Short Communication

The potential of a semi-decentralised bulk water treatment approach for emergency relief

Caetano C. Dorea and Vincent Jalaber

ABSTRACT

Humanitarian water treatment interventions vary from package bulk ‘kits’ to household (point-of-use) options. Whereas the former can be perceived to be too complex to operate, the latter, whilst relatively simple and effective, has logistical requirements that may hinder its application during relief operations. This study evaluates the potential of a semi-decentralised water treatment approach for humanitarian emergencies. Its performance was evaluated against the relevant water quality treatment objectives (The Sphere Project) under controlled laboratory conditions using a synthetic test water. Results revealed that whilst the recommended minimum free chlorine residual levels were not attained (possibly due to high chlorine demand of test water), all other treatment objectives were within desired values, namely: <1 colony-forming unit (cfu)/100 mL with regards to thermotolerant (faecal) coliforms and <5 NTU (nephelometric turbidity units) for treated water turbidity. Given the performance of the semi-decentralised approach tested here, it could be expected to attain all treatment objectives when tested in natural surface waters. It has the potential to bridge the gap between centralised (i.e. bulk water treatment kits) and fully decentralised (i.e. household) water supply strategies.

Key words | coagulation, disinfection, emergency, water treatment

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INTRODUCTION

Emergency water treatment and supply is a key intervention in humanitarian relief efforts to prevent the spread of diarrhoeal diseases. This is achieved through the deployment of a variety of packaged centralised bulk water treatment ‘kits’ by relief agencies. Some of the most utilised systems in practice use coagulants (e.g. aluminium sulphate) to condition raw water before a particle separation process (i.e. clarification or media filtration). A recent review (Loo *et al.* 2012) has assessed emergency water treatment options and considered coagulant-based systems to be relatively complicated to operate. This was attributed to the perceived difficulties in determining adequate coagulant dosages (i.e. jar-testing). Although simplified procedures for such operations are available and have been successfully implemented in relief contexts with trained non-experts (Dorea *et al.* 2009), the reality is that the capacity building capability of a relief agency may be limited, non-existent, or non-feasible during a response.

Coagulant/disinfection products (CDPs) are single-dose point-of-use (POU) water treatment options intended to treat waters of variable quality. CDPs can provide microbial quality improvements, turbidity reductions, and post treatment protective free chlorine residuals (FCRs). These decentralised (household) water treatment products typically come in the form of sachets containing predetermined amounts of coagulant, disinfectant and other sometimes proprietary ingredients that can treat anywhere between 10 to 20 L of water at a time. This approach could be advantageous in relief interventions where the affected population is dispersed (Luff & Dorea 2012) and a centralised water treatment and supply chain is unfeasible. Such a relief intervention still requires training of all the beneficiaries

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on the use of the CDPs, which could be somewhat demanding with regard to its logistical requirements.

Use of CDPs for water treatment at a semi-decentralised scale, say 200 to 2000 L at a time, could be advantageous in that training efforts could be focused on key individuals at water distribution points, rather than all beneficiaries. This could reduce the initial training requirements and effectively reach a larger amount of beneficiaries, thus, potentially taking advantage of the treatment benefits of such CDP products with reduced (perceived) complications of conventional coagulation relief applications. Whereas the small-scale performance of CDPs (i.e. between 10 to 20 L) is relatively well documented (e.g. Souter *et al*. 2003; McLennan *et al*. 2009; Marois-Fiset *et al*. 2013), this is the first known description of the adapted use of CDPs at a decentralised scale. The objective of this study was to evaluate the treatment performance of a CDP adapted for use as a potential humanitarian water treatment option at a semi-decentralised scale.

