Nanoparticle-Functionalized Ceramic Water Filters as Cost-Effective Solutions for Arsenic Contamination in Drinking Water Sources

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Highlights

- Ceramic water filters functionalized with nanoparticles was found to remove arsenic from contaminated water sources more efficiently.
- Clay and sawdust were mixed thoroughly and baked at high temperature to make strong, efficient ceramic filters for water purification.
- Addition of Fe/Cu and Fe-Ce nanoparticles to filters greatly improved arsenic removal.

Keywords: *ceramic water filters, arsenic removal, nanoparticles*

INTRODUCTION

Rivers, streams, and lakes are natural water sources that rural communities often depend on to fulfil their daily water needs. However, these sources often contain pollutants resulting from human activities, leading to the spread of diseases and fatalities transmitted through water (Zereffa and Bekalo, 2017). In addition, Point of Use (PoU) water treatment units have gained popularity, particularly among rural communities, as a potential remedy to this challenge (Nnaji et al., 2016; Pérez-Vidal et al., 2019) . Clay and ceramic filters are notable among the point-of-use (PoU) solutions because of their affordability, ease of use, lightweight design, excellent mechanical and thermal properties, and the fact that they do not require electricity and require only minimal maintenance (Yang et al., 2020). Recent research has focused on the development of ceramic water filters with the aim of enhancing their effectiveness in removing a diverse range of organic and inorganic pollutants from water.

METHODOLOGY

Filter Fabrication and Selection of Sawdust Proportion

Ceramic filters were fabricated by mixing clay and sawdust in different proportions of 90:10, 80:20, 70:30, 60:40 and 50:50 by volume, to achieve varying porosity levels, and the resulting mixtures were moulded into disc-shaped filters. These discs were sintered at 850°C to develop the porous ceramic structure. The filters were subjected to preliminary filtration tests to assess their performance based on two criteria: flow rate and removal of physicochemical parameters. The sawdust proportion yielding the best balance of flow rate and contaminant removal was selected for further modification by nanoparticles.

Filter Modification using Nanoparticles

Nanoparticles were prepared using co-precipitation method. The filters were modified using these nanoparticles by three different methods i.e., brush painting, dip in and fire in. After modifying with brush painting and dip in method, the filters were dried at 300°C for 3 hours to ensure proper adhesion of the nanoparticles to the ceramic matrix.

Arsenic Stock Solution Preparation

Arsenic stock solution was prepared by dissolving the salts sodium arsenate heptahydrate and sodium arsenite respectively in 1000ml distilled water. Working stock used was 3ppm concentration of arsenic.

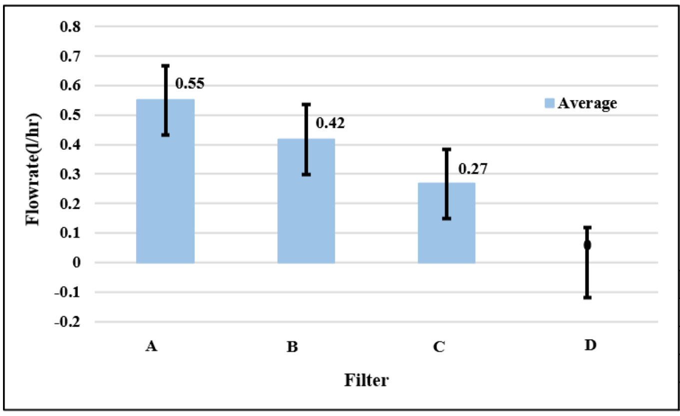
Testing Procedure

The prepared water samples were passed through the non-modified and nanoparticle-modified filters under gravity. The flow rate was maintained at a constant level to ensure uniform contact time for all samples. Samples of filtered water were collected and analyzed for Arsenic removal efficiency.

RESULTS AND CONCLUSION

Flowrate Test Results of Filters Prepared with different Proportion of Sawdust

Figure.1 presents the flow rate test results for filters containing 10%, 20%, 30%, and 40% sawdust by weight. The filter made with a 60:40 clay-to-sawdust ratio (Filter A) exhibited the best filtration performance. Filter A had the highest initial filtration rate, reaching 0.8 L/hr in the first hour, but this rate gradually decreased, stabilizing at 0.5 L/hr by the sixth hour. In contrast, Filter C (80:20 clay to sawdust) maintained a constant filtration rate of 0.26 L/hr throughout the test, although it was considerably slower. Filter B, with clay to sawdust ratio of 70:30, displayed significant variability in flow, with an average rate of 0.42 L/hr. For further water quality analysis, samples from Filters A and B, with sawdust proportion of 40% and 30%, respectively, were selected, as they demonstrated better overall filtration rates. Filter D, which contained the lowest amount of sawdust, exhibited almost no flow, likely due to the limited pore formation caused by the reduced quantity of burnout material.



Filter	Clay : Sawdust
A	60:40
B	70:30
C	80:20
D	90:10

Figure 1. Graph showing flowrate test results of clay filters.

