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Development and Performance Assessment of a Low-Cost Cylindrical Ceramic Clay Filter Using Synthetic Water

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***Abstract*—** *Access to safe drinking water remains a significant challenge in many rural and coastal communities in the Philippines because of limited water treatment infrastructure. This study developed and evaluated four low-cost cylindrical ceramic clay filter prototypes incorporating Nipa Fiber Ash and seashell powder as natural additives to enhance physicochemical filtration performance. The filters were tested under gravity-fed conditions using synthetic water based on selected Philippine National Standards for Drinking Water (PNSDW, 2017) parameters, including turbidity, pH, total dissolved solids (TDS), color, and nitrate. Results showed a trade-off between contaminant removal efficiency and flow rate. Increasing seashell powder content improved hydraulic conductivity but reduced treatment efficiency due to increased porosity and shorter retention time. Among the four formulations, Setup B, consisting of 60% clay, 20% Nipa Fiber Ash, and 20% seashell powder, demonstrated the best overall performance. During Trial 2, it achieved 95.4% turbidity removal, 97.7% color removal, and 79.4% TDS reduction while maintaining pH and nitrate levels within acceptable PNSDW limits. These findings indicate that ceramic clay filters with natural composite additives have strong potential as affordable and locally producible point-of-use water treatment systems for underserved Philippine communities. Further studies are recommended to optimize material ratios, improve firing conditions, expand long-term testing, and validate performance using actual rural and coastal water sources.*

***Keywords*—** *Cylindrical ceramic clay filter; synthetic water; Nipa fiber ash; seashell powder; turbidity; pH; total dissolved solids (TDS); color; nitrate; hydraulic performance; Philippine National Standards for Drinking Water (PNSDW, 2017)*

I. INTRODUCTION

Access to safe drinking water is a fundamental human need, yet millions of people worldwide continue to suffer from waterborne diseases and chemical contamination due to inadequate treatment infrastructure. This reality highlights the urgent demand for affordable and sustainable purification technologies, especially in underserved communities where centralized systems are inaccessible. Ceramic clay filters have emerged as a promising solution, offering low-cost, environmentally adaptable household treatment through mechanisms such as size exclusion, adsorption, and ionic interaction [3], [8]. Their reliance on locally available materials and ease of fabrication make them particularly suitable for developing regions [15], [16].

Despite their potential, research on ceramic clay filters remains limited in terms of systematic evaluation against the physicochemical parameters defined by the Philippine National Standards for Drinking Water (PNSDW, 2017) [10]. Many studies rely on natural or wastewater samples, which vary unpredictably and hinder reproducibility [2]. Furthermore, few investigations have assessed both removal efficiency and hydraulic performance under controlled laboratory conditions using synthetic water [4], [11]. This study addresses these gaps by testing cylindrical ceramic clay filters against selected PNSDW parameters, focusing on turbidity, color, nitrate, total dissolved solids, and pH, while also examining flow rate and filtration time.

The primary objective of this research is to fabricate and assess four prototypes of cylindrical ceramic clay filters with varying material compositions. Setup A served as the control composed of 100% clay, while Setups B, C, and D incorporated different proportions of Nipa fiber ash and seashell powder [6], [21]. Each prototype was subjected to laboratory testing to determine removal efficiency and hydraulic performance, with results benchmarked against PNSDW standards [10]. This method ensures repeatability and offers a strict framework for assessing the physicochemical characteristics of ceramic clay filters in regulated settings.

This study is significant as it advances the development of low-cost, sustainable, and locally adaptable water purification technologies utilizing waste-derived materials [13], [15]. The findings provide evidence-based insights into the capacity of ceramic clay filters to reduce turbidity, color, nitrate, and total dissolved solids while maintaining acceptable pH levels [1], [22]. These outcomes are directly relevant to rural and coastal households with limited access to centralized treatment systems. For the academic community, the research establishes a standardized evaluation framework, while policymakers may utilize the results to support scalable, non-chemical interventions aimed at reducing waterborne illness [10]. The scope of the study is confined to laboratory testing, excluding microbiological parameters, long-term durability, and large-scale applications, thereby ensuring focus on controlled physicochemical performance.

II. METHODOLOGY

A. Study Design and Sample Preparation

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This experimental laboratory-based study developed and evaluated low-cost cylindrical ceramic clay filters incorporating Nipa Fiber Ash and seashell powder as natural composite additives for household water treatment. Four filter prototypes were fabricated using varying material compositions. Setup A (Control) consisted of 100% clay, while Setup B contained 60% clay, 20% Nipa Fiber Ash, and 20% seashell powder. Setup C consisted of 50% clay, 20% Nipa Fiber Ash, and 30% seashell powder, whereas Setup D contained 40% clay, 10% Nipa Fiber Ash, and 50% seashell powder.

The raw materials were thoroughly mixed with distilled water until a uniform plastic consistency was obtained. The height and diameter of each mixture's cylindrical filters were around 16 cm and 5 cm, respectively, and they were shaped by hand. The molded filters were air-dried and fired in an oven at approximately 500°C to produce rigid porous ceramic filters. All prototypes were fabricated with identical dimensions to ensure that variations in filtration performance resulted solely from differences in material composition. The fabricated ceramic filter prototypes are shown in Fig. 1.

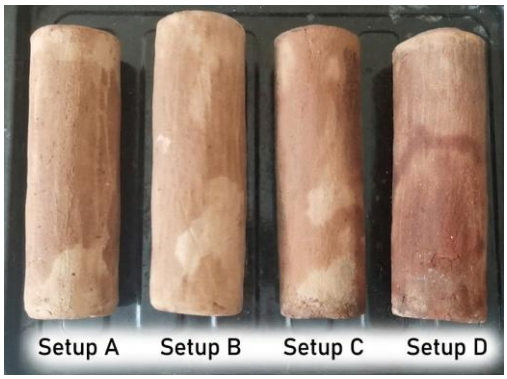

Fig. 1. Fabricated Cylindrical Ceramic Clay Filter Prototypes Before Final Firing

Synthetic water was prepared to simulate selected physicochemical parameters specified in the Philippine National Standards for Drinking Water (PNSDW 2017), namely turbidity, pH, total dissolved solids (TDS), apparent color, and nitrate. Using synthetic water provided uniform influent characteristics throughout the experiment, allowing direct comparison of filtration performance among the four filter formulations. Table 1 shows the composition of ceramic clay filter prototypes.

TABLE 1. Composition of f Ceramic Clay filter prototypes.

Prototype	*Clay*	*Nipa Fiber Ash*	*Seashell Powder*
Setup A (Control)	*100%*	*0%*	*0%*
Setup B	*60%*	*20%*	*20%*
Setup C	*50%*	*20%*	*30%*
Setup D	*40%*	*10%*	*50%*

B. Evaluation of Filter Performance

Each ceramic filter prototype was assembled into a gravity-fed filtration system and tested using identical batches of synthetic water under controlled laboratory conditions. Filtration was conducted without the use of external pressure to simulate household point-of-use water treatment.

Influent and effluent water samples were analyzed for turbidity, pH, total dissolved solids (TDS), apparent color, and nitrate concentration. The analytical results were compared with the maximum allowable limits specified in the Philippine National Standards for Drinking Water (PNSDW 2017). Removal efficiency for each parameter was determined by comparing influent and effluent concentrations.

Hydraulic performance was also evaluated by measuring filtration time and calculating the corresponding flow rate of each filter prototype. The formulation that demonstrated the highest contaminant removal while maintaining a practical filtration rate was identified as the optimum filter composition.

C. Statistical Analysis

Experimental data were summarized using descriptive statistics, including mean values and percentage removal efficiencies for all measured physicochemical parameters. The performance of the four ceramic filter prototypes was compared based on contaminant removal efficiency, compliance with PNSDW 2017 standards, and hydraulic performance. The optimum formulation was identified through overall comparison of treatment effectiveness and filtration rate.

