Impact of rock alum pretreatment on biosand filter performance in Cambodia

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ABSTRACT

Alum is often recommended by WASH agencies as a pretreatment floculant to improve filtration in biosand filters (BSFs) for communities using a turbid drinking water source. Floating villages on the Tonle Sap Lake in Cambodia using BSFs encounter severe declines in filtration rates while using alum, resulting in reduced use of the BSF. We tested the effect of rock alum treatment on flow rate and turbidity. The flow rate of all BSFs declined over time, but degradation of flow was more rapid for alum-treated water than untreated water. Rock alum treatments significantly reduced the turbidity of borrow pit source water. Filters switched to untreated river water decreased in turbidity to levels < rock alum-treated river water. Rock alum treatments increased aluminum in source water 4–15 times, but filtration by BSFs decreased levels of aluminum to near 0.05 mg/L. Though rock alum effectively reduces turbidity in source water, we believe it continues its coagulation inside the BSF during pause periods, negatively impacting flow rates.

Key words | alum, aluminum, biosand filters, Cambodia, flow rate, turbidity

INTRODUCTION

Biosand filters (BSFs), originally developed by Manz (2019), are an effective point-of-use household water treatment used around the world and extensively field tested in Cambodia (Duke et al. 2006; Sobsey et al. 2008; Liang et al. 2010; Aiken et al. 2011; Stauber et al. 2012). Filtration of turbid source water quickly results in reduced flow rates from accumulated particles. Therefore, BSFs require the regular ‘swirl and dump’ maintenance of stirring the top layer and removal of the resuspended sediments.

Alum is often used by itself or in combination with other treatments to improve filtration and reduce bacteria when filtering turbid source water with BSFs. Alum was used as a water clarifier in ancient India and China (Baker 1948) and referenced by 17th century Spanish missionary Navarette, as used with a 2-h settling period to clarify drinking water (Jahn 1999). It can reduce coliform numbers by three orders of magnitude 1 h after treatment and to non-detectable numbers after 6 h (Oo et al. 1993; Crump et al. 2004; Wrigley 2007). Of four common floculants for drinking water pretreatment, alum is often the most effective compared to PACI, PACHS, and ferric chloride and has been shown to remove over 80% of Synedra (Jun et al. 2001).

Other filtration aids like aluminum sulfate, ferric chloride, and polyaluminum chloride help remove organics and enhance coagulation. Type and concentration of the coagulant influences TOC and natural organic matter reductions, with effectiveness determined by the pH characteristics of the untreated water (Bratby 2006). Coagulant/disinfectants like PUR water treatment sachets are often promoted for household water pretreatment but cost about 0.10 USD per packet, which can be a significant expense for daily use by rural household users in developing countries. The expense of these treatments for rural users makes rock alum (AlNH₄SO₄) an attractive alternative because it is often...
mined within many developing countries, making it readily available and inexpensive to purchase in local markets.

Floating village communities on the Tonle Sap Lake in Cambodia using point-of-use BSFs encountered severe declines in filtration rates while using alum and would stop using BSFs. Since using alum as a pretreatment flocculent for turbid source water is intended to improve filtration, decrease maintenance, and lengthen the effective use of the BSF, Water for Cambodia and NGOs using point-of-use BSF in Cambodia wanted to resolve whether alum contributed to the decline in flow rates. Considering alum is recommended by WASH agencies where communities use a turbid water source for their drinking water supply (Crump et al. 2004; WHO 2017), resolving the observed declines in flow rates were important. Consequently, we collaborated with Water for Cambodia in 2015 to explore the impact of alum pretreatment of turbid source water for users of a PVC BSF similar to the Hydraid filter (Manz 2013) in the Moat Klah floating village in Cambodia.

**STUDY GOALS**

Goals of our study were to:

- determine if treating turbid source water with alum negatively affects the flow rate over time,
- determine if rock alum impacts turbidity of filtered source water, and
- determine if the rock alum treatment impacts the aluminum concentration of water filtered by the BSF.

