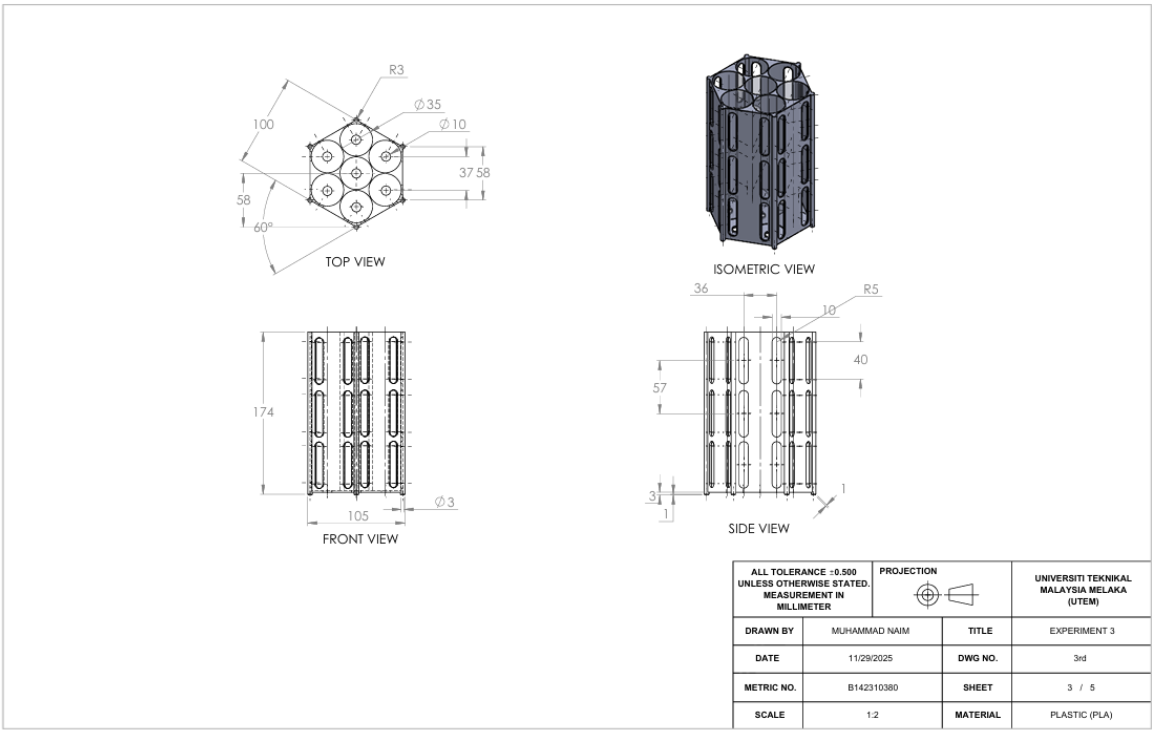


Figure 1. DHS Casing Design