III. Results and Discussion

A. Water Quality Assessment of the Influent (Raw Water)

The synthetic influent water was characterized prior to filtration to establish a controlled baseline for evaluating the performance of the ceramic clay filter prototypes. A single synthetic water formulation was used throughout the two experimental trials to ensure consistent testing conditions and minimize variability associated with natural water sources. Minor differences in influent water quality between Trial 1 and Trial 2 were attributed to the gradual physicochemical changes that occurred during storage and continuous replenishment over the one-month experimental period.

TABLE 2. *Physicochemical Laboratory Results for Influent (Raw Water) — Trial 1 and Trial 2*

Parameter	Trial 1 (Feb. 9, 2026)	Trial 2 (Mar. 4, 2026)	PNSDW 2017 Standard
pH	7.5	8.15	6.5–8.5
Turbidity (NTU)	39.0	35.2	≤5
Color (CU)	448	760	≤15
TDS (mg/L)	1,160	946	≤600
Nitrate (mg/L)	<0.4	6.89	≤50

The laboratory analysis showed that turbidity, apparent color, and total dissolved solids (TDS) exceeded the maximum allowable limits specified in the Philippine National Standards for Drinking Water (PNSDW 2017), whereas pH and nitrate concentrations remained within acceptable limits. These results indicate that the synthetic water provided a suitable challenge for evaluating the treatment performance of the ceramic clay filters. Since Trial 2 represented a more stable operating condition after the initial filtration cycle, its influent

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values were used as the primary reference for evaluating removal efficiency.

3.2 Physicochemical Water Analysis for Trial 1 (February 9, 2026)

Trial 1, conducted on February 9, 2026, evaluated the initial physicochemical performance of the ceramic clay filter prototypes under first-cycle operating conditions and served as a baseline for early-stage filter behavior. It assessed initial structural and adsorptive characteristics, including possible leaching of soluble compounds from freshly fired ceramic materials. Consistent with Lantagne (2001) and van Halem et al. (2009), newly fabricated ceramic filters often show non-representative performance during initial use due to unconditioned pore surfaces, loosely bound particles, and unstable mineral fractions. Thus, Trial 1 results are mainly interpreted for PNSDW 2017 compliance and early performance trends, serving as a reference for the more stable results observed in Trial 2.

3.2.1 pH

pH is a key indicator of water quality that measures acidity or alkalinity on a scale of 0 to 14. It affects chemical stability, corrosivity, solubility of substances, taste, and the effectiveness of disinfection processes such as chlorination, which becomes less effective at pH levels above 8.0 (WHO, 2017). The PNSDW (2017) sets the acceptable range for drinking water at 6.5 to 8.5. In ceramic filtration systems, pH changes may result from the dissolution of mineral components in the filter media or ion-exchange reactions within clay materials during filtration (Hammer et al., 2015).

TABLE 3. *Trial 1 pH results across all filter setups.*

Sample	Trial 1 pH	PNSDW Standard
Raw Water	7.5	6.5–8.5
Setup A	7.6	6.5–8.5
Setup B	7.4	6.5–8.5
Setup C	7.4	6.5–8.5
Setup D	7.0	6.5–8.5

As presented in Table 3, all four filter setups produced effluent pH values within the PNSDW 2017 acceptable range of 6.5 to 8.5 during Trial 1, indicating that none of the ceramic filter compositions introduced chemically unsafe acidity or alkalinity into the treated water. The effluent pH values ranged narrowly from 7.0 in Setup D to 7.6 in Setup A, remaining close to the influent value of 7.5 and confirming overall chemical stability across all treatment units. This limited variation is consistent with findings from recent studies on ceramic water filters, which report that pH is generally minimally affected by ceramic filtration systems unless highly reactive additives are present in significant proportions [23][31].

Setup A showed a slight increase in pH from 7.5 to 7.6, which may be attributed to ion-exchange processes occurring on clay mineral surfaces. Clay minerals such as smectite and illite contain negatively charged sites that facilitate the exchange of hydrogen ions with dissolved cations, resulting in a marginal reduction in hydrogen ion concentration and a slight increase in pH [32]. Recent ceramic filter studies have similarly observed mild alkalinization in clay-based systems due to surface exchange reactions and mineral interactions during early filtration cycles, particularly under gravity-driven household conditions [25][31]. This supports the interpretation that the observed pH increase in Setup A is a material-driven but minor effect.

In contrast, Setup D recorded a decrease in pH from 7.5 to 7.0, which may be associated with the initial interaction of calcium carbonate derived from seashell powder incorporated into the filter matrix. Fresh $CaCO_3$ surfaces may undergo early-stage dissolution and carbonate equilibrium adjustment upon first contact with water, temporarily influencing acidity–alkalinity balance before reaching equilibrium (Stumm & Morgan, 1996). Recent studies on calcium-rich ceramic media also indicate that carbonate-based additives may initially alter pH due to surface reactivity and stabilization processes during early wetting phases [23][31]. Over subsequent cycles, these systems typically stabilize and may contribute to buffering capacity, as reflected in the higher pH observed in later operation.

Overall, the results demonstrate that all setups maintained stable effluent pH within regulatory limits, with only minor variations attributable to clay ion exchange and carbonate surface interactions. These findings are consistent with recent literature emphasizing that ceramic filtration systems generally preserve influent pH stability while allowing only slight material-dependent shifts during initial operation [23][31][36]. The results therefore confirm that all filter prototypes are chemically safe in terms of pH from the initial filtration cycle onward.

3.2.2 Turbidity

Turbidity refers to the cloudiness of water caused by suspended particles such as clay, silt, organic matter, and microorganisms. It is a key water quality indicator because high turbidity can protect pathogens from disinfection, reducing the effectiveness of treatment processes (WHO, 2017; Crittenden et al., 2012). The PNSDW 2017 sets a limit of 5 NTU for safe drinking water. In ceramic filtration systems, turbidity is reduced mainly through physical straining, depth filtration, and particle trapping within the filter's pore structure, which depend on pore size, uniformity, and tortuosity [8].

TABLE 4. *Trial 1 turbidity results across all filter setups.*

Sample	Trial 1 (NTU)	PNSDW Standard
Raw Water	39.0	≤5 NTU
Setup A	5.5	≤5 NTU
Setup B	7.7	≤5 NTU
Setup C	11.0	≤5 NTU
Setup D	10.0	≤5 NTU

As shown in Table 4, all four ceramic filter setups achieved substantial turbidity reduction from the raw water

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value of 39.0 NTU; however, none fully met the PNSDW 2017 standard of ≤5 NTU during the first filtration cycle. Setup A recorded the lowest effluent turbidity at 5.5 NTU, closely approaching regulatory compliance, while Setups B, C, and D produced higher values of 7.7 NTU, 11.0 NTU, and 10.0 NTU, respectively. These results indicate a clear decline in turbidity removal efficiency with increasing seashell powder content, reflecting changes in pore structure and filtration pathways across the different ceramic compositions. Recent studies confirm that ceramic filters often require a conditioning phase before reaching optimal performance, particularly in terms of turbidity removal stability [23][31].

The superior performance of Setup A is attributed to its 100% clay composition, which forms a dense and highly sintered ceramic matrix after firing at 500°C. This structure produces smaller and more tortuous pore pathways, enhancing the removal of suspended particles through surface straining and depth filtration mechanisms. Recent literature emphasizes that turbidity removal in ceramic filters is strongly influenced by pore size distribution and tortuosity, where finer and more interconnected pore networks significantly improve particle capture efficiency [18][23]. This explains why Setup A demonstrated near-compliant turbidity levels compared to the other formulations.

In contrast, the increasing turbidity observed in Setups B, C, and D is associated with the incorporation of seashell powder and nipa fiber ash, which modify the ceramic microstructure. Seashell-derived calcium carbonate particles are less sinterable than clay at 500°C, resulting in larger interparticle voids and reduced filtration efficiency. In addition, the burnout of organic fiber components creates additional macro-pores that increase permeability but reduce effective particle retention. Recent studies on composite ceramic filters report that high proportions of pore-forming additives can improve flow rates but often compromise initial turbidity removal due to increased pore connectivity and reduced filtration resistance [21][31].

