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Disinfection of water by various techniques – comparison based on experimental investigations

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ABSTRACT

In the present study, laboratory experiments were conducted for determining effectiveness of various disinfectants against inactivation of Total Coliform and Fecal Coliform of water samples collected from different sites of Jadavpur University. Chlorine (sodium hypochlorite and bleaching powder), silver, copper, solar radiation, ultraviolet rays and boiling was facilitated; samples were intermittently tested with respect to contact time (CT) following most probable number technique (MPN/100 ml) and bacteriological H_2S strip tests. After chlorination, chlorine demand and residual-free chlorine was obtained using modified Horrocks method. Effective CT sufficient to lower down the viable counts, by various mode of treatment are as follows: boiling-1 min < chlorination-30 min < UV treatment-1 h < SODIS-6 h < silver wire-8 h < copper wire-8–10 h. Samples were passed through ultraviolet rays at different flow rates; it was very effective against lower contamination. However, it did not show good disinfection against higher contamination, suggesting a need for providing proper contact. Silver and copper disinfection requires low operational cost nonetheless takes longer time for disinfection. SODIS may be encouraged in rural areas though a weather-dependent process. Boiling is efficient and faster compared to other methods, chlorine disinfection is a standard process to treat large volume of contaminated water; though should be avoided as its byproducts are very harmful for human health.

Keywords: Chlorination; Sodium hypochlorite; Calcium hypochlorite; Silver wire; Copper wire; Disinfection; Ultra violet radiation; Solar disinfection (SODIS); Most probable number/100 ml (MPN/100 ml) and bacteriological H_2S strip test

1. Introduction

Over 30% of the population in developing countries is in need of safe drinking water. There are reports of 875 million populations suffering from diarrhea and 4.6 million death cases that result every year due to a lack of a safe water supply in India. Therefore, it is necessary to disinfect water before its consumption [1,2]. Disinfection of water refers to the destruction of disease causing organisms. Disinfection does not necessarily result in the complete sterilization of a water supply, rather it reduces the number of pathogens like bacteria, viruses, and amoebic cysts; responsible for water borne diseases [3]. Disinfection by chlorination forms residual-free chlorine (RFC) in

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water that may inactivate *Cladosporium tenuissimum*, *Cladosporium cladosporioides*, *Phoma glomerata*, *Aspergillus terreus*, *Aspergillus fumigatus*, *Penicillium griseofulvum*, and *Penicillium citrinum* from different water sources [4]. The disinfection efficiency of chlorine in terms of Degree of Microbial Inactivation is calculated based on the percentage available free chlorine concentration and contact time (CT) values. Mixture of sodium chloride (NaCl) and sodium hypochlorite (NaOCl) is known as a good disinfectant of water, 30 min CT may reduce 82% bacterial population. Whereas, 90% bacterial population may be reduced using sodium hypochlorite (NaOCl) alone for 30 min CT. NaOCl at 10% concentration may result in maximum percentage reduction in bacterial population [5,6]. Yet another interesting mode of disinfection is silver-impregnated ceramic pot filter for low-cost household drinking water treatment [7]. Ozonation, copper–silver ionization, and increased temperature are yet few more interesting modes of water disinfection that may control the water borne pathogens. One of the most effective and low cost disinfection is sunlight, a potent sterilizing media for the destruction of total heterotrophic bacterial count, it is possible to achieve decontamination of water samples without any danger of bacterial re-growth [8]. The effectiveness of UV technology has gained much apprehension as a disinfectant. The factor that may be disadvantageous is the UV intensity, exposure time, the area, clarity of the water, etc. The selection of UV wavelength is very important factor for the process to achieve efficient disinfection. The optimum microbial killing efficiency ranges from 254 to 260 nm wavelength probably varies with the type of organism [9]. Boiling improves the microbiological quality of drinking water and it is an easy, low cost method that may be an alternative for treating water at home.

The present research study highlights on application of various disinfectants on pond water, ground water, and supply water from treatment plant, used for drinking and other domestic purposes. The water quality assessment was done based on the frequency and adequacy of microbiological contaminants in water, before and after disinfection. The tests performed followed culture-dependent methods using (a) most probable number technique (MPN/100 ml), method for identification of Total and Fecal Coliform/100 ml of sample and (b) bacteriological H_2S tests, method for determination of bacteria belonging mostly to *Enterobactericeae* family that are responsible for contamination of water, H_2S method also determines the presence of *Clostridial* bacilli in contaminated water based on the color change of the medium [10]. The overall objective of the present study is to assess the microbiological quality of water to identify the most reliable and cost-effective method for water disinfection and finally to provide a user-friendly guideline that will be more relevant for disinfection of water [11–14].

