

SAFE Capsule: Development of Post-Disinfection Capsule for Microbiological Removal in Water from Refilling Station

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Abstract—This study focused on the development and evaluation of a post-disinfection capsule designed to improve the microbiological quality of water from refilling stations stored in five-gallon containers. The capsule integrates controlled chemical disinfection using sodium dichloroisocyanurate (NaDCC) with a polishing stage consisting of activated carbon and ceramic media to provide additional protection against microbial contamination during storage. An experimental–developmental research design was employed. Synthetic contaminated water was prepared and distributed into twelve (12) containers representing four treatment groups: Control, Design A, Design B, and Design C, with three (3) replicates each. Samples were collected at baseline, after one (1) hour, and after twenty-four (24) hours of contact time. Microbiological analysis was conducted by a third-party laboratory to determine levels of *Escherichia coli*, thermotolerant coliforms, and total coliforms. Results showed that all baseline samples exhibited high microbial contamination. Minimal reduction was observed after one (1) hour of contact time. However, improved reduction was evident after twenty-four (24) hours, with Design C demonstrating the most consistent performance among the tested configurations. Despite these reductions, none of the treated samples achieved full compliance with bacteriological standards for drinking water.

Keywords—Post-disinfection capsule; water refilling station; microbiological water quality; sodium dichloroisocyanurate (NaDCC); activated carbon; silver-impregnated ceramic media; point-of-use water treatment.

I. INTRODUCTION

In Zamboanga City, water refilling stations are widely utilized, with approximately 378 facilities operating to supply drinking water to households. These households commonly use refillable five-gallon plastic containers due to their affordability and convenience. However, repeated container reuse, frequent handling, transportation, and prolonged storage significantly increase the risk of microbial contamination, including total coliforms and *Escherichia coli*. Studies on the quality of bottled water produced by water refilling stations have reported variability in bacteriological quality, indicating that not all stations consistently meet drinking water standards. These concerns highlight the need for an additional layer of protection against microbial contamination after water is dispensed from refilling stations. The *Sanitary Anti-Microbial Filtration Enhancer* (SAFE) Capsule is designed as a reusable post-disinfection device for standard five-gallon water containers to provide sustained microbial protection and

enhance the microbiological quality of gallon-refilled drinking water. The study aims to evaluate the capsule's effectiveness in reducing *E. coli*, thermotolerant coliforms, and total coliforms at baseline, 1 hour, and 24 hours; determine the compliance of treated water with the Philippine National Standards for Drinking Water (PNSDW, 2017); and compare three capsule configurations with varying NaDCC perforation sizes and media compositions. The study may contribute to the development of point-of-use and post-disinfection water treatment technologies for Filipino households, although its evaluation is limited to laboratory and semi-field microbiological testing using synthetic contaminated water and does not cover chemical pollutants, microplastics, heavy metals, pharmaceuticals, or large-scale community and commercial applications. The prototype was fabricated using natural, food-grade PETG and evaluated using four treatment groups—Control, Design A, Design B, and Design C—with three replicates per group.

II. METHODOLOGY

A. Research Design

An experimental–developmental research design was utilized to develop and evaluate a post-disinfection capsule for five-gallon water containers. The capsule integrates controlled NaDCC disinfection with activated carbon and silver-infused ceramic media. Its microbiological performance was evaluated using synthetic contaminated water, focusing on the reduction of *E. coli*, thermotolerant coliforms, and total coliforms under controlled laboratory conditions.

B. Design Calculation

The capsule design was based on flow and dosing requirements. It has an outer diameter of 46 mm, a length of 128 mm, and a wall thickness of 1.2 mm. The capsule consists of a NaDCC disinfection chamber with controlled dissolution holes and a polishing chamber containing activated carbon and ceramic media.

C. Design Procedure

The capsule was systematically designed using AutoCAD and Fusion 360 to ensure compatibility with standard five-gallon water container caps. Three configurations were developed: Design A, with a 0.6 mm NaDCC hole, 40 g GAC,

and 30 g silver-infused ceramic media; Design B, with a 1.0 mm NaDCC hole and the same media composition; and Design C, with a 0.6 mm NaDCC hole, 30 g GAC, and 40 g silver-infused ceramic media. The capsule consisted of a NaDCC chamber, polishing chamber, PETG housing, threaded closure, internal flow outlet, and twist-lock mechanism.

