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Article

Comparison of shower filters for reducing total residual chlorine under household flow conditions

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SUMMARY

Tap water is disinfected to prevent microbial contamination, but chlorine-based disinfectants, such as chloramine, may contribute to skin irritation in individuals with sensitive skin conditions such as atopic dermatitis. We evaluated two commercial shower filters, specifically a low-cost 4-stage filter and a widely sold 20-stage filter, along with three filtration media commonly used for chlorine removal in commercial shower filters: calcium sulfite ($CaSO_3$), Kinetic Degradation Fluxion (KDF) 55, and granular activated carbon (GAC). We hypothesized that the two commercial filters would perform similarly to each other in their ability to remove chlorine, and that chlorine removal effectiveness would differ among the three individual media. We measured total residual chlorine concentrations before and after filtration under controlled low- and high-flow conditions using a colorimetric method. Under both flow conditions, the 4-stage and 20-stage filters significantly reduced total residual chlorine, with no statistically significant difference between them. When we tested each medium individually, $CaSO_3$ achieved chlorine reduction comparable to that of both commercial filters at both flow rates, while KDF 55 and GAC showed limited effectiveness, particularly under high-flow conditions where chlorine removal rates were only about 17%. These findings suggest that $CaSO_3$ plays a central role in chlorine removal during shower use and provide preliminary evidence supporting the design of low-cost and reusable shower filters.

INTRODUCTION

Tap water delivered to households undergoes standardized purification and disinfection at water treatment facilities, and regulated contaminants are managed to remain below health-based drinking water standards. In the United States, the U.S. Environmental Protection Agency (EPA) sets a maximum residual disinfectant level of 4.0 mg/L for chlorine in drinking water, while the World Health Organization (WHO) recommends a maximum of 5.0 mg/L (1, 2). Current regulatory limits are based on total residual chlorine, which refers to the total amount of chlorine present in water (1). This encompasses both free chlorine and the chlorine atoms bound within compounds formed when chlorine combines with ammonia (3). Total residual chlorine must be measured to accurately capture the chlorine content of tap water (4). In practice, total residual chlorine concentrations in tap water typically range from 0.5 to 3.5 mg/L, with higher concentrations found near water treatment facilities and lower concentrations at points farther from the source due to chlorine decay during distribution (5). These concentrations are commonly quantified using the N,N-diethyl-p-phenylenediamine (DPD) colorimetric method, the standard approach recognized internationally under Standard Methods 4500-Cl G (6).

While these disinfectant levels are considered safe for the general population, total residual chlorine in tap water, even at concentrations within regulatory limits, has been reported to exacerbate sensitive skin conditions such as atopic dermatitis (7–9). The specific form of residual disinfectant varies by region. While free chlorine is widely used, many regions including California use chloramine as an alternative (3, 9). In chloramine (NH_4Cl), a chlorine atom replaces one of the hydrogen atoms in ammonia (3). Chloramine produces less odor than free chlorine and remains stable throughout the water distribution system, persisting until it reaches the point of use (10,11). Given that chloramine persists, individuals are directly exposed to it during daily activities such as showering. As a result, many people use shower filters to reduce total residual chlorine exposure (12).

Commercial shower filters vary widely in design and price. Multi-stage filters are among the most commonly available consumer options, incorporating multiple filtration zones to target different impurities (13). In this study, we selected a 4-stage filter to represent a low-cost, simplified design, and a 20-stage filter to represent a highly popular, best-selling model on major e-commerce platforms. Both filters share identical chlorine-reducing media, though they differ substantially in overall design and the number of functional stages (**Figure 1**). The 4-stage filter used in this study (Keycozy KPF001) contains only an impurity removal zone composed of calcium sulfite ($CaSO_3$), Kinetic Degradation Fluxion (KDF) 55, and granular activated carbon (GAC), and an antibacterial ball for chlorine and chemical reduction (14). In comparison, the 20-stage filter (AquaBliss SF100) expands on this basic design by adding three additional zones: a sediment removal zone that captures dirt and particulates; a revitalizing zone that infuses water with vitamin C and minerals; and a protection zone consisting of cotton-based layers that acts as a final physical barrier to secure the media and trap any remaining fine particles (15). The 4-stage filter is available for under $10, while the 20-stage filter is priced at approximately $30–40. The additional stages in the 20-stage filter may offer supplementary benefits such as sediment filtration or mineral infusion, but they are unlikely to provide meaningful advantages for chlorine removal. This raises the practical question of whether the higher cost of the 20-stage filter is justified for consumers primarily concerned with chlorine reduction during showering.