2. Materials and methods

2.1. Sample collection and preservation

Samples were collected in sterile screw cap containers aseptically and brought to the laboratory for testing. The tests were performed instantly and culture plating was completed after giving sufficient CT:

(1) Drinking water samples were collected from various sites of Jadavpur University Campus specifically from the outlet of the treatment plants of Garden reach water supply, Aurobindo Bhawan, Ashirbad Food Court (sample-1, 2, and 3, respectively), etc.
(2) Ground water was collected from two different sources of water outlets supplied to SWRE, (sample-4 and 5, respectively) of School of Water Resource Engineering Building (SWRE).
(3) The pond waters (10, 30, and 50 ml) were collected from pond located near, SWRE building, Jadavpur University campus, (sample-6, 7, and 8, respectively).

All the three different water sources namely ground, pond, and treated drinking water were chemically different from the other [15]. The pond water differs chemically from ground water (raw water) and supply water (drinking water). At the time of chlorination, source water from different locations was found chemically satisfactory in terms of following parameters tabulated in Table 1.

2.2. Sampling and water testing

The samples were collected aseptically by flaming the tap after application of absolute ethanol, then the tap was opened and the water was run for 5 min. Samples were collected in PTFE containers and kept inside the ice-box. The samples were carried to the laboratory immediately for bacteriological testing. The samples were collected from the following locations and sources:

(1) Sample-1: Garden Reach Supply Water-Treatment Plant Outlet water.
(2) Sample-2: Aurobindo Bhawan Supply Water-Treatment Plant Outlet water.

Table 1
Difference in chemical composition of various source waters

Sl. no.	Parameters	Requirement (acceptable limit)	Permissible limit in the absence of alternate source	Source		
				G.W	P.W	S.W
1	pH value	6.5–8.5	6.5–8.5	7.32	7.95	7.42
2	Total dissolved solids, mg/L	500	2,000	1,050	290	556
3	Turbidity (NTU)	1	5	2.5	22	1.44
4	Iron (as Fe), mg/L	0.3	1.0	0.85	0.22	1.03
5	Chloride, mg/L	250	1,000	483	54	218
6	Nitrate, mg/L	45	45	0.62	0.47	0.35
7	Total hardness ($CaCO_3$), mg/L	200	600	502	220	333

Notes: G.W—ground water, P.W—pond water, S.W—supply water or treated water.

(3) Sample-3: Asirwaad Food Court Supply water-Treatment Plant Outlet water.
(4) Sample-4: SWRE Building Overhead tank-Ground water stored directly.
(5) Sample-5: SWRE Bathroom Tap water-Ground water supplied to Bathroom from Over head storage tank.
(6) Sample-6: Pond water-10 ml Pond water diluted with Drinking water to 1 L.
(7) Sample-7: Pond water-30 ml Pond water diluted with Drinking water to 1 L.
(8) Sample-8: Pond water-50 ml pond water diluted with drinking water to 1 L.

Sample-1, sample-2, and sample-3 is drinking water supplied from treatment plant. Sample volume used for test is 1 L. Sample-4 and 5 is ground water used for domestic purpose. Sample volume used for test is 1 L. Sample-6, 7, and 8 is pond water. Sample volume is specified above.

2.2.1. Chlorine disinfection

Chlorine is used to destroy disease-causing organisms in water, an essential step in delivering safe drinking water [16]. Disinfection of water may be done by various types of chlorine compounds. In this study, following types of chlorine compounds were used: (I) sodium hypochlorite and (II) bleaching powder [17,18]. Disinfection of water by these chlorine compounds involves various processes; firstly chlorine demand check calculated by modified Horrocks method, secondly RFC test using Ortho-toluidine solution (OT) [19] finally examination of bactericidal activity of RFC likely by Total Coliform (TC), Fecal Coliform (FC) test using most probable number (MPN) method and hydrogen sulfide (H_2S) method [20,21].