Although none of the setups achieved full compliance during Trial 1, the results are expected to improve in subsequent cycles due to filter ripening effects. During initial operation, deposited fine particles gradually accumulate within the pore structure and on the filter surface, reducing effective pore size and enhancing particle capture efficiency over time. This conditioning phenomenon has been widely documented in ceramic filtration studies, where progressive turbidity reduction is observed after several filtration cycles as a stable filtration cake layer develops [14][23]28]. Consequently, the Trial 1 results primarily reflect initial conditioning behavior rather than long-term filtration performance, particularly for composite filter setups such as B, C, and D.

3.2.3 Color

Apparent color in water is primarily attributable to dissolved organic compounds — most notably humic and fulvic acids arising from the decomposition of natural organic matter — as well as dissolved iron, manganese, and tannin species [34]. While not always directly harmful at low concentrations, elevated apparent color significantly reduces the aesthetic acceptability of drinking water and is a recognized indicator of dissolved organic matter concentrations that may serve as precursors to disinfection by-product formation during downstream chlorination (Crittenden et al., 2012). The PNSDW (2017) sets a maximum allowable apparent color of 15 Color Units (CU). In ceramic filtration systems, color removal occurs predominantly through the adsorption of dissolved chromophoric compounds onto the internal pore surfaces of the ceramic matrix, with secondary contributions from physical straining of colloidal color-bearing particles and diffusion of dissolved species into micropore structures [3].

TABLE 5. *Trial 1 color results across all filter setups.*

Sample	Trial 1 (CU)	PNSDW Standard
Raw Water	448	≤15 CU
Setup A	15	≤15 CU
Setup B	10	≤15 CU
Setup C	126	≤15 CU
Setup D	30	≤15 CU

As presented in Table 5, Trial 1 color removal performance varied significantly across the four filter setups, ranging from full compliance to substantial non-compliance relative to the PNSDW 2017 limit of ≤15 CU. The raw water color of 448 CU indicates a highly contaminated influent with strong chromophoric organic content. Setup B achieved the best performance, producing 10 CU and fully complying with the standard, followed by Setup A at 15 CU, which met the regulatory threshold exactly. In contrast, Setup D and Setup C recorded 30 CU and 126 CU, respectively, indicating insufficient removal efficiency during the initial filtration cycle. Recent studies on ceramic filtration confirm that early-cycle performance variability is common due to ongoing pore conditioning and stabilization of adsorption sites [23][31].

The superior performance of Setup B can be attributed to its composite structure, which integrates clay minerals, seashell-derived calcium carbonate, and nipa fiber ash, thereby providing a heterogeneous and high-surface-area adsorption environment. This combination enhances multiple removal mechanisms, including electrostatic attraction, surface complexation, and physical adsorption of dissolved organic compounds responsible for color. Recent literature has shown that multi-component ceramic matrices generally outperform single-material systems in removing natural organic matter due to the increased diversity of reactive surface sites and pore structures [3][23]. This explains why Setup B achieved the lowest effluent color despite the high influent load.

Setup A recorded exactly 15 CU, indicating borderline but effective removal performance under the PNSDW limit. This result reflects the adsorption capacity of pure clay minerals, particularly smectite-rich structures with high specific surface area and active edge sites capable of binding humic and fulvic substances. Clay minerals remove dissolved organic chromophores primarily through electrostatic attraction and surface adsorption mechanisms [32][33]. However, recent findings suggest that single-component clay filters often reach adsorption saturation more quickly under high organic loading

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conditions, limiting their capacity to maintain a safety margin below regulatory threshold [31]. This explains why Setup A complied only marginally under Trial 1 conditions.

In contrast, Setup C exhibited the poorest performance with a significantly elevated effluent color of 126 CU. Early-stage leaching of residual organic compounds from the filter matrix, in addition to the reduced adsorption capacity, is a probable cause of this unexpected increase. Nipa fiber ash and other biomass-derived components may contain incompletely combusted organic residues when fired at 500°C, as full thermal decomposition of lignocellulosic materials typically requires higher temperatures above 600°C [7]. Upon initial wetting, these residual compounds may dissolve and contribute additional chromophoric substances to the effluent. Similar observations have been reported in ceramic filter studies, where newly fabricated composite filters release soluble organic residues during initial operation before stabilizing [23][30]. This interpretation is supported by the rapid drop in Trial 2's Setup C color to 20 CU, which confirms a conditioning or stabilization effect.

Setup D recorded a moderate but non-compliant effluent color of 30 CU, reflecting the combined influence of increased porosity and reduced adsorption contact time. Although seashell-derived calcium carbonate and clay minerals provide potential adsorption sites, the higher porosity of this composition increases flow rate and reduces hydraulic retention time, limiting the interaction between dissolved chromophoric compounds and reactive surfaces. Studies in porous media filtration indicate that adsorption efficiency is strongly dependent on contact time, with higher flow velocities reducing the probability of solute–surface interactions [17][31]. Consequently, despite having reactive materials, Setup D's structural characteristics constrained its ability to achieve full color removal during the initial filtration cycle.

Overall, the results demonstrate that color removal efficiency in ceramic filters is strongly governed by matrix composition, surface chemistry, and early-stage conditioning effects. Composite formulations such as Setup B provide superior performance due to synergistic adsorption mechanisms, while pure clay systems offer moderate but limited removal capacity. Early-cycle anomalies, particularly in Setup C, highlight the importance of filter stabilization before steady-state performance evaluation, consistent with recent ceramic filtration studies [23][31].

3.2.4 Total Dissolved Solids (TDS)

Total Dissolved Solids (TDS) represents the aggregate concentration of all dissolved inorganic and organic substances in water — encompassing dissolved salts, minerals, metals, and other ionically dissolved species that pass through a 2-micron filter membrane. Elevated TDS reduces the palatability of drinking water, increases its corrosivity and scaling potential, and may adversely affect domestic uses including cooking, laundering, and household appliance longevity (MWH, 2005). The PNSDW (2017) sets a maximum allowable TDS of 600 mg/L. In ceramic filtration, TDS reduction is achieved through ion exchange at clay mineral surface sites, adsorption of dissolved ionic species onto reactive pore surfaces, and diffusion resistance within the tortuous pore pathways of the ceramic matrix — mechanisms that are significantly influenced by pore geometry, hydraulic retention time, and the chemical composition of the filter media [35].

TABLE 6. *Trial 1 TDS results across all filter setups.*

Sample	Trial 1 (mg/L)	PNSDW Standard
Raw Water	1,160	≤600 mg/L
Setup A	427	≤600 mg/L
Setup B	1,131	≤600 mg/L
Setup C	830	≤600 mg/L
Setup D	1,153	≤600 mg/L

As shown in Table 6, only Setup A achieved PNSDW-compliant total dissolved solids (TDS) in Trial 1, recording 427 mg/L from an influent of 1,160 mg/L. This represents substantial removal efficiency and reflects the stability of the pure clay matrix in promoting consistent ion-exchange behavior without interference from soluble additives. In contrast, Setups C and D recorded non-compliant TDS values of 830 mg/L and 1,153 mg/L, respectively, indicating limited net removal. The most notable result is Setup B, which produced an effluent TDS of 1,131 mg/L, nearly equivalent to the influent, indicating negligible removal during the first filtration cycle. Recent studies on ceramic and ash-modified filtration media confirm that early-stage performance variability in TDS is commonly associated with leaching of soluble inorganic constituents from fresh composite materials prior to stabilization [31][37].

The anomalous performance of Setup B is strongly attributed to mineral leaching from its composite additives, particularly nipa fiber ash and seashell-derived calcium carbonate. These materials contain readily soluble ions such as Ca^{2+}, K^{+}, Na^{+}, and carbonate species that can be released upon initial contact with water, temporarily increasing effluent TDS and offsetting removal via clay ion exchange. Biomass ash materials are widely documented to exhibit high initial solubility due to the presence of loosely bound alkali and alkaline earth metal salts, which are rapidly depleted during early wetting cycles [37]. The sharp improvement observed in Trial 2, where Setup B TDS dropped significantly, further supports the interpretation that the system undergoes rapid chemical conditioning after initial leaching.