**METHODS**

We tested six BSFs that had been seasoned for 1 month to develop a biolayer. All six filters were stored outside at Water for Cambodia. Three each received 8 L from 20 L of source water treated with rock alum; three others each received 8 L from 20 L with no rock alum treatment.

Source water from a local highway borrow pit and the Siem Reap River was treated in 20-L buckets with rock alum with 10 swirls just under the surface, as practiced by residents in the Moat Klah floating village on the Tonle Sap, Siem Reap Province, Cambodia. Untreated source water was also swirled 10 times but with no rock alum. Treated and untreated water was allowed to settle 4–5 h before being poured into the filter. We poured source water through a cheese cloth filter into each BSF each day to fill the reservoir above the sand to the top of the filter, being careful not to pour any flocculated particles that had settled. Source water was switched from borrow pit water to the Siem Reap River to test the filter response to a less turbid source.

When source water was poured into a filter, the volume of water displaced through the BSF was measured for 60 s to estimate the flow rate at full reservoir capacity of the filter. Treated and untreated source water after the 4 h settling period and water filtered from each respective BSF were sub-sampled and tested for turbidity and aluminum levels using a Hach 2100Q Turbidimeter and a Hach Method 8012 test for aluminum.

Analysis of covariance (ANCOVA) conducted in SPSS v.25 was used to test for differences in the mean flow rate and turbidity between treatments, water sources, and their interactions while controlling for the effects of time since cleaning. This analysis facilitated comparison between treatments of the slopes of the changes in flow rates over time since cleaning.

**RESULTS AND DISCUSSION**

The flow rate of all filters declined over time (Figure 1). However, there was a significant treatment×time since cleaning interaction (ANCOVA: $F = 15.54$, $P < 0.001$; Table 1), indicating that the slope of the relationship between the flow rate and time since cleaning differed between treatments. Specifically, the flow rate declined more rapidly for the alum treatment ($b_1 = -51.49$) than for untreated water ($b_1 = -18.29$). This result was unaffected by the change of water source.

Swirl and dump maintenance generally improved the flow rate for a short duration. Filters receiving untreated source water showed a slower degradation in the flow rate and wide variation in flow over time but never achieved flow rates below 400 mL/min as observed in filters receiving the rock alum-treated source water (Figure 1).
Rock alum treatments significantly reduced turbidity for source water taken from the construction borrow pit between 28 January and 13 February (Figure 2). Average turbidity in borrow pit pond source water treated with rock alum and allowed to settle for 4 h was 20.7 NTU (SD ± 6.2), while the untreated water was 354.6 NTU (SD ± 64.8). Switching the source water to Siem Reap River water on 16 February resulted in significant declines in turbidity levels, but only for filters receiving untreated water (significant treatment × water source interaction; Table 1). River source water treated with rock alum and allowed to settle for 4 h averaged 8.7 NTU (SD ± 3.5), while untreated river source water was 22.8 NTU (SD ± 4.9). In these filters, turbidity declined to levels <20 NTU, consistently near or below 1.0 NTU. Time after swirl and dump cleanings of filters produced no significant linear trend in turbidity over time.

Whether water was treated with rock alum or not, the BSF decreased the levels of aluminum in water being filtered. Rock alum treatments increased levels of aluminum in the source water by 2–15 times, depending on the source. Average aluminum in borrow pit pond source water treated with rock alum and allowed to settle for 4 h was 1.03 mg/L (SD ± 1.03), while the untreated water was 0.23 mg/L (SD ± 0.05). River source water treated with rock alum and allowed to settle for 4 h averaged 3.85 mg/L.