Despite the wide availability of shower filters, consumers have limited means to objectively compare their chlorine

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reduction performance. To address this, we evaluated two widely available commercial filters at different price points (a low-cost 4-stage filter and a widely sold 20-stage filter), alongside three individual filtration media commonly incorporated in commercial shower filters for chlorine removal: $CaSO_3$, KDF 55, and GAC (13, 16, 17). Each medium utilizes a distinct removal mechanism. $CaSO_3$ has been reported to remove chloramine through rapid chemical reactions (16). KDF 55, a copper–zinc alloy, removes free chlorine through redox reactions but is generally considered less effective for chloramine removal, as the electrochemical mechanism that targets free chlorine is less reactive with chlorine bound within the chloramine molecule (13). GAC primarily removes chlorine through adsorption, but its performance may be limited when contact time is short, such as during high-flow shower use (17).

To isolate the specific contribution of each material without introducing arbitrary experimental variables, we standardized the mass of each individual medium to precisely match the baseline quantities measured from the commercial 4-stage filter. Building on these distinct mechanisms and strictly controlled conditions, we hypothesized that the two commercial filters would perform similarly in reducing total residual chlorine, given that both contain identical chlorine-reducing media despite differences in overall design and price. We also hypothesized that chlorine removal effectiveness would differ among the three individual media based on their distinct removal mechanisms. Our findings showed that the 4-stage filter removed total residual chlorine with a negligible difference from the 20-stage filter despite its simpler design and lower cost, and that $CaSO_3$ demonstrated the strongest chlorine removal performance among the individual media tested. These results provide practical guidance for consumers selecting shower filters and offer preliminary evidence supporting the development of low-cost, reusable filtration systems for individuals sensitive to residual chlorine exposure.

RESULTS

To evaluate the chlorine reduction performance of two commercial shower filters and three individual filtration media, we tested five filter configurations under low- (2.4 liters per minute) and high-flow (9.6 liters per minute) conditions representative of hand/face washing and household shower use, respectively **(Figure 1)**. Total residual chlorine was measured in unfiltered tap water, independent of flow conditions, and in water collected after passing through each filter configuration under both low- and high-flow conditions.

Validation of experimental replicates

Prior to pooling the data, we evaluated potential unit-to-unit variation by comparing the results from two identical, independent units (experimental replicates) tested for each configuration in separate sessions. Because each session used freshly collected tap water with a different baseline chlorine concentration, the two units were compared using the reduction in total residual chlorine relative to the unfiltered control measured in the same session. Independent two-sample t-tests detected no statistically significant differences between the two units across all tested filter types and flow conditions (10 comparisons, $p = 0.577$ to 1.000). Given these comparable outcomes, the measurements from both units were compiled into a single population (n = 6) to allow for more robust statistical analyses.

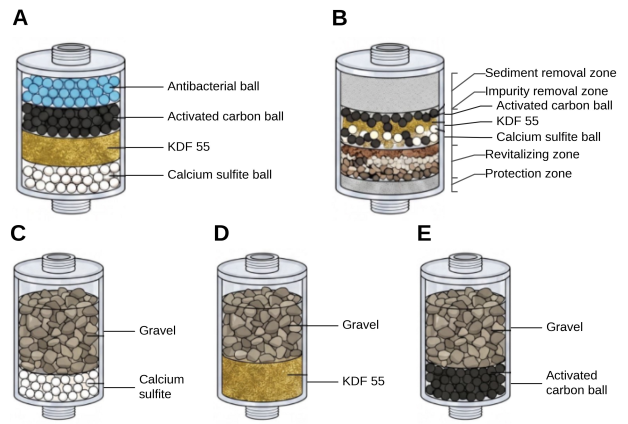

Figure 1. Schematic diagrams of filter configurations. The diagrams represent simplified conceptual illustrations of filter media composition based on manufacturer product descriptions and are not exact cross-sectional reproductions of the commercial products. (A, B) The (A) 4-stage and (B) 20-stage commercial filters contain three main materials for chlorine removal: calcium sulfite ($CaSO_3$), Kinetic Degradation Fluxion (KDF) 55, and granular activated carbon (GAC). (C, D, E) To test individual components, single-media filters were made using only one type of filtration material: (C) $CaSO_3$, (D) KDF 55, and (E) GAC. The empty space was filled with inert gravel to keep the total volume and water flow consistent with the other filters.