In contrast, Setup A demonstrated stable and effective TDS reduction due to the dominance of clay mineral ion-exchange processes. Clay minerals possess permanent negative surface charges resulting from isomorphous substitution within their crystalline structure, enabling the attraction and exchange of dissolved cations in water [32]. This mechanism is particularly effective under low-flow conditions, where extended hydraulic retention time enhances ion-surface interactions. Recent studies confirm that ceramic filters composed primarily of clay exhibit more consistent dissolved solids reduction due to stable surface chemistry and

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reduced risk of solute release compared to composite or ash-amended systems [18][31].

Setups C and D recorded non-compliant TDS levels of 830 mg/L and 1,153 mg/L, respectively, which reflect the combined effects of reduced ion-exchange capacity and increased hydraulic conductivity. The higher seashell powder content in these formulations increases microporosity and reduces pore tortuosity, resulting in shorter contact time between water and reactive clay surfaces. This limits the effectiveness of cation exchange processes responsible for TDS reduction. Studies on porous ceramic filtration systems show that increased pore size and flow rate significantly reduce dissolved ion removal efficiency due to decreased residence time and reduced surface interaction probability [22][35]. Consequently, despite containing reactive components, Setups C and D were unable to achieve regulatory compliance during the initial filtration cycle.

3.2.5 Nitrate

Nitrate (NO_3^-) is a highly soluble inorganic contaminant commonly introduced into water through agricultural runoff, fertilizer leaching, and decomposition of nitrogenous wastes. It poses serious health risks when present above 50 mg/L, particularly methemoglobinemia in infants, where oxygen transport in the blood is impaired [38]. Both WHO (2017) and the Philippine National Standards for Drinking Water (PNSDW, 2017) set the maximum allowable limit at 50 mg/L to protect public health. Chemically, nitrate is a stable, negatively charged ion that is generally not effectively removed by conventional ceramic filtration because clay mineral surfaces also carry a net negative charge, leading to electrostatic repulsion and limited adsorption capacity [5][32].

TABLE 7. *Trial 1 nitrate results across all filter setups.*

Sample	Trial 1 (mg/L)	PNSDW Standard
Raw Water	<0.4	≤50 mg/L
Setup A	<0.4	≤50 mg/L
Setup B	<0.4	≤50 mg/L
Setup C	2.7[a]	≤50 mg/L
Setup D	<0.4	≤50 mg/L

[a] *Setup C Trial 1 effluent nitrate of 2.7 mg/L exceeded the raw water value (<0.4 mg/L), indicating initial nitrate leaching from filter materials; see discussion below.*

As shown in Table 7, the Trial 1 influent and most effluent nitrate concentrations were below the analytical detection threshold of <0.4 mg/L, indicating negligible dissolved nitrate in the Trial 1 synthetic influent — consistent with the absence of specific nitrate supplementation in the Trial 1 water formulation and the insufficient elapsed time for significant microbial nitrification to have occurred in the synthetic water body at the time of the first trial. The sole exception was Setup C, whose effluent registered 2.7 mg/L — a concentration exceeding the influent value itself — unambiguously indicating that the filter was a net nitrate source during this initial cycle rather than a removal medium.

This anomaly is most plausibly attributable to nitrate leaching from organic nitrogen compounds retained within the Nipa Fiber Ash component of Setup C's formulation following the 500°C firing process. Nipa palm fiber contains organic nitrogen-bearing lignocellulosic constituents — including proteins, nucleic acids, and nitrogen-containing structural polymers — that, when incompletely combusted at sub-500°C firing temperatures, may retain nitrogenous residues within the resulting ash matrix. Under moist conditions during the initial filter pre-saturation or the first filtration cycle, these residual nitrogen-bearing organic fractions can undergo partial chemical or microbially mediated oxidative decomposition, releasing nitrate as a terminal oxidized nitrogen end-product into the filtered water [7]. This leaching mechanism is consistent with the nitrogen release dynamics documented by [37] for biomass-derived ash systems, who observed that incompletely calcined organic nitrogen fractions in plant-based ash materials are selectively mobilized as soluble nitrogen oxyanions upon initial aqueous contact — a process that is largely completed within the first contact cycle, after which nitrate release stabilizes at substantially lower levels in subsequent filtration cycles.

It is notable that this nitrate leaching anomaly was observed specifically in Setup C and not in Setup B, despite both setups incorporating Nipa Fiber Ash. This selectivity may reflect the combined influence of Setup C's higher seashell content (30% vs. 20% in Setup B) — which produces a more open, macroporous matrix that allows greater water-to-ash contact and more complete extraction of soluble nitrogen fractions during the initial cycle — and the specific spatial distribution of incompletely calcined ash residues within each setup's ceramic body. Despite this isolated anomaly, all effluent nitrate values, including Setup C's 2.7 mg/L, remained substantially below the PNSDW maximum of 50 mg/L, confirming full regulatory compliance across all filter setups in Trial 1. The leaching anomaly in Setup C was entirely absent in Trial 2, confirming that the responsible nitrogen-bearing fractions were effectively depleted from the filter matrix during the Trial 1 conditioning cycle, consistent with the single-cycle stabilization behavior documented by [37].

3.3 Physicochemical Water Analysis for Trial 2 (March 4, 2026)

Trial 2 was conducted on March 4, 2026, approximately one month after Trial 1, to assess the physicochemical filtration performance of each ceramic clay filter prototype under conditioned operational conditions. This trial represents the more operationally stable and representative state of the filters, as the initial conditioning cycle in Trial 1 depleted readily soluble surface mineral fractions, expelled loosely bound ceramic debris from pore surfaces, and allowed the internal pore structure and surface chemistry of each filter to approach a more stable physicochemical equilibrium [14][36].

3.3.1 pH

Trial 2 evaluated the ceramic clay filter prototypes under more stable, conditioned operating conditions following the initial stabilization phase in Trial 1, where loosely bound materials were removed and pore structures reached greater

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equilibrium [14][36]. For pH, all effluent values remained within the PNSDW 2017 acceptable range of 6.5 to 8.5, as shown in Table 7, indicating that none of the filter setups introduced harmful acidity or alkalinity into the treated water. Minor variations in pH were attributed to ion-exchange reactions within clay minerals and potential carbonate dissolution from seashell-based components, both of which can slightly influence alkalinity but generally remain within safe drinking water limits [12][38].

TABLE 8. *Trial 2 pH results across all filter setups.*

Sample	Trial 2 pH	PNSDW Standard
Raw Water	8.15	6.5–8.5
Setup A	8.14	6.5–8.5
Setup B	7.82	6.5–8.5
Setup C	7.86	6.5–8.5
Setup D	8.06	6.5–8.5

As presented in Table 8, all four ceramic filter setups produced effluent pH values within the PNSDW 2017 acceptable range of 6.5 to 8.5 during Trial 2, confirming chemical stability under conditioned operational conditions. The effluent pH values ranged narrowly from 7.82 in Setup B to 8.14 in Setup A, closely approximating the influent pH of 8.15. This limited variation indicates that all filter configurations-maintained equilibrium with the influent water chemistry, consistent with findings that ceramic filtration systems generally do not substantially alter pH unless highly reactive additives are present in significant amounts [19][38].

Setup A recorded an effluent pH of 8.14, nearly identical to the influent value of 8.15, indicating negligible chemical alteration during filtration. This stability reflects the inert behavior of the pure clay matrix under conditioned operation, where major leachable components have already been removed during initial use cycles. Any slight deviation can be attributed to clay mineral ion-exchange processes, where surface sites exchange hydrogen ions with dissolved cations, producing minor buffering effects that slightly adjust pH without significantly altering overall water chemistry [32]. This confirms that pure clay ceramics provide stable pH performance under steady-state conditions.

Setup D produced an effluent pH of 8.06, representing the most noticeable deviation from the influent among all setups. This slight reduction is attributed to the interaction between the clay fraction and the high proportion of seashell-derived calcium carbonate. Carbonate materials can dissolve gradually, releasing bicarbonate ions that contribute to buffering reactions in water and influence pH stability over time [33]. Recent studies on carbonate-amended ceramic filters have shown that $CaCO_3$-based additives can induce mild shifts in pH depending on dissolution dynamics and equilibration with dissolved CO_2, particularly during early operational cycles [12].