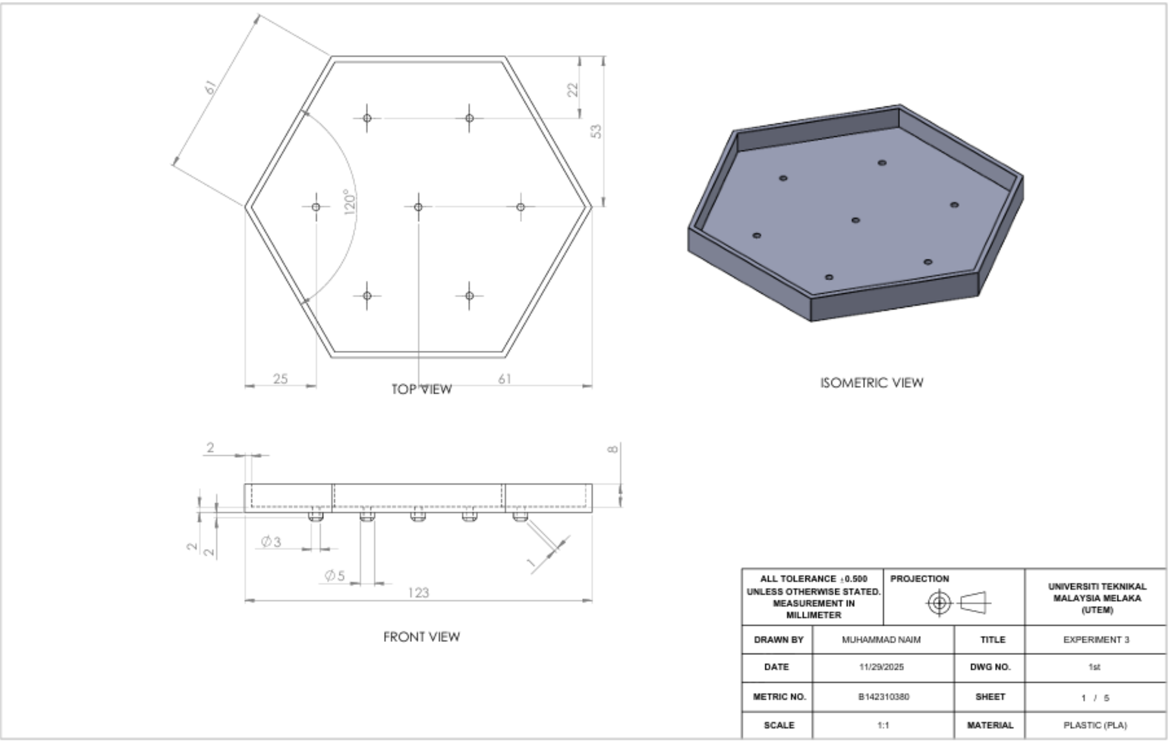
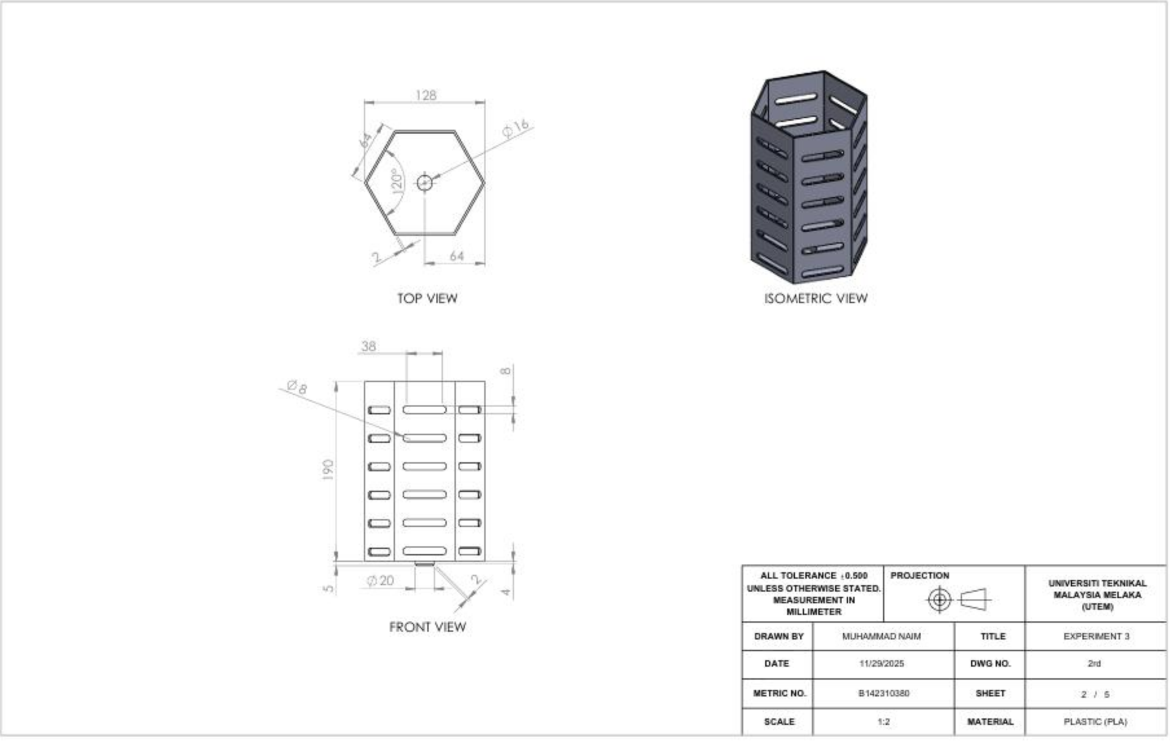