Unfiltered control

The unfiltered control had a mean total residual chlorine concentration of 2.40 ± 0.23 ppm (mean ± SD, n = 6) **(Figure 2).**

Commercial filters under low-flow conditions

Under low-flow conditions, the 4-stage and 20-stage filters produced significant reductions in total residual chlorine. Both the 4-stage filter and the 20-stage filter reduced total residual chlorine to 0.04 ± 0.02 ppm, achieving chlorine removal rates of 98.4% and 98.5%, respectively **(Figure 2)**. Both reductions were statistically significant relative to the unfiltered control ($p < 0.01$). We observed no statistically significant difference between the two filters ($p = 0.856$, paired t-test) **(Figure 2)**.

Commercial filters under high-flow conditions

Under high-flow conditions, total residual chlorine levels were higher than those observed under low-flow conditions. The 4-stage and 20-stage filters reduced total residual chlorine to 0.20 ± 0.06 ppm and 0.22 ± 0.06 ppm, achieving removal rates of 91.9% and 90.7%, respectively **(Figure 2).** Both reductions were statistically significant compared with unfiltered tap water (2.40 ± 0.23 ppm, $p < 0.01$). We observed no statistically significant difference between the two filters at high-flow ($p = 0.207$) **(Figure 2).**

Single-media filters under low-flow conditions

Under low-flow conditions, all single-media filters produced

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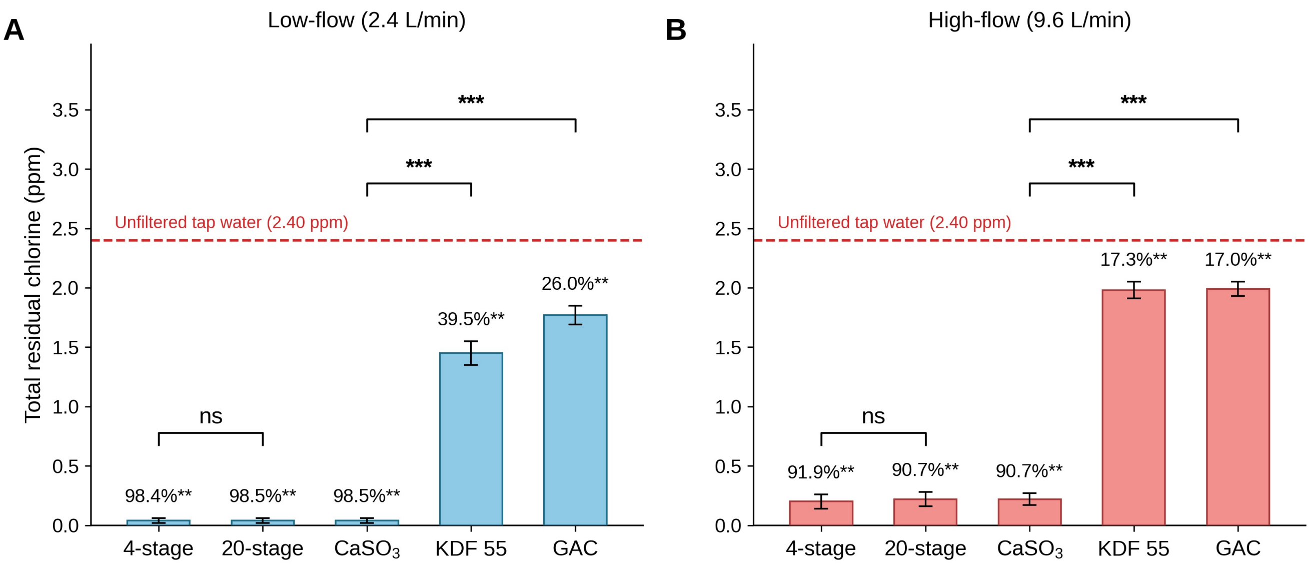