Filtration Test Results of Clay Filters

Table 1 gives the filtration test results of Filters with 40% and 30% sawdust proportion. Turbidity, Solids and MPN tests conducted on raw water sample showed it is highly contaminated and unsafe for drinking. Turbidity was measured to be 17.8 NTU and MPN- >24000/100ml. The filtered samples showed large reduction in these values and were found to be within the BIS permissible limits. Filter A (60:40) showed 97% turbidity removal, 94% TS removal efficiency and 100% microbial removal whereas filter B (70:30) had 96% turbidity removal efficiency, 93% TS removal and 98% microbial removal. Both the proportions for the filter produced similar results in quality analysis. Considering better filtration rate of filter (60:40), it was concluded that 60(clay):40(saw dust) was the proportion for producing modified filters.

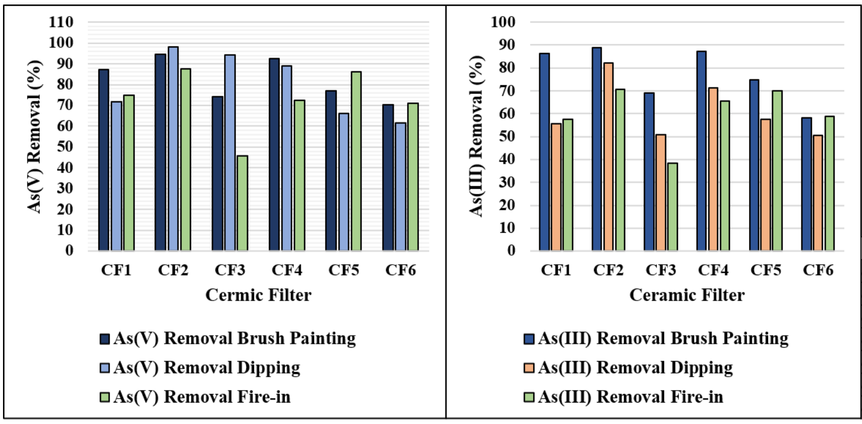
Table 1. **Filtration test Results of Clay Water Filters**

Parameters	Raw water sample	Filtered water from Filter A (60:40)	Filtered water from Filter B (70:30)	Permissible Limit (IS 105600:2012)
pH	7.68±0.26	6.8±0.185	6.8± 0.23	6.5-8.5
Turbidity	17.8 NTU	0.61 NTU	0.72 NTU	<10 NTU
TSS	440 ± 4.04 mg/l	40 ± 2.51 mg/l	60 ± 3.6 mg/l	500 mg/l
TDS	826 ± 6 mg/l	43.6 ± 1.52 mg/l	44 ± 4 mg/l	500 mg/l
Alkalinity	8.1 ± 0.1 mg/l as CaCO3	4.13 ± 0.11 mg/l as CaCO3	3.48 ± 0.27mg/l as CaCO3	200 mg/l as CaCO3
Total Hardness	79.6 ± 1.15 mg/l as CaCO3	30.16 ± 0.35mg/l as CaCO3	29.6 ± 0.76 mg/l as CaCO3	200 mg/l as CaCO3
MPN	>2400/100ml	-	40/100ml	0/100ml

Performance of Modified Filters with respect to Arsenic and Total coliform Reduction

All the filters, modified or non-modified displayed excellent coliform removal above 99.4%, which was in par with the literature. Figure. 2 represents As(V) and As (III) removal efficiency by non-modified and modified ceramic filters. As(V) and As (III) removal by non-modified ceramic filters were 51.06% and 24.73% respectively. The highest As (V) removal was at 98.2% by ceramic filter modified with Fe-Cu binary oxide (CF2) by dipping method. Filter modified with Fe-Ce binary oxide (CF4) using brush painting also displayed promising results with As(V) removal at 92.46%. Least removal was at 45.7% by filter modified with CuO nanoparticles (CF3) by fire-in method. CF2 and CF4 displayed removal efficiencies above 70% for all the three methods used for nanoparticle addition. Similarly for As(III) removal, CF2, brush painted displayed a removal efficiency of 88.79% and CF4 brush painted displayed 87.28%. Least removal was at 38.26% by CF3 modified by fire-in method. CF2 displayed removal above 70% for all the three methods of nanoparticle addition. The filters were effective in removing As(V) more than As(III).

The findings of this study indicate that modifying ceramic filters with specific nanoparticles, particularly Fe/Cu binary oxide and Fe-Ce binary oxide, significantly enhances their capability to remove arsenic from water. This approach offers a cost-effective and efficient solution for improving drinking water quality in remote rural areas of developing countries. The development and implementation of such enhanced ceramic filters could play a crucial role in mitigating the health risks associated with contaminated water sources and contribute to the well-being of rural populations.



Filter	Modified with
CF0	no modification
CF1	Iron Oxide
CF2	Fe/Cu bimetal oxide
CF3	CuO
CF4	Fe-Ce bimetal oxide
CF5	CeO2
CF6	La(III)

Figure.2. Graph showing As (V) and As (III) removal using filters modified with nanoparticles

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