Figure 2. DHS Casing Design



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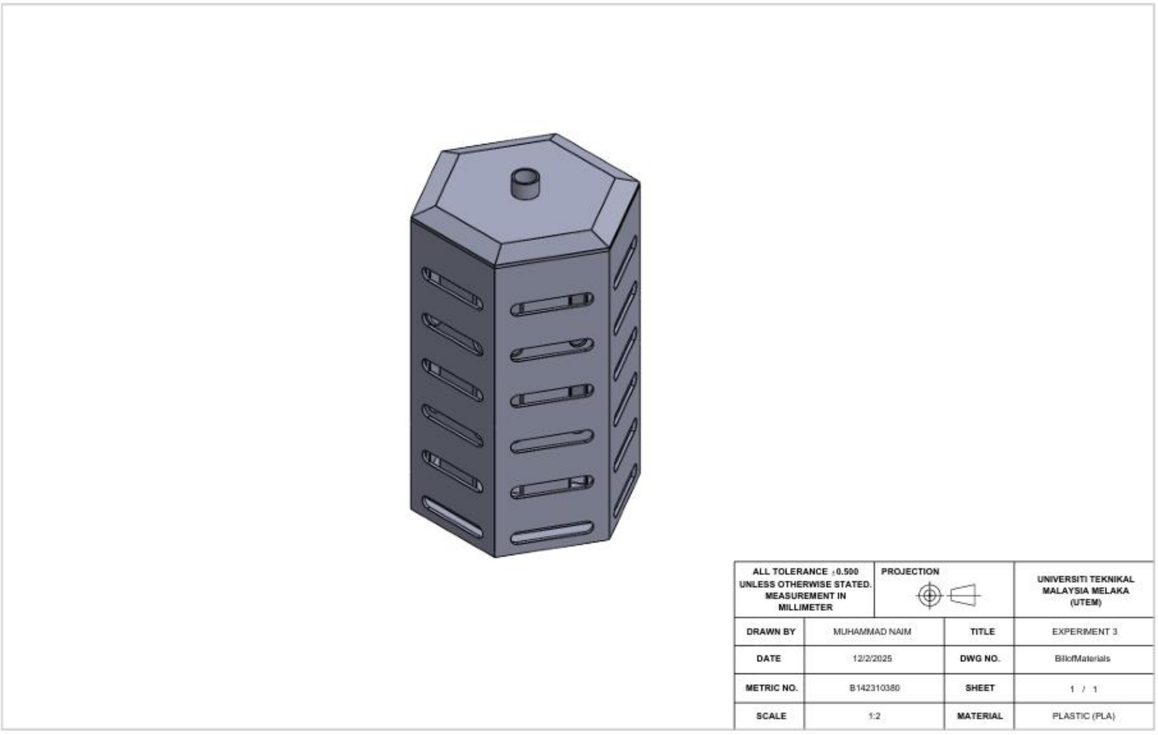