MATERIALS AND METHODS

A commercially-available CDP for the treatment of 10 L of water, PUR Purifier of Water (Procter and Gamble Co., Pakistan – now marketed as P&G Purifier of Water), was adapted for use in a 200 L plastic reservoir. The contents of 20 sachets were emptied into a single polypropylene container and used within 5 minutes of being opened. Once applied (Figure 1), the CDP was mixed (for 5 min) with a plunger made out of a circular-shaped piece of plastic (30 cm diameter) fixed onto a shaft. Such a procedure guaranteed the mixing and dissolution of the product in the test water. Thus, the reaction time of both the principal active ingredients (i.e. ferric sulphate and calcium hypochlorite) of the CDP was considered to have started upon addition. Once the 25 minute settling period was over, aliquots were decanted by dipping a sterile container in the clarified supernatant of the testing reservoir. The clarified water that was collected was subsequently filtered through a sterile non-woven viscose fibre fabric (J-Cloth; Associated Brands, Canada). This procedure was in line with the original product instructions for use in 10 L batches. Filtrate for a bacterial analysis was collected in autoclaved polypropylene bottles containing sodium thiosulfate to quench residual chlorine. All other containers were sterilised with ethanol before use during experiments.

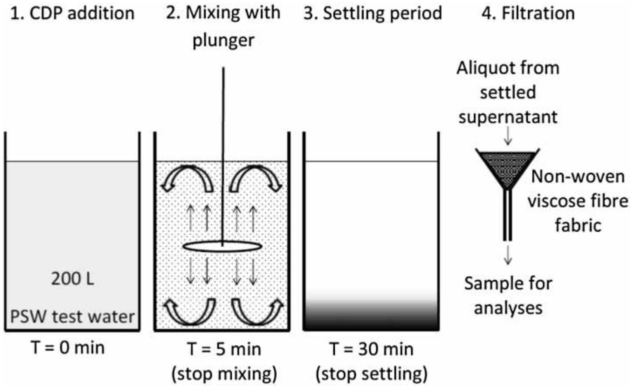

Figure 1 | Schematic representation of the 200 L CDP water treatment experiment.

The test water matrix consisted of a 1:5 dilution of a primary settled wastewater (PSW) from a local wastewater treatment plant in dechlorinated tap water. This would simulate a grossly polluted source. Turbidity was adjusted to approximately 100 nephelometric turbidity units (NTUs) using a kaolin (Sigma-Aldrich Co., Canada) clay slurry. Target pHs were set at 5 ('acidic pH'), 7 ('neutral pH'), and 9 ('alkaline pH') with appropriate amounts of NaOH or H_2SO_4 before the CDP was added. This was in line with the objective of evaluating the CDP's performance under simulated extreme conditions known to affect the efficiencies of the product's underpinning processes (i.e. coagulation and disinfection) as per previous work (Marois-Fiset *et al*. 2013). Each test water condition (100 NTU + target pH) was tested twice resulting in a total of six tests.

CDP treatment potential was assessed with regard to its bactericidal efficiency, turbidity reductions, and FCR levels. Water quality treatment objectives for humanitarian relief water interventions (The Sphere Project 2011) consist of no *E. coli* (or thermotolerant coliforms) per 100 mL, turbidity less than 5 NTU, and a FCR of 0.5 mg/L after a 30 minute contact time and with a pH < 8. Triplicate thermotolerant (faecal) coliform (TFC) concentrations were determined according to procedures established in Ayres & Mara (1996). Turbidity, pH, and FCRs were measured using a 2,100 P turbidimeter, HQ40d pH meter, and pocket colorimeter, respectively, as specified by the manufacturer

(HACH, USA). With the exception of turbidity, every other parameter was sampled before and after CDP treatment; that is, 30 minutes after CDP application once cloth filtration was done. In addition, turbidity was analysed just before the filtration step as well as after 1 and 2 hours of settling.

RESULTS AND DISCUSSION

The performance results summary of the CDP for semi-decentralised bulk water treatment is presented in Table 1. Water quality objectives for humanitarian relief water interventions as defined by The Sphere Project (2011) were attained with the exception of FCRs, namely: no TFCs per 100 mL, turbidity less than 5 NTU, and a FCR of 0.5 mg/L after a 30 minute contact time and with a pH < 8. Such treatment objectives are also aligned with the World Health Organization (WHO) (2011) guidelines.