Setups B and C recorded effluent pH values of 7.82 and 7.86, respectively, reflecting a more balanced interaction between clay ion-exchange buffering and carbonate contribution from seashell components. Their intermediate compositions reduce the dominance of either alkalinizing or buffering processes, resulting in values slightly lower than the influent but still within a stable neutral-to-slightly-alkaline range. This behavior is consistent with ceramic filtration systems containing mixed mineral phases, where competing surface reactions moderate pH fluctuations under continuous flow conditions [13][18]. Overall, all setups maintained full compliance with PNSDW 2017 standards, confirming that the composite ceramic filters provide chemically stable effluent water suitable for potable use under conditioned operational conditions.

3.3.2 Turbidity

Turbidity is the cloudiness of water caused by suspended particles such as clay, silt, organic matter, and microorganisms. It is an important water quality indicator because high turbidity can shield pathogens from disinfection processes, reducing treatment effectiveness [9][38]. The PNSDW 2017 sets a maximum allowable limit of 5 NTU. The removal of turbidity in ceramic filtration systems takes place through physical straining, depth filtering, and particle entrapment within the pore structure, all of which are influenced by the pore size, uniformity, and tortuosity [8]. Trial 2 turbidity results were assessed using an influent value of 35.2 NTU and reflect conditioned filter performance after ripening, providing a more reliable indication of long-term filtration efficiency compared to initial-cycle results [14][28].

TABLE 9. *Trial 2 turbidity results and removal efficiencies.*

Sample	Trial 2 Result (NTU)	PNSDW Standard	Removal Efficiency (%)
Raw Water	35.2	≤5 NTU	—
Setup A	12.6	≤5 NTU	64.2%
Setup B	1.63	≤5 NTU	95.4%
Setup C	9.35	≤5 NTU	73.4%
Setup D	23.6	≤5 NTU	32.9%

As shown in Table 8, turbidity removal performance varied significantly across the four ceramic filter prototypes under Trial 2 conditions, with influent turbidity of 35.2 NTU. Setup B achieved full compliance with the PNSDW 2017 standard, recording the lowest effluent turbidity of 1.63 NTU and the highest removal efficiency of 95.4%. This superior performance is attributed to its optimized composite pore structure, where clay sintering, Nipa fiber ash burnout, and seashell-derived void formation collectively create a multi-scale filtration network. Recent studies on ceramic water filtration confirm that heterogeneous pore systems enhance turbidity removal by enabling sequential particle capture across macro- and micropores, while maintaining hydraulic conductivity through interconnected pathways [31], [23]. The ripening effect of the filters is improved by this structural variety, which enables gradual pore refining through particle deposition, increasing the long-term efficiency of filtration [14], [28].

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Setup A recorded an effluent turbidity of 12.6 NTU with a removal efficiency of 64.2%, failing to meet the PNSDW standard despite its dense 100% clay matrix. While clay ceramics generally provide strong initial particle retention due to small pore sizes and high tortuosity, recent studies indicate that single-material clay filters are more susceptible to performance decline under continuous operation due to surface instability and limited structural reinforcement [31]. Additionally, minor release or mobilization of loosely sintered particles from pore surfaces can contribute to elevated effluent turbidity during sustained flow conditions [22]. These limitations explain the moderate performance of Setup A despite its inherently compact pore structure.

Setup C achieved intermediate performance, with an effluent turbidity of 9.35 NTU and a removal efficiency of 73.4%. This result reflects partial improvement due to the inclusion of seashell powder and Nipa fiber ash, which introduce additional pore-forming effects but also reduce pore tortuosity compared to Setup B. Although composite ceramic systems generally enhance filtration performance, excessive or imbalanced additive proportions can create larger interconnected pore channels that reduce fine particle retention efficiency [23], [18]. Consequently, Setup C demonstrated improved performance over Setup A but remained insufficient for full compliance due to suboptimal pore architecture and moderate hydraulic conditions.

Setup D exhibited the poorest performance, with an effluent turbidity of 23.6 NTU and a removal efficiency of only 32.9%, indicating limited particle capture under conditioned operation. This poor performance is attributed to its high seashell content and resulting highly porous structure, which increases pore size and reduces filtration resistance. Combined with the highest flow rate among all setups, this configuration significantly reduced hydraulic retention time, limiting particle–surface interactions necessary for effective removal. Recent research confirms that increased flow velocity and macroporosity in ceramic filters are strongly associated with reduced turbidity removal efficiency due to shortened contact time and insufficient depth filtration development [31], [8]. Overall, the results demonstrate that optimal turbidity removal is achieved through a balanced pore structure that supports both filtration resistance and progressive pore refinement, as exemplified by Setup B.

3.3.3 Color

Apparent color in water is mainly caused by dissolved organic substances such as humic and fulvic acids, as well as iron, manganese, and tannins [34]. Although not always directly harmful at low levels, high color reduces aesthetic water quality and indicates the presence of organic precursors that may form disinfection by-products during chlorination [9]. The PNSDW 2017 sets a limit of ≤15 CU. In ceramic filtration systems, color removal occurs primarily through adsorption onto pore surfaces, with minor contributions from physical straining and diffusion into micropores [3]. Trial 2 used an influent color of 760 CU, representing a highly demanding condition due to accumulated organic compounds over time, thereby testing the sustained adsorption capacity of each filter under conditioned operation.

TABLE 10. *Trial 2 color results and removal efficiencies.*

Sample	Trial 2 Result (CU)	PNSDW Standard	Removal Efficiency (%)
Raw Water	760	≤15 CU	—
Setup A	21	≤15 CU	97.3%
Setup B	11	≤15 CU	97.7%
Setup C	20	≤15 CU	97.4%
Setup D	600	≤15 CU	20.7%

As presented in Table 10, Trial 2 color removal performance varied significantly across the four ceramic filter prototypes under an influent color loading of 760 CU, which represents highly elevated dissolved organic contamination. Setup B achieved full compliance with the PNSDW 2017 standard, producing an effluent of 11 CU and the highest removal efficiency of 97.7%. This superior performance reflects the synergistic adsorption mechanisms of its multi-component ceramic matrix, where clay minerals provide electrostatic adsorption sites for humic substances, while Nipa fiber ash increases microporosity and internal surface area, and seashell-derived carbonate phases contribute additional reactive surface sites for organic compound interaction. Recent studies confirm that multi-phase ceramic media significantly enhance dissolved organic matter removal due to the combined effects of surface adsorption diversity and pore-scale diffusion pathways, enabling more efficient capture of chromophoric compounds under high organic loading conditions [3], [31].

Setup A recorded an effluent color of 21 CU with a 97.3% removal efficiency, indicating strong adsorption performance but marginal non-compliance with the 15 CU standard. Despite its high removal percentage, the pure clay matrix reached its adsorption capacity limit under the elevated influent concentration, highlighting the practical limitation of single-component systems under high organic loads. Clay minerals such as smectites effectively adsorb humic and fulvic substances through electrostatic attraction and surface complexation; however, their finite number of active sites leads to saturation effects at high contaminant concentrations [32], [33]. Recent adsorption studies in ceramic filtration systems confirm that performance decline at high influent concentrations is primarily driven by site saturation rather than loss of structural integrity, explaining Setup A's inability to consistently meet regulatory thresholds despite high percentage removal [31].

Setup C produced an effluent of 20 CU with a 97.4% removal efficiency, also failing to meet compliance despite performance comparable to Setup A. This result reflects the intermediate composition of the filter, where reduced clay content and increased seashell proportion alter both adsorption capacity and hydraulic retention time. While the inclusion of Nipa fiber ash and carbonate phases introduces additional adsorption pathways, excessive porosity and higher flow velocity reduce contact time between dissolved organic compounds and reactive surfaces. Studies on porous ceramic

filtration systems show that increased flow rates negatively affect adsorption efficiency by limiting diffusion and surface interaction opportunities, even when multi-component media are used [17], [18]. Consequently, Setup C's structural balance was insufficient to achieve full compliance under extreme influent loading.