Figure 4. DHS Casing Design

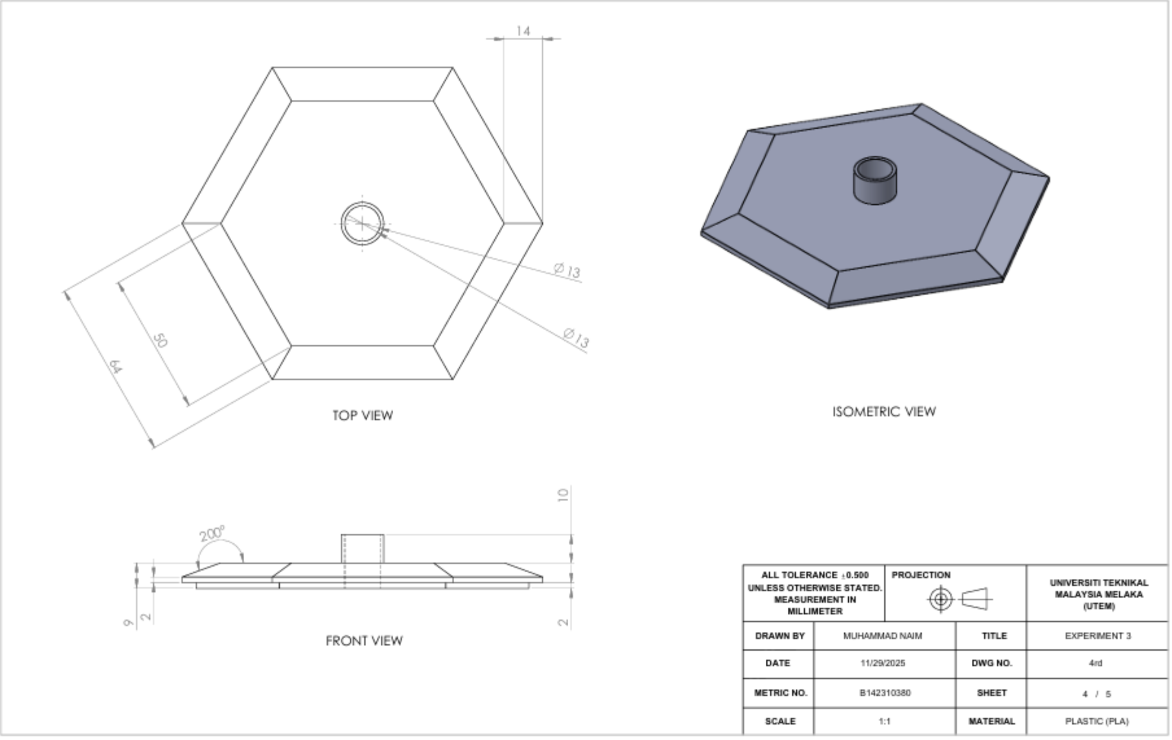

Figure 5. DHS Casing Design

Development of the DHS Filter Casing (3D Printing Process)

The casing prototype was fabricated using a fused deposition modelling (FDM) 3D printer. PLA filament was selected due to its ease of printing, dimensional stability, and suitability for experimental prototyping. The model was sliced using Cura software with standard printing parameters, including a 0.2 mm layer height, 20% infill density, and support structures for internal overhangs.

The printing process allowed rapid iteration and ensured precise alignment of the sponge compartment and water-splitting channel. After printing, the casing was cleaned, support material removed, and the internal pathways inspected to ensure no obstructions would affect water flow. This development method provides an accessible, low-cost, and reproducible approach suitable for aquaculture practitioners.

Both systems were tested using catfish wastewater sourced from a local aquaculture farm to simulate real-world water conditions.

Figure 6. DHS Casing Design

Measurement of Water Quality Parameters

To evaluate the performance of the redesigned casing, both the traditional DHS setup and the new 3D-printed casing were tested using real catfish wastewater. Water-quality parameters were measured at consistent intervals over the testing period. The following parameters were recorded:

i. Dissolved Oxygen (DO) — using a digital DO meter
ii. Ammonia (NH_4^+) — using a vernier ammonia detector
iii. Ammonia (NH_3) — Using nessler method
iv. pH — using a portable pH meter
v. Temperature — using a digital thermometer
vi. Total Dissolved Solids (TDS/ppm) — using a TDS meter

All measurements were taken in triplicate to ensure accuracy and reliability. The results were then compared between the traditional and the redesigned casing to determine the improvement in aeration efficiency and filtration performance.

Results and Discussion

The proposed DHS casing demonstrated improved DO levels compared to the traditional setup. The air-intake feature enhanced oxygen diffusion as water moved through the sponge layers. Ammonia concentrations also decreased more rapidly, indicating improved nitrification and biofilm activity. Other parameters such as temperature and pH remained stable, confirming that the observed improvements stemmed from design enhancements rather than external factors.

These findings suggest that the redesigned casing offers a practical solution for aquaculture practitioners seeking low-cost filtration upgrades. The modular and compact design makes it suitable for aquarium hobbyists, small farm operators, and educational settings.