As treated water samples all had non-detectable bacterial indicator concentrations, the method detection limit of 1 colony-forming unit (cfu)/100 mL was used to calculate the TFC $\log_{10}$ reductions (LRs). LRs for the different test conditions were of 4.4 (pH 5), 3.9 (pH 7), and 3.0 (pH 9). This decreasing trend was attributed to the decreasing initial bacterial concentrations of each test condition (which limits the maximum possible LRs). The initial pH of the test waters is not thought to have affected observed LRs due to the buffering capacity of the product (further discussed later). PSW samples were collected from a wastewater treatment plant served by a unitary sewerage system; resulting in some samples being more dilute due to rain events during the test period. With some bacterial levels below the detection limit after treatment with the CDP, some LR values could be expected to be higher as they were limited by the initial bacterial concentrations in the PSW dilution. Previous work with the same CDP tested at a household scale (10 L) has shown that LRs of 6 to 8 can be expected under laboratory conditions (Souter *et al.* 2003; McLennan *et al.* 2009; Marois-Fiset *et al.* 2013).

Despite the varying initial target pH, final pH in treated waters was relatively stable (Table 1). These values remained close to the range typically considered to be good for disinfection and coagulation (between 6 and 7). This is thought to be due to a buffering agent contained in the CDP's formulation. Similar observations were made in previous work (Marois-Fiset *et al.* 2013) using the same CDP on a reduced scale (i.e. 10 L).

Considerable turbidity reductions were achieved through settling during the 30 minute treatment time with marginal improvements with longer settling times (Figure 2). Through settling alone (i.e. without considering improvements due to the subsequent filtration step), turbidity reduction targets were achieved. By the end of each test, most of the flocs were settled at the bottom of the tank in a relatively compact layer of settled sludge estimated to be less than 5 cm deep by visual inspection. However, during the trials it was observed that some of the formed floc was floating. No correlation was made between the appearance of floating flocs and particular water quality characteristics. Occurrence of floating flocs was also observed in preliminary tests using the product in its original 10 L application. It is not thought that the issue with floating flocs was due to the scaling-up of the treatment volume. A particular effort was made to avoid floating flocs while decanting off the supernatant when sampling, as this could deteriorate the treated water quality. In a potential field application, it is likely that the user would avoid (as much as possible) floating or settled flocs. Nonetheless, the final filtration step provided additional turbidity reductions

Table 1 | Treatment performance summary data for average TFC, turbidity, FCR, and pH results at 30 minutes after start of treatment

	TFC (cfu/100 mL)		Turbidity (NTU)		FCR (mg/L)	pH
Test condition	**Initial**	**Treated**	**Initial**	**Treated**	**Treated**	**Treated**
pH 5	2.3×10^4	< 1	94	0.66	0.08	5.7
pH 7	6.7×10^3	< 1	91	0.72	0.10	6.6
pH 9	8.6×10^2	< 1	97	0.86	0.10	6.7

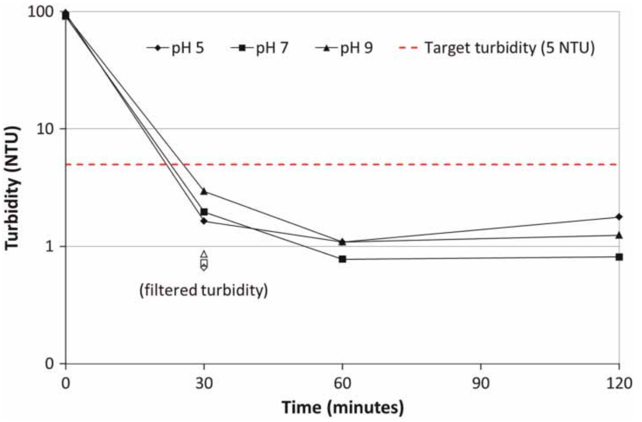

Figure 2 | Turbidity settling profiles at different initial target pH conditions. Initial target test turbidity was set at 100 NTU. Empty markers indicate turbidity after cloth filtration.

further improving the quality of treated water. In practice, it would be advisable to devise a more hygienic way of collecting settled water, as collection containers may not be sanitised and could be a source of post-treatment contamination. To this end, a tap could be installed at the bottom of the tank making provisions to avoid settled sludge during the collection of treated water.