Setup D exhibited the poorest performance, with an effluent color of 600 CU and only 20.7% removal efficiency, indicating severe failure of the adsorption system. This behavior is attributed to its high seashell content and low firing temperature, which likely resulted in incomplete calcination of calcium carbonate and structural instability of the ceramic matrix. Inadequately fired carbonate materials can undergo partial dissolution or structural weakening under continuous aqueous exposure, reducing effective surface area and pore integrity over time [33]. Recent studies on ceramic water filters confirm that excessive carbonate incorporation without sufficient thermal stabilization can lead to progressive loss of adsorption capacity due to pore collapse and surface degradation [30], [23]. This explains the drastic decline in performance observed in Setup D compared to all other configurations.

Overall, the results demonstrate that color removal efficiency in ceramic filtration systems is strongly governed by a balance between adsorption site diversity, pore structure, and hydraulic retention time. Multi-component systems such as Setup B provide optimal performance through synergistic mechanisms, while imbalanced or structurally unstable compositions significantly reduce long-term adsorption effectiveness under high organic loading conditions.

3.3.4 Total Dissolved Solids (TDS)

TDS removal in Trial 2 was evaluated against the PNSDW 2017 maximum of 600 mg/L, with removal efficiencies computed from the Trial 2 influent value of 946 mg/L, as shown in Table 10. The Trial 2 TDS assessment reveals the true ion-exchange and adsorption performance of each filter matrix in its conditioned, operationally stable state, free from the confounding early-stage leaching effects that affected certain setups during the initial filtration cycle.

TABLE 11. *Trial 2 TDS results and removal efficiencies.*

Sample	Trial 2 Result (mg/L)	PNSDW Standard	Removal Efficiency (%)
Raw Water	946	≤600 mg/L	—
Setup A	357	≤600 mg/L	62.3%
Setup B	195	≤600 mg/L	79.4%
Setup C	762	≤600 mg/L	19.5%
Setup D	845	≤600 mg/L	10.7%

As shown in Table 10, Trial 2 TDS removal performance varied considerably across the four ceramic filter prototypes, with an influent concentration of 946 mg/L exceeding the PNSDW 2017 limit of ≤600 mg/L. Only Setups A and B achieved compliance, with Setup B demonstrating the highest removal efficiency of 79.4% and the lowest effluent TDS of 195 mg/L. This superior performance reflects the synergistic interaction of clay ion-exchange sites with additional reactive surfaces introduced by Nipa fiber ash and seashell components. Recent studies on composite ceramic filtration confirm that multi-mineral systems enhance dissolved ion removal by increasing surface heterogeneity and expanding the range of available adsorption and exchange mechanisms [31], [23]. In addition, [35] emphasized that optimal TDS reduction occurs when high reactive surface area is combined with sufficient hydraulic residence time, both of which are maximized in Setup B due to its balanced composition and moderate flow rate.

Setup A achieved compliant performance with an effluent TDS of 357 mg/L and a removal efficiency of 62.3%, demonstrating the stable ion-exchange capacity of a pure clay matrix. Clay minerals possess permanent negative structural charges resulting from isomorphous substitution within their crystal lattice, allowing effective cation exchange with dissolved ions in water [32]. This mechanism is highly dependent on contact time and pore accessibility, both of which are enhanced by Setup A's low flow rate of 5.0 mL/min and highly tortuous pore network. Recent ceramic filtration studies confirm that single-material clay filters provide consistent but moderate TDS reduction due to limited but stable ion-exchange capacity compared to composite systems [31], [18]. This explains Setup A's reliable compliance despite lower performance than Setup B.

In contrast, Setups C and D remained non-compliant, with effluent TDS values of 762 mg/L and 845 mg/L and removal efficiencies of 19.5% and 10.7%, respectively. These poor outcomes reflect the combined effects of reduced clay content and increased seashell proportion, which dilute the ion-exchange capacity of the ceramic matrix. As seashell powder content increases, the proportion of active clay surface area decreases, directly reducing the number of available cation exchange sites responsible for dissolved ion removal [22]. Additionally, higher flow rates in these setups (10.0 and 14.2 mL/min) significantly reduce hydraulic retention time, limiting the interaction between dissolved ions and reactive surfaces. Studies on porous filtration systems confirm that increased porosity and flow velocity lead to hydraulic short-circuiting, where water bypasses active adsorption zones, thereby reducing TDS removal efficiency [17], [31].

Overall, the results demonstrate a clear inverse relationship between seashell content, flow rate, and TDS removal efficiency. While composite systems can enhance performance when properly balanced, excessive seashell incorporation disrupts ion-exchange continuity and reduces effective surface contact. Setup B represents the optimal configuration, where sufficient clay content and controlled porosity enable high ion-exchange efficiency while maintaining hydraulic stability, consistent with recent findings on optimized ceramic water filtration media [23], [35].

3.3.5 Nitrate

Nitrate is a highly soluble inorganic contaminant commonly introduced into water through agricultural runoff, fertilizer leaching, and decomposition of nitrogenous wastes. It poses serious health risks above 50 mg/L, particularly

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methemoglobinemia (blue baby syndrome) in infants, where oxygen transport in the blood is impaired [38]. Both [38] and PNSDW (2017) [10] set the maximum allowable limit at 50 mg/L. Chemically, nitrate is a stable, negatively charged ion that is difficult to remove using conventional ceramic filtration due to electrostatic repulsion from negatively charged clay mineral surfaces, which limits adsorption capacity [32], [5]. As shown in Table 11, the influent nitrate concentration was 6.89 mg/L, remaining within regulatory limits and likely resulting from gradual nitrification processes during storage, providing a low but measurable baseline for evaluating apparent removal performance.

TABLE 12. *Trial 2 nitrate results and removal efficiencies.*

Sample	Trial 2 Result (mg/L)	PNSDW Standard	Removal Efficiency (%)
Raw Water	6.89	≤50 mg/L	—
Setup A	0.63	≤50 mg/L	90.8%
Setup B	0.16	≤50 mg/L	97.7%
Setup C	0.38	≤50 mg/L	94.5%
Setup D	0.48	≤50 mg/L	93.0%

As shown in Table 11, all filter setups produced effluent nitrate concentrations well below the PNSDW 2017 limit of 50 mg/L during Trial 2, with values ranging from 0.16 mg/L (Setup B) to 0.63 mg/L (Setup A). Corresponding apparent removal efficiencies ranged from 90.8% to 97.7%, with Setup B achieving the highest performance. The influent concentration of 6.89 mg/L was already low relative to the regulatory threshold, representing only 13.8% of the allowable limit. This confirms that all effluent values remained safely within drinking water standards; however, the magnitude of "removal efficiency" should be interpreted cautiously due to the well-established limitations of ceramic filtration for nitrate reduction [38].

From a physicochemical perspective, nitrate is a stable, monovalent anion that is not effectively removed by conventional ceramic filtration mechanisms. Clay mineral surfaces possess a permanent negative charge due to isomorphous substitution, which leads to electrostatic repulsion of anions such as NO_3^- and limits adsorption or ion-exchange interactions [32]. Similarly, [5] emphasize that common porous media, including clays and ceramics, exhibit anion exclusion behavior under normal environmental pH conditions, preventing meaningful nitrate retention at the solid–liquid interface. Therefore, true chemical removal of nitrate in ceramic filters is generally not expected, and any observed concentration decreases must be attributed to non-reactive processes rather than adsorption.

The observed reductions in nitrate concentration across all setups are most plausibly explained by physical and hydraulic effects rather than true chemical removal. These include dilution from residual low-nitrate pore water retained from previous filtration cycles, which mixes with the incoming influent and lowers measured effluent concentrations, as well as transient transport lag within the tortuous pore network of the ceramic matrix [27]. In addition, diffusion-limited mass transfer within the porous structure can create short-term non-equilibrium conditions, particularly during early sampling periods, leading to temporarily reduced effluent concentrations [5]. The lack of a consistent trend between filter composition, flow rate, and nitrate "removal efficiency" further supports the conclusion that these reductions are not governed by adsorption or ion exchange mechanisms.