Table 1
Water Quality Comparison

Sample	Time	Temperature		DO (mg/L)		pH		TDS		Ammonium ion (NH4)		Ammonia Nessler (NH3)	
		DHS	TDL	DHS	TDL	DHS	TDL	DHS	TDL	DHS	TRDL	DHS	TDL
1	1200	29.2	25.4	4.67	4.75	7.04	7.84	184	181	4.4	4.4	3.09	2.90
2	1400	25.4	25.4	5.74	5.46	8	7.82	127	124	3.49	4.29	3.49	2.99
3	1600	27.5	27.5	5.23	5.21	7.65	7.98	136	132	4.32	3.67	2.95	2.98
4	1800	27.1	26.7	5.12	5.1	7.45	7.34	125	141	2.89	3.74	2.52	3.00
5	2000	28.9	28.8	5.22	5.3	8.1	7.69	136	132	2.67	2.89	2.95	2.85
6	2200	28.5	28.9	5.98	4.15	8.2	7.8	130	128	3.04	3.16	2.89	2.84
7	0	28.4	28.4	6.01	3.72	8.12	7.65	118	120	2.96	4.89	2.73	2.38
8	1200 (D2)	28.8	28.6	5.44	3.87	8.03	7.51	112	118	1.75	2.4	2.56	3.24
9	0000 (D2)	28.3	28.1	5.56	3.54	7.54	7.45	97	114	1.23	1.81	2.41	2.72
10	1200 (D3)	28.2	28.4	5.49	2.82	6.99	7.31	92	111	0.45	1.49	2.63	2.89
11	0000 (D3)	28.4	28.3	5.67	2.78	6.54	7.21	110	109	0.47	1.27	2.87	3.22
12	1200 (D4)	28.3	28.2	5.99	2.89	5.59	6.92	105	115	0.46	1.07	2.57	3.14
13	1200 (D5)	27.9	27.9	6.01	2.8	5.93	6.72	109	107	0.36	0.86	-	2.77
14	1200 (D6)	28.4	28.3	6.06	2.8	5.91	6.58	103	109	0.33	0.44	2.65	2.86
15	1200 (D7)	27.8	27.7	6.04	2.86	6.78	6.31	102	103	0.34	0.43	1.85	3.12

Table 2
Features of the Proposed DHS Casing

Feature	Description	Function
Air-intake opening	Allows external air entry	Improves DO levels
3D-printed structure	Custom casing for sponge stacking	Organized flow
Water-split inlet	Splits 1 pipe into multiple flows	Uniform distribution
Vertical sponge layout	Sponges placed in layers	Higher biofilm area
Modular design	Easy to assemble and clean	User-friendly

Results and Discussion

The redesigned DHS filter casing demonstrated notable improvements in dissolved oxygen (DO) levels, ammonia reduction, and overall water-quality stability compared to the traditional seep-through DHS system. The performance enhancement is primarily attributed to three design innovations: the external air-intake opening, the internal water-splitting channel, and the vertical layered sponge compartment. These features collectively improved aeration efficiency and increased the effective contact area between water, air, and biofilm-supporting media.