According to the manufacturer of the CDP, the treatment sludge should be disposed of 'away from children and animals.' However, no further details are given on how this should be done. Given the extreme circumstances, common practice in many emergency bulk water treatment operations is to discard the sludge into watercourses (Dorea 2009). For the semi-decentralised treatment being assessed, it is difficult to evaluate possible undesirable environmental effects of such a disposal practice given the type of coagulant (i.e. ferric sulphate), the scale of treatment, and the relatively short duration it is intended to be used for in emergencies.

FCRs (measured at 30 minutes) were all below the recommended level of 0.5 mg/L. This is probably due to the PSW test water dilution's relatively high chlorine demand. Similar observations with regard to FCRs were made in another study using the same CDP and similar test water composition (McLennan *et al.* 2009). Tests in naturally occurring surface waters have shown that FCRs between 0.5 and 1.5 mg/L could be expected (Reller *et al.* 2003). Thus, higher FCRs could be expected from the semi-decentralised approach with the tested product in natural waters, as final FCR levels do not seem to be related to the scale of the treatment, rather to the type of water (i.e. chlorine demand) being treated.

The tests done at 200 L reveal that the volume to be treated by the CDP has the potential to be successfully scaled up from 10 L with regard to humanitarian water quality treatment objectives (The Sphere Project 2011). The full potential of this approach warrants field testing in an emergency setting for validation. This quantity would be enough to meet the daily survival (i.e. drinking and cooking) requirements of about 66 people or 11 families; considering a minimal recommended supply of 3 L per person per day (The Sphere Project 2011). In such a case, the logistical requirements for the training of users could be considerably reduced by needing to train only one user/operator instead of all the beneficiaries. Such training requirements may hinder implementation efforts of household-based water treatment interventions, particularly during the first phases of an emergency response. Such difficulties were reported in the Indian Ocean tsunami emergency response when the implementation of some POU water treatment activities were attempted (Clasen *et al.* 2006). The semi-decentralised approach tested here could help to bridge the gap between centralised (i.e. bulk water treatment kits) and fully decentralised (i.e. household) water supply strategies. However, such an approach would possibly work best were water is readily available (e.g. floodings). Furthermore, it is also possible that this approach could be further scaled to treat larger volumes of say 1,000 or 2000 L at a time, with its implementation depending mainly on the practicalities related to reservoir volume, mixing capacity, and CDP packaging.

To take advantage of the relative simplicity of this form of batch water treatment, precautions would also need to be taken to ensure that the water quality is preserved until the point of consumption. That is, in a semi-decentralised water supply approach, beneficiaries would still need to collect, transport, and store water – these actions all present potential post-treatment recontamination opportunities similar to centralised water treatment approaches, especially if adequate FCR levels can't be maintained. Thus, hygiene promotion activities would need to ensure that effective measures are put in place to preserve water quality until consumption (e.g. cleaning of water vessels and POU chlorination). Another important consideration for its implementation is to ensure that adequate monitoring and evaluation is carried out by relief agencies to ensure the efficacy of treatment, as is done with other approaches.

CONCLUSIONS

A semi-decentralised emergency water treatment approach using a commercially-available coagulant/disinfection product was tested in laboratory conditions. Humanitarian water quality treatment objectives were met with regard to TFCs and turbidity. The minimum recommended FCR level of 0.5 mg/L was not attained. However, this could have been due to the high organic content (i.e. high chlorine demand) of the test waters used. Based on the results attained, it is thought that this approach could be a potential alternative to the perceived complexity of centralised bulk water treatment kits and the logistical requirements of fully-decentralised household options.

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