# Prototype for Removal of Residual Chlorine, Hardness and Manganese from Drinking Water

**Silva D.A.[1], Hansen E.[2,3,*], Rodrigues M.A.S.[2], Aquim P.M.[1]**

[1] Post-graduation Program in Materials Technology and Industrial Processes, Feevale University, Novo Hamburgo, Brazil
[2] Post-graduation Program in Environmental Quality, Feevale University, Novo Hamburgo, Brazil
[3] FEPAM - State Environmental Protection Foundation, Porto Alegre, Brazil

*corresponding author:
e-mail:everton-hansen@fepam.rs.gov.br

**Abstract** Residual chlorine, while crucial for water disinfection, can lead to skin irritation and hair degradation over time. Additionally, water hardness exacerbates dermatological conditions such as atopic dermatitis and hair breakage, and elevated manganese concentrations can be toxic, negatively impacting neurological health. This study aimed to develop a domestic-use prototype designed to improve water quality. The methodology involved constructing the prototype using ion exchange resins and granular activated carbon and evaluating its effectiveness in removing residual chlorine, hardness, and manganese from synthetic solutions. The adsorption capacity of the filtration bed was assessed through the breakthrough curve. The prototype reduced 99±0.02% residual chlorine, 97±0.00% hardness, and 98.5±1.00% manganese in synthetic solutions. The average breakthrough time was 1,020 minutes, while the average saturation time was 1,440 minutes, with a solution flow rate of 136.03 $cm^3.min^{-1}$. The results demonstrate the prototype's potential for improving specific quality parameters in potable water.

**Keywords:** Drinking water; Residual chlorine; Hardness; Activated carbon; Ion exchange resin.

## 1. Introduction

Although treated water is suitable for consumption, substances such as residual chlorine, manganese, and hardness-inducing ions can lead to undesirable effects. Residual chlorine and water hardness have been related to increased risks for atopic dermatitis through skin barrier dysfunction and transepidermal water loss (Perkin, 2016). Additionally, hard water is a major cause of hair breakage (Luqman *et al.*, 2018) and prolonged exposure to chlorinated water leads to hair degradation over time (Morini *et al.*, 2017). The provisional guideline for manganese is 0.08 mg/L to protect against neurological effects, but this value is subject to change due to uncertainties (WHO, 2022).

Innovative techniques have been developed to remove residual compounds from conventional water treatment, ensuring water meets specific usage requirements. Thus, this study aimed to develop a prototype filter to remove residual chlorine, hardness, and manganese from drinking water for specific needs, such as hypersensitivity or hair care.

## 2. Methodology

The prototype was constructed using PVC components. The filter body consists of a tube with a diameter of 2.2 cm and a length of 17.4 cm. Inside the tube, the following materials were layered: 7.0 cm of activated carbon (AC) (manufacturer: Alphacarbo, granulated type 8x30), 5.2 cm of strong acidic cationic resin (Supergel™ SGC650H), and 5.2 cm of strong basic anionic resin (Supergel™ SGA550OH). Figure 1 shows the filter bed (a) and the fully assembled prototype (b).

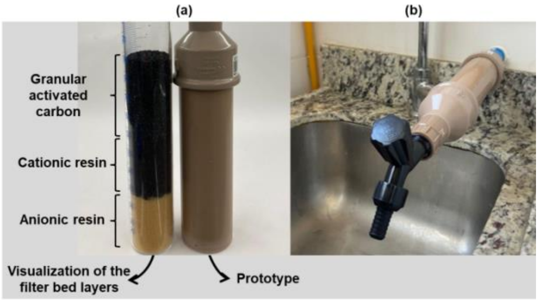


**Figure 1.** Filter bed (a) and the assembled prototype (b).

The synthetic solutions used to test the prototype's efficiency were prepared as follows: residual chlorine was generated by dissolving sodium hypochlorite in deionized water (3,400 ppm); hardness was simulated by dissolving $CaCO_3$ in HCl and diluting the solution in deionized water (196.5 ppm); and manganese was prepared by dissolving $MnSO_4 \cdot 4H_2O$ in $H_2SO_4$, followed by dilution in deionized water (1,161.2 ppm). Removal efficiencies were determined from the analysis of residual chlorine, hardness and manganese in the raw and treated solutions. The tests were performed in triplicate.