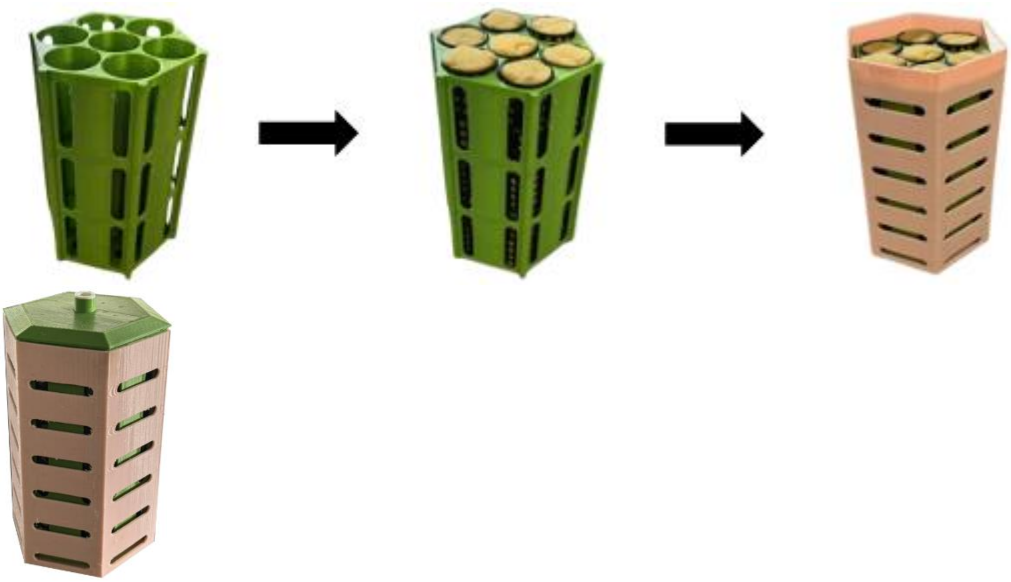

Figure 7. DHS Casing Design

Dissolved Oxygen (DO) Performance

Throughout the monitoring period, the redesigned casing consistently achieved *higher DO concentrations* than the traditional DHS setup. Initial readings for both systems were between 4.6–4.7 mg/L; however, the redesigned model demonstrated an upward trend, reaching *6.04 mg/L* by *Day 7*, while the traditional setup peaked only at *2.86 mg/L*.

This improvement can be directly linked to the *air-intake opening*, which facilitated passive aeration as wastewater traveled downward through successive sponge layers. The internal water-splitting channel also ensured that flow was evenly distributed across all sponge modules, preventing dead zones and maximizing oxygen diffusion.

Higher DO levels are critical for nitrifying bacteria efficiency. As such, the enhanced aeration conditions provided by the new casing contributed directly to improved ammonia oxidation performance observed in later stages.

Ammonia and Ammonium Reduction

Ammonia (NH_3) and ammonium ion (NH_4^+) concentrations declined more rapidly in the redesigned system, indicating heightened nitrification activity. At the start of the experiment, both systems recorded ammonia values above 3.0 mg/L. Over time, the redesigned casing showed a sharp decrease, reaching as low as 0.33–0.36 mg/L by Day 6 and Day 7.
In contrast, the traditional DHS system maintained higher ammonia values, with several readings above 2.0–3.0 mg/L, and exhibited slower decline rates.
The improved performance can be attributed to:

i. Enhanced aeration, which supports aerobic nitrifying bacteria.
ii. Increased surface area due to organized vertical sponge stacking, producing more active biofilm zones.
iii. Uniform hydraulic flow, enabling more effective biological contact and reducing bypassing flow.

These findings confirm that the geometric modifications in the redesigned casing directly accelerate nitrogen conversion processes.

Temperature, pH, and TDS Stability

Both systems demonstrated consistent temperature and pH readings over the testing period. Temperature remained stable between 27.1–29.2°C, which is suitable for catfish aquaculture and does not independently influence filtration performance.

pH values in both systems fluctuated narrowly within the 6.5–8.1 range, remaining within acceptable biological filtration thresholds. TDS levels also exhibited minimal differences, indicating that neither system experienced significant solids accumulation or dissolution variability.

The similarity of these parameters between the two setups suggests that the improvements recorded in DO and ammonia reduction can be attributed directly to the redesigned casing, rather than external or environmental factors.

Overall System Performance and Practical Implications

The combination of enhanced aeration, organized flow pathways, and structured sponge support resulted in:

i. Faster biological activation of sponge media
ii. Improved oxygen availability for microbial metabolism
iii. More efficient ammonia removal
iv. Better long-term water stability

These features contribute to creating a more efficient yet low-cost filtration system suitable for small-scale aquaculture operators, aquarium hobbyists, and educational setups.

Furthermore, the use of 3D printing enables rapid prototyping, ease of customization, and scalable production, making the redesigned DHS casing accessible for future refinement and onsite implementation.

Summary of Key Findings

The findings of this study clearly show that the redesigned DHS casing outperformed the traditional seep-through DHS system in several critical aspects of water-quality management. First, the redesigned casing consistently achieved higher dissolved oxygen levels, reaching values above 6.0 mg/L, while the traditional system peaked at only around 4.89 mg/L. This improvement highlights the effectiveness of the air-intake opening and the structured internal flow pathway in enhancing aeration.

Second, the redesigned system demonstrated significantly faster and more consistent ammonia removal. Ammonia concentrations declined more rapidly and reached much lower final levels compared to the traditional DHS, which exhibited slower and irregular nitrification performance. This accelerated ammonia reduction indicates stronger biofilm activity supported by better oxygen availability and more uniform water distribution.