Figure 2. Effect of filter configuration and flow rate on total residual chlorine removal. Total residual chlorine concentrations in parts per million (ppm) were measured for five filter configurations under (A) low-flow (2.4 L/min) and (B) high-flow (9.6 L/min) conditions. Bars represent the mean of six independent trials (two distinct physical filters tested three times each, n = 6), and error bars indicate the standard deviation. The horizontal dashed line represents the mean total residual chlorine concentration of unfiltered tap water (2.40 ± 0.23 ppm), which served as the control. The percentage above each bar indicates the chlorine removal rate relative to the control. Each filter condition was compared with the unfiltered control using a paired t-test, and the 4-stage and 20-stage filters were compared with each other using a paired t-test. Differences among the single-media filters ($CaSO_3$, KDF 55, and GAC) were assessed by one-way analysis of variance (ANOVA) followed by Tukey's Honestly Significant Difference (HSD) post hoc test. Statistical significance was defined as $p < 0.05$. **$p < 0.01$ compared with the unfiltered control. ***$p < 0.001$ for the indicated comparison. ns, not significant (p = 0.856 in (A) and $p = 0.207$ in (B)). $CaSO_3$: calcium sulfite; KDF 55: Kinetic Degradation Fluxion 55; GAC: granular activated carbon.

statistically significant reductions in total residual chlorine compared with unfiltered tap water (p < 0.01 for $CaSO_3$, KDF 55, and GAC) **(Figure 2)**. $CaSO_3$ reduced total residual chlorine to 0.04 ± 0.02 ppm, achieving a 98.5% removal rate, which was comparable to the reductions achieved by the 4-stage and 20-stage filters. KDF 55 and GAC reduced total residual chlorine to 1.45 ± 0.10 ppm and 1.77 ± 0.08 ppm, respectively, representing chlorine removal rates of 39.5% and 26.0%. One-way ANOVA revealed significant differences in total residual chlorine levels among the single-media filters, while post hoc analysis showed that chlorine levels following $CaSO_3$ filtration were significantly lower than those observed for GAC and KDF 55 *($p < 0.001$)* **(Figure 2)**.

Single-media filters under high-flow conditions

Under high-flow conditions, $CaSO_3$ reduced total residual chlorine to 0.22 ± 0.05 ppm, achieving a removal rate of 90.7%. This reduction was statistically significant relative to unfiltered tap water ($p < 0.01$). KDF 55 (1.98 ± 0.07 ppm) and GAC (1.99 ± 0.06 ppm) showed statistically significant reductions relative to the unfiltered control ($p < 0.01$). However, they only achieved chlorine removal rates of 17.3% and 17.0%, respectively **(Figure 2)**.

Comparisons among the single-media filters revealed significant differences in total residual chlorine levels (one-way ANOVA, $p < 0.001$). Post hoc analysis indicated that chlorine levels following $CaSO_3$ filtration were significantly lower than those observed for GAC and KDF 55 *($p < 0.001$)* **(Figure 2)**.

DISCUSSION

We evaluated whether a low-cost 4-stage shower filter performs comparably to a widely sold 20-stage filter in reducing total residual chlorine. We also identified the relative contribution of three individual filtration media commonly used in commercial shower filters to remove chlorine. We hypothesized that the two commercial filters would perform similarly but that chlorine removal effectiveness would differ among $CaSO_3$, KDF 55, and GAC based on their distinct removal mechanisms.

The mean total residual chlorine concentration measured in unfiltered tap water was 2.40 ppm, consistent with the Irvine Ranch Water District report indicating an average of 2.5 ppm with a range of 1.5 to 3.9 ppm (19). This value also falls within the range previously associated with skin irritation in sensitive individuals (7–9). Our findings support the rationale for evaluating shower filtration as a practical approach to reduce chlorine exposure, as measured levels are high enough to cause irritation in sensitive individuals.

We observed measurable reductions in chlorine under both low- and high-flow conditions; however, chlorine removal was consistently more effective under low-flow conditions than under high-flow conditions. This pattern suggests that contact time between water and filtration media plays a key

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role in overall removal efficiency.

Under both low- and high-flow conditions, the 4-stage and 20-stage filters produced statistically significant reductions in total residual chlorine, and no statistically significant difference was observed between the two filters. This result suggests that, in this experimental setting, the higher-cost multi-stage filter did not demonstrate a clear improvement in total residual chlorine reduction compared with the lower-cost filter.