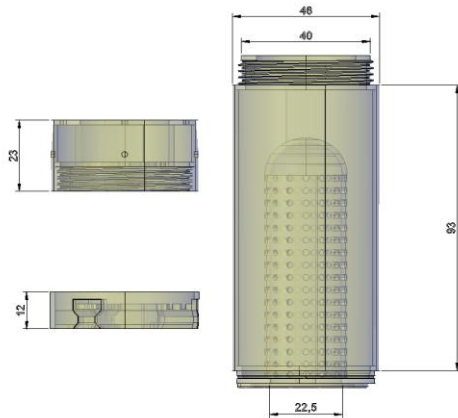


Figure 1. Capsule Overall Geometry and Key Dimensions

was fabricated with controlled perforations, while the polishing chamber was packed with GAC and silver-infused ceramic media secured by food-grade mesh. A twist-lock mechanism with a silicone ferrule was incorporated to securely attach the capsule to the five-gallon container cap.

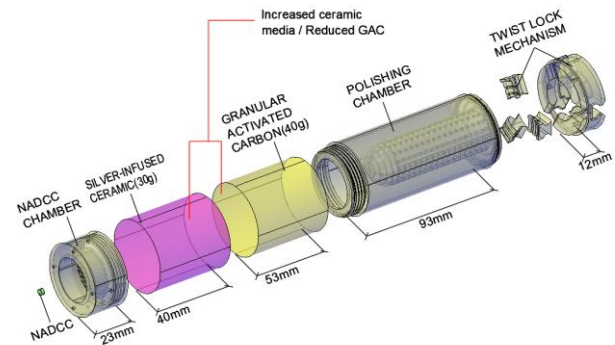


Figure 4. Design C – Modified Media Composition

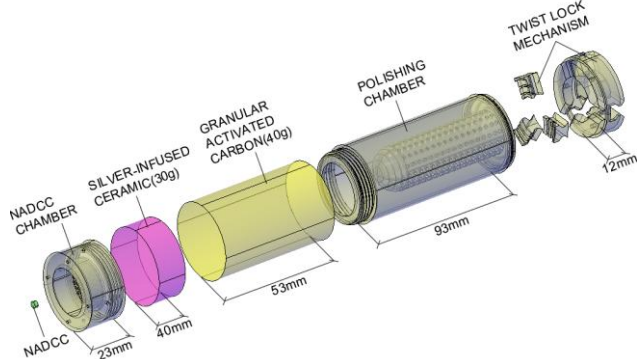


Figure 2. Design A – Baseline Configuration



Figure 5. 3D printing set up

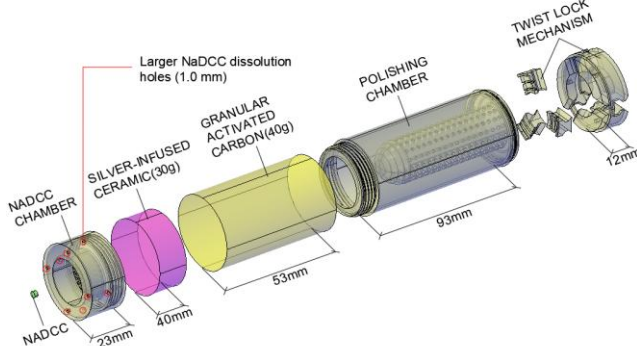


Figure 3. Design B – Modified NaDCC Perforation Size



Figure 6. The Actual Fabricated Capsule

D. Fabrication Process

The capsule was fabricated through FDM 3D printing using natural, food-grade PETG filament. The components were modeled, printed, cleaned, and subjected to UV-C surface sanitization before assembly. The NaDCC chamber

E. Experimental Setup and Procedure

The printed components were cleaned, disinfected, inspected, and assembled, with the NaDCC chamber fitted with mesh and a calibrated NaDCC tablet and the polishing chamber filled with pre-washed GAC and silver-infused ceramic beads. A twist-lock compression mechanism with a silicone O-ring was installed to secure the capsule inside the container cap, followed by leakage, attachment, and water-flow checks before microbiological testing. The experiment