In terms of hydraulic performance, the redesigned casing maintained a more even water flow due to its integrated water-splitting channel. This prevented bypassing and ensured that all sponge layers were actively utilized, unlike the traditional setup where flow was less controlled.

Finally, the overall biological efficiency of the redesigned DHS was noticeably higher. Enhanced DO levels, improved sponge utilization, and increased biofilm formation collectively contributed to superior filtration performance. In summary, the redesigned 3D-printed DHS casing provided measurable improvements in aeration, nitrification, and hydraulic consistency, confirming its advantage over conventional DHS units in small-scale aquaculture settings.

Conclusion

The development of a 3D-printed DHS casing with enhanced aeration and structured flow distribution significantly improved DO levels and ammonia reduction in aquaculture water. This demonstrates the potential for affordable, customizable filtration solutions suitable for small-scale and hobbyist aquaculture operations. Future work may include long-term monitoring, further geometric optimization, and integration with real-time water-quality sensors for improved system automation.

The redesign of the Downflow Hanging Sponge (DHS) filter casing through 3D printing technology represents a meaningful advancement in the theoretical understanding of how engineering geometry influences dissolved oxygen (DO) transfer and biological treatment efficiency. Unlike conventional DHS studies that emphasize biological media and hydraulic parameters, this research highlights casing architecture as a critical determinant of oxygen diffusion and ammonia removal. The improved water-splitting flow paths and vertical sponge arrangement introduced in this study demonstrate that filtration performance is strongly governed by structural flow control, thereby extending existing biofiltration theory toward a more integrated bio–mechanical framework. This contribution strengthens the scientific foundation of DHS system design and provides new direction for future engineering-oriented aquaculture filtration research.

In the practical context of small-scale and educational aquaculture systems, the findings of this study offer a cost-effective and easily customizable filtration solution through additive manufacturing (3D printing). The ability to rapidly prototype and locally fabricate DHS casings reduces dependency on expensive commercial systems and significantly lowers the barrier of technology adoption for small farmers and teaching laboratories. The successful validation of the redesigned casing using real catfish wastewater under operating conditions further demonstrates its suitability for real-world application, supporting sustainable water-quality management and stable fish production in low- to medium-resource settings.

However, several challenges remain for the broader implementation of 3D-printed DHS filtration systems. The long-term mechanical durability of printed materials under continuous water exposure, biofouling resistance, and scalability for higher flow rates require further investigation. In addition, while the system offers lower capital cost than commercial filters, operational optimization is still needed to ensure consistent DO enhancement under variable loading conditions. To address these limitations, future research should prioritize the development of more durable eco-friendly printing materials, refined internal flow structures for large-scale operation, and standardized casing dimensions for modular expansion.
Building upon the outcomes of this research, several key areas for future development are recommended:

1. Optimization of DHS Casing Geometry: Future work should focus on refining internal water splitter angles, sponge arrangement, and air exposure pathways to maximize DO transfer efficiency and nitrification performance across different flow regimes.
2. Material Enhancement for 3D Printing: Advanced filament materials such as reinforced PLA, PETG, or biodegradable composites should be explored to improve mechanical strength, heat resistance, and environmental sustainability of the casing.
3. Integration with Smart Monitoring Systems: The incorporation of real-time DO, pH, and temperature sensors can enable automated system optimization, reducing human intervention and ensuring stable aquaculture conditions.
4. Modular and Scalable System Design: Modular DHS units should be developed to allow flexible scaling for different tank sizes and stocking densities, increasing adaptability for small and medium scale aquaculture operations.
5. Techno-Economic and Sustainability Assessment: Comprehensive cost benefit and life cycle assessments should be conducted to evaluate the long-term financial and environmental feasibility of implementing 3D printed DHS systems in commercial aquaculture.

By addressing these aspects, this research contributes not only to the theoretical advancement of biofiltration system design but also to the practical realization of affordable, scalable, and sustainable aquaculture wastewater treatment solutions. The integration of engineering design innovation with biological filtration principles, as demonstrated in this work, provides a promising pathway toward improving aquaculture productivity, environmental protection, and long-term food security.

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