Individual media tests suggest that $CaSO_3$ plays a major role in chlorine reduction under conditions relevant to shower use. $CaSO_3$ alone achieved chlorine reduction comparable to that of the 4-stage and 20-stage filters used in this study at both flow rates. In contrast, although KDF 55 and GAC produced statistically significant reductions in total residual chlorine under high-flow conditions ($p < 0.01$), the reductions were minimal, with chlorine removal rates of only 17.3% and 17.0%, respectively, leaving residual chlorine levels near 2.0 ppm relative to the unfiltered control of 2.40 ± 0.23 ppm. This degree of reduction may not be practically meaningful for individuals seeking to minimize chlorine exposure during showering, and this distinction between statistical and practical significance should be considered when evaluating filtration media for shower use. These differences can be explained by the previously described removal mechanisms of each medium (16–18).

Each filter configuration was evaluated using two independent physical filters, each tested in triplicate, although the total number of physical filters was limited. This design incorporates experimental replication to assess variation between filter units and technical replication to account for measurement variability over time. These runs were performed on different days using freshly collected tap water, so they also capture day-to-day variation in the water source and are not purely technical in nature. Overall, the data demonstrated consistent results across trials, suggesting reasonable reproducibility within the limitations of this study. The standard deviations were consistently low, ranging from ±0.02 to ±0.10 ppm across all filter configurations.

Several limitations should be considered when interpreting these findings. First, as this study used tap water from a single municipal source in California, where chloramine is used as the primary disinfectant, the findings may not directly generalize to regions where different disinfectants or water treatment practices are employed, as chlorine and chloramine composition can vary substantially by location. Second, this study focused only on minimizing total residual chlorine concentration and did not examine other components of tap water that may also contribute to skin irritation, such as minerals associated with hard water, metal ions, and acidic substances. Therefore, the reduction of total residual chlorine alone cannot be interpreted as direct evidence of clinical improvement in skin conditions nor does it imply that the tested commercial filters would produce identical effects on skin outcomes. Specifically, while $CaSO_3$ demonstrated strong chlorine reduction in our tests, KDF 55 may contribute to the removal of free chlorine and heavy metals, and GAC may provide supplementary adsorption of organic compounds. Despite our results on the individual capabilities of these filtration media, the combined effects were not evaluated in this study. The measurement technique itself also has a limitation, as the DPD colorimetric method responds to oxidizing agents in general rather than to chlorine alone. However, chlorine and chloramine are the primary oxidants in municipal water, and the presence of other interfering oxidizing agent is generally considered negligible.

Additionally, the conclusions regarding the two commercial products tested in this study, the Keycozy KPF001 and the AquaBliss SF100, should not be generalized to all 4-stage or 20-stage shower filters, as performance may vary across different manufacturers and product designs. Although filter housing volume was standardized across all configurations, differences in packing density, particle size, and potential water channeling among the filtration media may have influenced hydraulic behavior within each filter. These factors could affect the actual contact time between water and the filtration medium and may represent an additional source of variability in the observed chlorine removal performance. Another important limitation of this study is that it evaluated only the immediate, short-term filtration performance. In real-world household settings, shower filters remain loaded with water for extended periods and process large volumes of water daily. Over time, filtration media can become saturated, which may lead to a decline in filtration capacity. Because this study did not simulate long-term usage, it does not address filter durability, lifespan, or saturation effects. It is possible that while certain media display comparable initial performance, their effectiveness may degrade at different rates over time.

Future studies with larger sample sizes, additional environmental conditions (including temperature variation), and long-term experiments to evaluate filter lifespan and saturation effects may strengthen confidence in the observed differences. More precise characterization of flow dynamics within individual filter configurations would also help clarify sources of variability in chlorine removal performance. Further work may also investigate combinations of filtration media such as $CaSO_3$ paired with GAC or KDF 55 to determine whether synergistic effects might achieve more complete chlorine removal. Additionally, future studies could assess 4-stage and 20-stage filters from multiple manufacturers to determine whether differences in component quality, media composition, or filter design among brands affect chlorine removal performance. Optimizing media quantity and thickness within such combined configurations may further improve performance while maintaining low-cost and reusability.

In summary, this study sought to determine whether a low-cost 4-stage shower filter performed comparably to a widely sold 20-stage filter in reducing total residual chlorine and to identify the relative contribution of individual filtration media. Consistent with our hypothesis, both commercial filters achieved equivalent chlorine reduction despite differences in design and price, and $CaSO_3$ demonstrated the strongest performance among the individual media tested. These findings provide practical guidance for consumers selecting shower filters and offer preliminary evidence supporting the feasibility of developing effective, low-cost filtration systems centered on $CaSO_3$ for the reduction of chlorine exposure during showering.