Despite these interpretive limitations, all setups achieved full compliance with the PNSDW 2017 nitrate limit, confirming that the effluent water remained safe with respect to nitrate content under the study conditions. However, this compliance is primarily attributable to the low influent nitrate level rather than any intrinsic nitrate removal capability of the ceramic filters. Consequently, the results do not demonstrate effective treatment of nitrate-contaminated water at environmentally relevant concentrations. Future evaluations should therefore employ higher influent nitrate levels approaching regulatory limits under true steady-state conditions to accurately assess any potential nitrate attenuation mechanisms in ceramic filtration systems, in line with [38] recommendations for rigorous point-of-use water treatment assessment.

3.4 Hydraulic Performance of Filter Setups

The hydraulic performance of the cylindrical ceramic clay filter prototypes was evaluated based on the volume of water filtered within a one-hour period and the corresponding computed flow rate for each setup. Hydraulic behavior is a critical operational parameter in ceramic water filtration because it governs hydraulic retention time, water-to-surface contact duration, and the overall efficiency of physicochemical contaminant removal. Variations in hydraulic performance among the prototypes primarily reflect differences in pore structure, pore connectivity, and ceramic matrix density resulting from the varying proportions of clay, Nipa Fiber Ash, and seashell powder incorporated into each composition and their structural transformation during firing at 500°C. Recent studies have emphasized that ceramic filter permeability is strongly controlled by additive composition and pore-forming material burnout, which directly influence pore diameter distribution and internal tortuosity within the fired ceramic matrix [16], [1].

All four filter prototypes possessed identical physical dimensions, consisting of a 16 cm height, 5 cm outer diameter, and a 2 cm outlet opening, and were operated under identical gravity-fed conditions throughout the experimental period. Despite these uniform design conditions, substantial differences in filtration volume and flow rate were observed, confirming that material composition was the principal determinant of hydraulic behavior.

Setup A exhibited the lowest hydraulic throughput, filtering only 300 mL/hr at a flow rate of 5.0 mL/min. This behavior is attributed to the dense and compact microstructure produced by the 100% clay composition. During firing, clay particles undergo partial vitrification and compaction, generating a ceramic body characterized by fine pore

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channels, high pore tortuosity, and limited interconnected void spaces. Similar hydraulic behavior has been reported in [4], which observed that pure clay ceramic filters generally exhibit lower permeability due to their compact microstructure and reduced macroporosity. Although the low flow rate restricts water production capacity, the extended hydraulic retention time improves adsorption and ion-exchange processes by prolonging contact between the water and the reactive clay mineral surfaces. This prolonged retention time contributed to Setup A's comparatively strong TDS reduction performance despite its non-compliance for turbidity and color.

TABLE 13. *Hydraulic performance of ceramic clay filter setups.*

Setup	Composition	Volume Filtered (1 hr)	Flow Rate (mL/min)	Hydraulic Behavior
A	100% Clay	300 mL	5.0	Slow filtration; high resistance; long hydraulic retention time
B	60% Clay, 20% Nipa Fiber Ash, 20% Seashell	420 mL	7.0	Balanced flow; optimal retention time; best overall physicochemical performance
C	50% Clay, 20% Nipa Fiber Ash, 30% Seashell	600 mL	10.0	Moderately fast flow; reduced but acceptable retention time
D	40% Clay, 10% Nipa Fiber Ash, 50% Seashell	850 mL	14.2	Very fast flow; low retention time; reduced physicochemical filtration contact

Setup D produced the highest hydraulic throughput, filtering 850 mL/hr at a flow rate of 14.2 mL/min, nearly three times higher than Setup A. The elevated flow rate is directly associated with the high seashell powder content (50%) and reduced clay fraction (40%), which generated a highly porous ceramic matrix with large interconnected pore channels. Recent investigations in [6] demonstrated that increasing calcium carbonate-based additives in ceramic filters significantly increases porosity and permeability by reducing matrix densification during firing. The coarse particle structure of seashell powder inhibits close particle packing and leaves substantial inter-particle void spaces after firing. However, the high permeability of Setup D negatively affected physicochemical treatment efficiency. The reduced hydraulic retention time limited suspended particle capture, adsorption of dissolved organic compounds, and ion exchange interactions, which corresponded with its poor Trial 2 turbidity (23.6 NTU), color (600 CU), and TDS (845 mg/L) performance. Similar inverse relationships between flow rate and contaminant removal efficiency have been documented in porous ceramic filtration systems in [11], which reported that excessive permeability reduces effective contaminant-surface interaction time.

Setup C exhibited an intermediate hydraulic performance, filtering 600 mL/hr at a flow rate of 10.0 mL/min. The moderate increase in seashell powder content relative to Setup B increased porosity and hydraulic conductivity, while the remaining clay fraction maintained partial structural compactness and pore tortuosity. Consequently, Setup C demonstrated moderate contaminant removal efficiency but failed to achieve PNSDW compliance for turbidity, color, and TDS. The moderate flow behavior observed in Setup C is consistent with findings in [24], which reported that partially porous ceramic composites may achieve improved water production rates but often exhibit reduced adsorption efficiency due to shortened hydraulic residence time.

Among all prototypes, Setup B demonstrated the most balanced hydraulic behavior and overall treatment performance. The setup filtered 420 mL/hr at a flow rate of 7.0 mL/min, providing a practical filtration rate while maintaining sufficient hydraulic retention time for effective physicochemical treatment. The balanced combination of 60% clay, 20% Nipa Fiber Ash, and 20% seashell powder generated a heterogeneous pore network containing both micro- and macropore structures, enabling adequate water permeability without excessively compromising pore tortuosity. Studies in [15] and [13] have shown that composite ceramic filters incorporating moderate pore-forming additives commonly achieve superior operational balance between permeability and contaminant removal due to optimized pore connectivity and internal surface area. This balanced hydraulic behavior was reflected in Setup B's superior Trial 2 removal efficiencies for turbidity (95.4%), color (97.7%), and TDS (79.4%), as well as its compliance with PNSDW standards for turbidity and color.

Overall, the results demonstrate a clear inverse relationship between hydraulic conductivity and physicochemical treatment efficiency across the four filter configurations. Increasing seashell powder content and decreasing clay proportion progressively enhanced water permeability but simultaneously reduced contaminant removal performance due to lower hydraulic retention time and reduced pore tortuosity. Similar trends have been consistently reported in recent ceramic filtration studies evaluating biomass-derived and carbonate-based additives in porous ceramic matrices [1], [6]. An effective household ceramic filter must therefore achieve a balanced combination of permeability and retention time to ensure both practical water production and regulatory-compliant water treatment performance.

Based on the combined hydraulic and physicochemical performance results, Setup B, consisting of 60% clay, 20% Nipa Fiber Ash, and 20% seashell powder, was identified as the optimum filter composition. It demonstrated the most favorable balance between hydraulic conductivity and contaminant removal efficiency while consistently maintaining PNSDW-compliant water quality parameters under conditioned operational conditions.

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REFERENCES

[1] Abdullahi, M., Musa, A., & Sani, I. (2022). Hydraulic conductivity and contaminant removal performance of porous ceramic water filters produced from clay composite materials. Journal of Water Process Engineering, 47, 102731. https://doi.org/10.1016/j.jwpe.2022.102731

[2] Abed, S. N., Almuktar, S. A., & Scholz, M. (2020). Long-term physicochemical changes in stored synthetic wastewater under ambient environmental conditions. Environmental Technology & Innovation, 20, 101102. https://doi.org/10.1016/j.eti.2020.101102

[3] Ahammed, M. M., & Meera, V. (2010). Water quality improvements from household-based ceramic water filters: Assessment of microbial and physicochemical performance. Water Practice and Technology, 5(1), 1–9. https://doi.org/10.2166/wpt.2010.003

[4] Amin, M. T., Alazba, A. A., & Shafiq, M. (2020). Comparative performance of clay-based ceramic filters for household water treatment applications. Environmental Technology, 41(18), 2365–2376. https://doi.org/10.1080/09593330.2019.1576934

[5] Appelo, C. A. J., & Postma, D. (2005). Geochemistry, groundwater and pollution (2nd ed.). A. A. Balkema.