The breakthrough curve was obtained by treating a drinking water flow rate of 136.03 $cm^3.min^{-1}$ in the prototype and collecting aliquots of both raw and filtered water every 15 minutes (triplicate). The salinity was monitored using a multiparameter meter (Hach HQ40D).

## 3. Results and Discussion

The efficiency of the prototype to remove residual chlorine, hardness and manganese is shown in Figure 2.

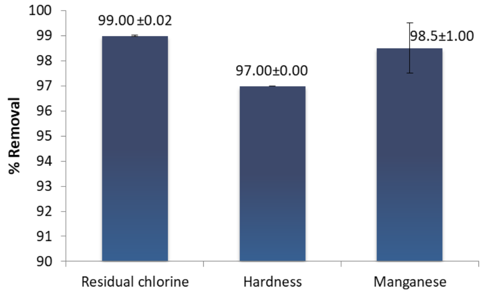


**Figure 2.** Prototype efficiency to remove residual chlorine, hardness and manganese.

The prototype achieved removal efficiencies greater than 97% for all parameters. Residual chlorine removal efficiency was comparable to that observed in previous studies, which reported 95% removal in drinking water treated with commercial AC (Schmidt, 2011) and 99% removal using AC from *Cocos nucifera Linn* fiber (Paz *et al*., 2021). The prototype's hardness removal was higher than that reported in studies using AC from *Mimosa hostilis* biomass (89% removal) (Silva *et al*., 2023) and ion exchange resins (40% efficiency with cationic resin (Levindo *et al*., 2024) and 46% to 82.45% efficiency with commercial resins (Boonpanaid and Piyamongkala, 2023)). Manganese removal by the prototype was similar to that found in a study using commercial AC, cation resin, and zeolite, which achieved 98.3% removal (Cyrne *et al*., 2020). The characteristic breakthrough curve for the assembled prototype is shown in Figure 3.

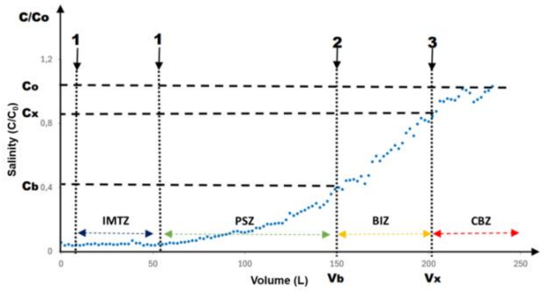


**Figure 3.** Breakthrough curve.

The curve exhibits a sigmoidal pattern, beginning with a phase of minimal salinity increase in the treated water, suggesting that most of the solute is being removed by the adsorbent bed (Initial Mass Transfer Zone - IMTZ). As the treatment progresses, the solute concentration in the effluent gradually rises, marking the Partial Saturation Zone (PSZ).

At the point (Vb; Cb), the Breakthrough Initiation Zone (BIZ) begins, where the solute concentration in the effluent starts to rise more rapidly. This indicates that the adsorption zone has reached the end of the bed, and the system is approaching a breakthrough. The final part of the curve, marked by (Vx; Cx), corresponds to the Complete Breakthrough Zone (CBZ), where the solute concentration in the effluent sharply increases until it reaches a plateau. At this point, the adsorption zone has traversed the entire bed length, and the system is nearly in equilibrium with the feed solution. The adsorbent bed is fully saturated and can no longer efficiently remove the solute from the solution.

The average breakthrough time was 17 hours, with an average saturation time of 24 hours. The average breakthrough volume was 145 L, while the average saturation volume was 202 L.

## 4. Conclusions

A prototype filter was successfully developed to remove residual chlorine, hardness, and manganese. Analysis of the synthetic solution samples demonstrated that the prototype effectively reduced residual chlorine by 99±0.02%, hardness by 97±0.00%, and manganese by 98.5±1.00%, confirming the filter bed's adsorption capacity.

The breakthrough curve analysis indicated sustained efficiency until the adsorbent materials reached saturation. The prototype achieved an average breakthrough time of 17 hours and an average saturation time of 24 hours, operating at a solution flow rate of 136.03 $cm^3 \cdot min^{-1}$.


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