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MATERIALS AND METHODS

Water source and chlorine measurement

All experiments were conducted using municipal tap water collected from a residence in Irvine, California, that was not equipped with a water softener or a household water purification system. Total residual chlorine concentrations were measured using a HANNA HI711 colorimeter (measurement range 0.00 to 3.50 ppm, resolution 0.01 ppm, stated accuracy ±0.03 ppm ±3% of reading) based on the standard DPD colorimetric method (20).

In this method, DPD was oxidized by chlorine present in the sample, and a magenta product was formed. The intensity of the color increased as the chlorine concentration of the sample increased. The reagent used here (Hanna Instruments HI711-0 Total Chlorine Reagent, one packet per measurement) contained potassium iodide in addition to DPD. DPD was not oxidized directly by chlorine bound within chloramine at a useful rate, so iodide was first oxidized to iodine, which then oxidized the DPD. Because of this additional step, the resulting color reflected both free chlorine and the chlorine bound within chloramine, and the measured values were reported as total residual chlorine in ppm of Cl_2. The amount of light absorbed by the colored sample was measured at a fixed wavelength of 525 nm and converted into a concentration by the colorimeter.

All measurements were performed at a controlled water temperature of approximately 100°F, maintained by keeping the shower valve at a fixed setting and verified using a digital thermometer (Thermomaven F1 Stealth, accuracy ±0.2°F). Each water sample was collected in a transparent glass vial and inserted into the instrument to establish a reference reading before the reagent was added, so that any color or turbidity already present in the sample was excluded from the final value. The reagent was then added to the same vial, and the vial was returned to the instrument for the measurement.

To minimize sampling error, tap water was flushed through the installed filter for at least one minute before each sample was collected to reduce the influence of stagnant water retained in the plumbing system or filter housing.

Flow conditions

Filtration experiments were conducted under two flow conditions. Flow rate was measured by collecting water in a graduated cylinder for 10 seconds and the valve was adjusted accordingly. Low-flow was defined as 2.4 liters per minute, approximating low-flow household use such as hand or face washing. High-flow was defined as 9.6 liters per minute, approximating typical shower flow rates in household settings.

Filter configurations

Five filter configurations were evaluated: two commercially available shower filters and three custom single-media filters. The commercial filters included a low-cost 4-stage Keycozy filter (Model KPF001) and a widely sold 20-stage AquaBliss filter (Model SF100). Each custom single media filter contained only one filtration material: calcium sulfite ($CaSO_3$), Kinetic Degradation Fluxion (KDF) 55, or granular activated carbon (GAC). The same housing was used for all filters, and empty 4-stage filter casings were refilled with a single medium for the custom configurations.

To establish a standardized baseline for the amount of each medium, a single representative 4-stage filter was disassembled, and the mass of each corresponding component was measured using a precision balance (VISKA VK-KS1000; accuracy: ±3 g). GAC (12 g), KDF 55 (27 g), and $CaSO_3$ (15 g) were loaded into separate empty filter casings. The remaining volume in each filter was filled with chemically inert gravel (Aqua Natural Ice White; particle size: 4–6 mm) to maintain a filter bed volume, flow resistance, and hydraulic conditions similar to those of the commercial filters. This approach was used to isolate the effect of each filtration medium while minimizing differences in flow dynamics between experimental and commercial filters.

Experimental design

To ensure reproducibility and explicitly distinguish between technical and experimental replicates, two independent physical units of each filter configuration were constructed and tested. Each of the two units was evaluated in three separate filtration runs on different days, yielding a total of six experimental trials, derived from triplicate testing of each physical unit.

Statistical analysis

For each experimental session, unfiltered tap water was measured once at the start and used as the paired control for all filtration measurements performed on that day, including both low- and high-flow conditions, based on the assumption that tap water chlorine concentration remains stable within a single session. To verify the consistency between experimental replicates, an independent two-sample t-test was conducted for each filter type to compare the chlorine reduction performance (calculated as the decrease in total residual chlorine relative to the paired control measured in the same session) of the two independent physical units. Differences between unfiltered and filtered samples were evaluated using paired t-tests. A paired t-test was also used to directly compare total residual chlorine levels between the 4-stage and 20-stage filters. To assess whether chlorine reduction differed among the single-media filters, one-way analysis of variance (ANOVA) was performed, followed by Tukey's Honestly Significant Difference (HSD) post hoc test for multiple comparisons. A two-tailed p-value of less than 0.05 was considered statistically significant.

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