was conducted in a controlled indoor workspace with washable flooring, adequate ventilation, restricted access, metal stands, and spill containment basins. All storage tanks, containers, and equipment were cleaned and disinfected using approximately 100 mg/L sodium hypochlorite solution with a 30-minute contact time before rinsing. For spill containment, inverted five-gallon containers were placed above plastic basins to collect spilled or leaked water. Microbiological testing for *E. coli*, thermotolerant coliforms, and total coliforms was conducted by CHEMPRO Laboratory in Tetuan, Zamboanga City, with results reported in CFU/100 mL or MPN/100 mL following PNSDW (2017) and relevant WHO guidelines. Synthetic contaminated water was prepared using commercially refilled drinking water inoculated with 50 g of fresh cow manure submerged in 260 L of water for 30 minutes, followed by gentle stirring and thorough mixing to achieve uniform microbial distribution, with a baseline sample collected to establish the initial condition. The experiment consisted of four groups—Control, Design A, Design B, and Design C—with three replicates each, using samples collected at baseline, 1 hour, and 24 hours, resulting in 25 microbiological samples. Appropriate biosafety measures, including the use of disposable gloves and protective masks and disinfection of work surfaces and equipment, were implemented throughout the experiment. Finally, contaminated wastewater was disinfected with sodium hypochlorite for at least 30 minutes before disposal, while solid organic materials and manure residues were sealed and disposed of according to local waste management practices.



Figure 7. Experimental Setup



Figure 8. Weighing of Cow Manure used as Contaminant for Synthetic Raw Water Preparation.



Figure 9. Developed Post-disinfection Capsule Showing Internal and External Components

F. Data Collection

The data analysis involved organizing laboratory results from the baseline, 1-hour, and 24-hour sampling periods to compare the microbiological performance of the Control and three capsule designs. Percent bacteriological reduction was not calculated because several results were reported as >8.0 MPN/100 mL, making exact reductions impossible for all samples. Instead, the results were interpreted using descriptive and comparative analysis and assessed against the PNSDW (2017). Microbial trends were also examined over time to determine whether treatment performance was sustained, improved, remained stable, declined, or showed possible regrowth. Due to the limited number of replicates and censored laboratory values, the study relied primarily on descriptive statistics, with results presented through tables, graphs, and comparative discussion rather than advanced statistical tests such as ANOVA.

III. RESULTS AND DISCUSSION

The chapter presents the microbiological evaluation of the post-disinfection capsule, focusing on its effectiveness in reducing *E. coli*, thermotolerant coliforms, and total coliforms and its compliance with PNSDW (2017). Four treatment groups—Control, Design A, Design B, and Design C—were evaluated at baseline, 1 hour, and 24 hours, with three replicates for each treatment group. The capsule designs differed in chlorine release, flow characteristics, and media arrangement, and their performance was assessed based on microbiological reduction and compliance with drinking-water standards. The single baseline sample showed >8.0 MPN/100 mL for *E. coli*, thermotolerant coliforms, and total coliforms,

confirming that the synthetic contaminated water had a sufficiently high microbial load for evaluating treatment performance and establishing the initial condition for comparison with the 1-hour and 24-hour results.

TABLE I. Microbiological Results After 1 Hour of Contact Time.

Treatment	Trial	Thermotolerant Coliform (MPN/100 mL)	Total Coliform (MPN/100 mL)	E. coli (MPN/100 mL)
Design A	1	>8.0	>8.0	>8.0
Design A	2	1.1	1.1	1.1
Design A	3	>8.0	>8.0	>8.0
Design B	1	>8.0	>8.0	>8.0
Design B	2	>8.0	>8.0	>8.0
Design B	3	>8.0	>8.0	>8.0
Design C	1	>8.0	>8.0	>8.0
Design C	2	>8.0	>8.0	>8.0
Design C	3	>8.0	>8.0	>8.0
Control	1	>8.0	>8.0	>8.0
Control	2	>8.0	>8.0	>8.0
Control	3	>8.0	>8.0	>8.0
PNSDW	1	0	0	0

After 1 hour, most samples from all treatment groups remained at >8.0 MPN/100 mL for all three bacterial indicators. However, one Design A replicate recorded 1.1 MPN/100 mL for E. coli, thermotolerant coliforms, and total coliforms, indicating an early treatment effect but inconsistent performance. The Control group remained at >8.0 MPN/100 mL in all replicates, suggesting no substantial natural reduction during the first hour. These results indicate that the combined effects of NaDCC, activated carbon, and silver-infused ceramic media may require longer contact time to achieve more consistent microbial reduction.

TABLE III. Microbiological Results After 24 Hours of Contact Time.