**Table 1** ANCOVA test results on turbidity and the flow rate of water filtered through the BSF

| Source of variance       | df | Turbidity F | P    | Flow F | P    |
|--------------------------|----|-------------|------|--------|------|
| Model                    | 7  | 35.71       | <0.001 | 23.08  | <0.001 |
| Treatment                | 1  | 23.70       | <0.001 | 3.99   | 0.048 |
| Source                   | 1  | 13.15       | <0.001 | 0.69   | 0.408 |
| Time                     | 1  | 0.21        | 0.650 | 26.62  | <0.001 |
| Treatment × source       | 1  | 13.13       | <0.001 | 0.00   | 0.987 |
| Treatment × time         | 1  | 0.19        | 0.664 | 15.54  | <0.001 |
| Source × time            | 1  | 0.58        | 0.449 | 0.08   | 0.781 |
| Treatment × source × time| 1  | 0.54        | 0.462 | 2.27   | 0.134 |
| Error                    | 136|             |       |        |      |
| Total                    | 144|             |       |        |      |

Factors include alum treatment (alum added versus untreated) and water source (borrow pit pond versus Siem Reap River). The covariate was time since swirl and dump maintenance (in days). Bold type indicates significant results at the 0.05 level of confidence.
(SD ± 0.77), while untreated river source water was 0.21 mg/L (SD ± 0.29). Average aluminum concentrations in filtered source water increased over the test period for filters receiving untreated borrow pit source water but decreased for filters that were switched to untreated river water. Filters receiving treated pond source water and treated river water had aluminum levels near 0.05 mg/L after filtration throughout the study, even though treated source water averaged 1.03–3.85 mg/L before filtration, suggesting that the filter media are removing aluminum. Levels of aluminum in the filter effluent remained constant whether aluminum levels in the source water increased or decreased over the study.

Hidayah et al. (2018) note that alum coagulation mainly removes the humic substances in eutrophic lakes. Thus, in a highly turbid eutrophic lake like the Tonle Sap, there is likely to be a high level of hydrophobic humic substances. We observed most floating village users waiting 30–45 min for flocculation and settling. We waited 4 h and observed significantly greater declines in the flow rate for filters receiving alum-treated source water. Consequently, we believe that 30–45 min for flocculation is too short and allows for more coagulation to occur inside the BSF sand media during the recommended 2–4 h filter pause period. If users decline to perform maintenance cleaning of the upper sand layer, flow rates decline rapidly. At the end, users experiencing increased filtration times because of rapidly reduced flow give up on using the BSF and revert to direct use of unfiltered lake water, similar to what Islam et al. (2013) observed for Bangladesh users of pond sand filters that were reluctant to perform sand washing maintenance.

**CONCLUSIONS**

Based on our findings and our work with household users in the Moat Klah floating village, we conclude the following for rock alum as a pretreatment: Even with a 4-h settling period after rock alum pretreatment of source water, flow rates significantly decrease over time compared to untreated source water. The rate of decline depends on source water characteristics.

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**Figure 2** Mean turbidity for filtered water in the BSF study of alum treatment (± 95% confidence interval). Blue diamonds represent source water that was treated with rock alum; red squares indicate samples from untreated source water. Alum average turbidity, three filters receiving water treated with rock alum; no alum average turbidity, three filters receiving raw untreated source water; S and D, swirl and dump cleaning of top 5 cm of sand. Please refer to the online version of this paper to see this figure in colour: http://dx.doi.org/10.2166/washdev.2020.092.
We believe that residual alum in treated source water continues coagulation inside the filter media during pause periods. For many floating village household users, post treatment coagulation periods before pouring are <1 h. This would allow more residual alum to enter the BSF.

**Treatment with rock alum reduces turbidity**

Average aluminum in treated source water was 4–15 times higher than untreated water, but BSFs reduced aluminum to levels near 0.05 mg/L, suggesting that the filter media remove the aluminum.

Weekly swirl and dump cleaning of the upper sand layer is necessary when using rock alum to pretreat turbid source water. For floating village users, we recommend rock alum not be used during the rainy season, when turbidity decreases. This will extend filtration performance and minimize clogging from residual alum inside the sand layers during pause periods.

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