[6] Bello, O. S., Adegoke, K. A., & Oyewole, R. O. (2023). Influence of calcium carbonate additives on the porosity and permeability of ceramic filtration systems. Materials Today: Proceedings, 74, 438–445. https://doi.org/10.1016/j.matpr.2022.09.534

[7] Bridgwater, A. V. (2012). Review of fast pyrolysis of biomass and product upgrading. Biomass and Bioenergy, 38, 68–94. https://doi.org/10.1016/j.biombioe.2011.01.048

[8] Brown, J., Sobsey, M. D., & Loomis, D. (2007). Local drinking water filters reduce diarrheal disease in Cambodia: A randomized, controlled trial of the ceramic water purifier. American Journal of Tropical Medicine and Hygiene, 79(3), 394–400. https://doi.org/10.4269/ajtmh.2008.79.394

[9] Crittenden, J. C., Trussell, R. R., Hand, D. W., Howe, K. J., & Tchobanoglous, G. (2012). MWH's water treatment: Principles and design (3rd ed.). John Wiley & Sons.

[10] Department of Health Philippines. (2017). Philippine National Standards for Drinking Water 2017 (Administrative Order No. 2017-0010). Department of Health.

[11] El-Khaiary, M. I., Malash, G. F., & Ho, Y. S. (2021). Effects of porosity and hydraulic retention time on contaminant removal in porous ceramic filtration systems. Journal of Environmental Chemical Engineering, 9(5), 106328. https://doi.org/10.1016/j.jece.2021.106328

[12] Hammer, M. J., Hammer, M. J., Jr., & MacFarland, D. (2015). Water and wastewater technology (8th ed.). Pearson.

[13] Ibrahim, H. K., Yusuf, A. S., & Salisu, L. (2023). Optimization of pore-forming additives in ceramic water filters for improved household water treatment. Results in Engineering, 18, 101085. https://doi.org/10.1016/j.rineng.2023.101085

[14] Lantagne, D. S. (2001). Investigation of the Potters for Peace colloidal silver impregnated ceramic filter: Report 2 – Field investigations. Alethia Environmental.

[15] Maharana, M., Patel, R., & Singh, P. (2021). Performance evaluation of porous ceramic water filters fabricated using biomass additives. Materials Today: Proceedings, 46, 10965–10971. https://doi.org/10.1016/j.matpr.2021.02.326

[16] Mashauri, D. A., Shayo, J., & Mdoe, J. (2021). Influence of pore-forming materials on the hydraulic properties of ceramic water filters. Physics and Chemistry of the Earth, 123, 103016. https://doi.org/10.1016/j.pce.2021.103016

[17] Metcalf & Eddy. (2014). Wastewater engineering: Treatment and resource recovery (5th ed.). McGraw-Hill.

[18] Mwabi, J. K., Dlamini, S., & Mahlangu, T. O. (2021). Evaluation of clay-based ceramic filters for household drinking water treatment applications. Water Supply, 21(5), 2390–2403. https://doi.org/10.2166/ws.2021.057

[19] Mwabi, J. K., Mamba, B. B., & Momba, M. N. B. (2012). Removal of waterborne pathogens from river water using small-scale membrane systems for household water treatment in rural communities of Southern Africa. Science of the Total Environment, 422, 151–164. https://doi.org/10.1016/j.scitotenv.2012.01.035

[20] MWH. (2005). Water treatment: Principles and design (2nd ed.). John Wiley & Sons.

[21] Ngwenya, N., Ncube, E. J., & Dube, T. (2022). Influence of pore-forming organic additives on ceramic water filter permeability and turbidity removal efficiency. Environmental Technology & Innovation, 27, 102490. https://doi.org/10.1016/j.eti.2022.102490

[22] Nkwonta, O. I., & Ochieng, G. M. (2009). Total dissolved solids removal in ceramic filtration systems using low-cost adsorptive materials. Physics and Chemistry of the Earth, 34(13–16), 995–1001. https://doi.org/10.1016/j.pce.2009.06.004

[23] Oaikhena, E. E., Okeke, C. U., & Egbosiuba, T. C. (2023). Performance evaluation of modified ceramic water filters for household water treatment applications. Journal of Water Process Engineering, 52, 103492. https://doi.org/10.1016/j.jwpe.2023.103492

[24] Ojedokun, A. T., Bello, O. S., & Akinyemi, B. A. (2022). Porosity–permeability relationships in biomass-modified ceramic filtration

materials. Materials Today: Proceedings, 62, 3575–3582. https://doi.org/10.1016/j.matpr.2022.03.147
[25] Omoniyi, T. E., Akinola, O. S., & Salami, A. O. (2022). Influence of clay mineral surface chemistry on pH stability during ceramic water filtration. Applied Water Science, 12(7), 163. https://doi.org/10.1007/s13201-022-01674-9
[26] Rantanen, P., Miettinen, I. T., & Keinänen-Toivola, M. M. (2020). Nitrification and nitrite formation in drinking water distribution systems: A review. Water Research, 176, 115725. https://doi.org/10.1016/j.watres.2020.115725
[27] Rao, N. S., & Mathur, P. (1994). Transport of ions through porous ceramic media under gravity filtration conditions. Journal of Membrane Science, 89(1–2), 65–74. https://doi.org/10.1016/0376-7388(94)85045-9
[28] Rayner, J., Skinner, B., & Lantagne, D. (2013). Current practices in manufacturing locally produced ceramic pot filters for water treatment in developing countries. Journal of Water, Sanitation and Hygiene for Development, 3(2), 252–261. https://doi.org/10.2166/washdev.2013.103
[29] Shi, P., Jia, S., Zhang, X., Zhang, T., Cheng, S., & Li, A. (2020). Metagenomic insights into nitrification and denitrification in drinking water systems. Water Research, 174, 115630. https://doi.org/10.1016/j.watres.2020.115630
[30] Simonis, J. J., & Basson, A. K. (2011). Manufacturing a low-cost ceramic micro-porous filter and silver-nanoparticle for use in a low-cost point-of-use water filtration system. Desalination, 275(1–3), 277–282. https://doi.org/10.1016/j.desal.2011.03.014
[31] Solomon, A. T., Desta, M. B., & Gebremedhin, K. G. (2023). Recent advances in clay-based ceramic water filters for household drinking water treatment: Physicochemical and microbial performance review. Environmental Technology Reviews, 12(1), 1–18. https://doi.org/10.1080/21622515.2023.2174587
[32] Sposito, G. (1989). The chemistry of soils. Oxford University Press.
[33] Stumm, W., & Morgan, J. J. (1996). Aquatic chemistry: Chemical equilibria and rates in natural waters (3rd ed.). John Wiley & Sons.
[34] Tchobanoglous, G., Burton, F. L., & Stensel, H. D. (2003). Wastewater engineering: Treatment and reuse (4th ed.). McGraw-Hill.
[35] Van der Bruggen, B., Vandecasteele, C., Van Gestel, T., Doyen, W., & Leysen, R. (2003). A review of pressure-driven membrane processes in wastewater treatment and drinking water production. Environmental Progress, 22(1), 46–56. https://doi.org/10.1002/ep.670220116
[36] van Halem, D., van der Laan, H., Heijman, S. G. J., van Dijk, J. C., & Amy, G. L. (2009). Assessing the sustainability of the silver-impregnated ceramic pot filter for low-cost household drinking water treatment. Physics and Chemistry of the Earth, 34(1–2), 36–42. https://doi.org/10.1016/j.pce.2008.01.006
[37] Vassilev, S. V., Baxter, D., Andersen, L. K., & Vassileva, C. G. (2013). An overview of the composition and application of biomass ash. Fuel, 105, 19–39. https://doi.org/10.1016/j.fuel.2012.09.041
[38] World Health Organization. (2017). Guidelines for drinking-water quality (4th ed., incorporating the 1st addendum). WHO.