Treatment	Trial	Thermotolerant Coliform (MPN/100 mL)	Total Coliform (MPN/100 mL)	E. coli (MPN/100 mL)
Design A	1	>8.0	>8.0	>8.0
Design A	2	2.6	2.6	2.6
Design A	3	>8.0	>8.0	>8.0
Design B	1	8.0	8.0	8.0
Design B	2	>8.0	>8.0	>8.0
Design B	3	8.0	8.0	8.0
Design C	1	1.1	2.6	1.1
Design C	2	4.6	4.6	4.6
Design C	3	8.0	8.0	8.0
Control	1	>8.0	>8.0	>8.0
Control	2	>8.0	>8.0	>8.0
Control	3	>8.0	>8.0	>8.0
PNSDW	1	0	0	0

After 24 hours of contact time, clearer bacteriological reduction was observed compared with the 1-hour results, although none of the designs achieved complete microbial removal. Design A recorded 2.6 MPN/100 mL in one replicate, while the other two remained at >8.0 MPN/100 mL, indicating partial and inconsistent reduction. Design B showed limited reduction, with two replicates at 8.0 MPN/100 mL and one at >8.0 MPN/100 mL, suggesting that the larger NaDCC opening did not result in consistently improved disinfection. Design C showed the greatest overall reduction, with results of

1.1, 4.6, and 8.0 MPN/100 mL across the three replicates. Its improved performance may be associated with the higher proportion of silver-infused ceramic media and reduced activated carbon, which may have supported antimicrobial activity while maintaining disinfectant availability. In contrast, the Control group remained at >8.0 MPN/100 mL in all replicates, supporting the interpretation that the observed reductions were associated with the capsule treatments rather than natural microbial decline.

Design C showed the greatest microbiological reduction, with the lowest recorded values after 24 hours and a more consistent reduction pattern across replicates. Design A demonstrated partial but inconsistent effectiveness, while Design B showed the least reduction, with values remaining near the upper detection limit. The Control group showed no improvement, supporting that the observed reductions were associated with the capsule treatments. The results showed greater microbiological reduction at 24 hours than at 1 hour, particularly for Designs A and C, but none of the treatment groups achieved 0 MPN/100 mL and therefore none complied with PNSDW (2017) under the tested conditions.

TABLE IIIII. Compliance Interpretation of Treated Samples.

Group	Time	Observed Condition	Compliance Interpretation
Control	1	All values >8.0	Non-compliant
Design A	1	One replicate reduced to 1.1; others >8.0	Non-compliant, partially effective
Design B	1	All values >8.0	Non-compliant
Design C	1	All values >8.0	Non-compliant
Control	24	All values >8.0	Non-compliant
Design A	24	One replicate reduced to 2.6	Non-compliant, partially effective
Design B	24	Values of 8.0 and >8.0	Non-compliant, minimally effective
Design C	24	Values of 1.1, 4.6, and 8.0	Non-compliant, partially effective

IV. CONCLUSION

The study found that the post-disinfection capsule was capable of reducing E. coli, thermotolerant coliforms, and total coliforms in gallon-refilled water, with greater reductions observed after 24 hours compared with 1 hour of contact time. Among the tested configurations, Design C showed the best overall performance, demonstrating the influence of media composition and capsule design on treatment effectiveness. However, none of the treated samples achieved zero detectable organisms, meaning the capsule did not meet the bacteriological requirements of PNSDW (2017). Thus, while the capsule shows potential as a post-disinfection device, further optimization is needed to achieve consistent and compliant treatment performance.

V. RECOMMENDATIONS

The capsule design should be further optimized, particularly in terms of NaDCC release, media composition, internal flow, and contact efficiency. Additional trials using more samples and baseline measurements are recommended to

improve the reliability and reproducibility of the results. Longer contact times beyond 24 hours should also be investigated to determine whether greater microbial reduction can be achieved. Finally, future studies should evaluate the capsule under actual household or field conditions using real refilled water containers to assess its practical effectiveness.

APPENDICES

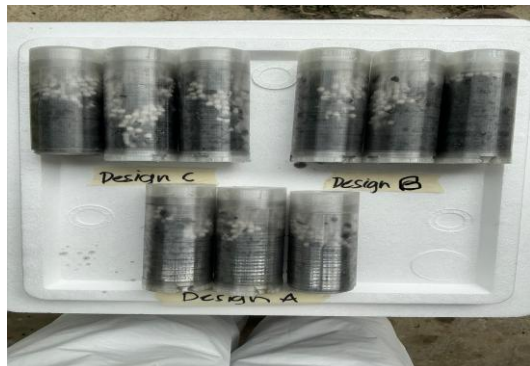


Figure 10. Post-Experimental Condition of the Capsule Prototypes Showing Media after Exposure to Contaminated Water for Designs A, B, and C



Figure 11. Measurement of Ceramic Media Mass using a Digital Weighing Scale prior to Capsule Assembly



Figure 12. UV Sterilization of Capsule Components prior to Media Loading and Experimental use.

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