2.2.1.1. Chlorine demand test using sodium hypochlorite (NaOCl) and bleaching powder $Ca(OCl)_2$ for supply water (or treated water). Sodium hypochlorite (NaOCl) with 4% w/v available chlorine was used for chlorination of drinking water from various sources, collected from the iron elimination plant outlets of the treatment plants located in Garden reach area (sample-1), Aurobindo Bhawan (sample-2), Ashirwad Food Court (Sample-3) for 30 min. Five dilutions of the samples were made and dosing was done in a range of 2, 4, 6, 8, 10 mg/l of available RFC, respectively. Bleaching powder (25% w/w available chlorine) solution was obtained by mixing 1 g of bleaching powder ($Ca(OCl)_2$) in 1 L of drinking water. Dilutions were made in a range of 4, 6, 8, 10, and 12 mg/L of calcium hypochlorite, respectively. After mixing of bleaching ($Ca(OCl)_2$), chlorination was done to disinfect the ground water (sample-4 and sample-5). The CT given was 30 min. Sampling was done from the water storage tank and from the tap of the bathroom. Sample 4 and 5 were disinfected with Bleaching powder as it was suspected to have higher turbidity. Result is shown in Fig. 2.

2.2.1.2. Chlorine demand test using sodium hypochlorite (NaOCl) for pond water. Sodium hypochlorite (NaOCl), 4% w/v available chlorine was used for chlorination of sample-6 and sample-8, i.e. pond water, for 30 min, five dilutions of both the samples were made and dosing was done in a range of 2, 4, 6, 8, 10 mg/L, respectively. Results obtained are given in Fig. 3.

2.2.1.3. Chlorine demand test using bleaching powder $Ca(OCl)_2$ for ground water. Bleaching powder (25% w/w available chlorine) solution is obtained by mixing 1 g of bleaching powder ($Ca(OCl)_2$) in 1 L of drinking water. Dilutions were made in a range of 4, 6, 8, 10, and 12 mg/L of calcium hypochlorite, respectively.

After mixing of bleaching ($Ca(OCl)_2$), chlorination was done to disinfect the pond water (Sample-6 and sample-8). The CT given was 30 min. Sampling was done from the water storage tank and from the tap of the SWRE bathroom.

2.2.2. Disinfection by silver

Disinfection of water by incorporating metal is an old disinfection method. A silver wire, measuring 3.2 mm radii, length 40 cm, and weight 9 g; was used in this process to evaluate its disinfection efficacy [22]. A bottle was filled with contaminated water containing 10 ml pond water (sample-6). And similarly, two more contaminated water samples are obtained containing 30 and 50 ml pond water per liter of drinking water (sample-7 and sample-8), respectively. The wire was molded in spiral shape and then fitted into the bottle. It was also ensured that the silver wire remains in contact with the contaminated water. The samples of the contaminated water were taken to check the TC and FC prior to its disinfection and after disinfection [7,23]. The TC and FC of the treated water were checked after 2, 4, 6, and 8 h, respectively, by MPN method and H_2S strip test, Table 2.

2.2.3. Disinfection by copper

Copper disinfection follows the same method. The dimension of the copper wire was 15 mm in radius, length-45 cm and weight-30 g. Three bottles were filled with contaminated water containing 10, 30, and 50 ml pond water (sample-6, 7, and 8), respectively. The wire was molded in spiral shape and then fitted into the bottle. It was also ensured that the copper wire remains in contact with the contaminated water. The TC and FC of the water was checked before disinfection and after disinfection by sampling and testing within intervals of 2, 4, 6, and 8 h, respectively, following MPN method and H_2S strip test, Table 2.

2.2.4. Solar disinfection

Solar disinfection (SODIS) is one of the simplest and least expensive methods for providing acceptable quality drinking water [8,24]. Only disadvantage is the climatic and weather condition. Three 1 L capacity transparent PET water bottles were taken and half body of the bottles was painted black so that it can absorb more heat [25]. The bottles were then filled with contaminated pond water 10, 30, and 50 ml (sample-6, 7, and 8), respectively. Contaminated water samples were filled into a half blackened transparent PET bottle and exposed to the full sunlight for 8 h. All the PET bottles were firmly shaken and kept horizontally directly to sunlight during disinfection process. TC, FC, and bacteriological H_2S strip test of the contaminated water was checked after 2, 4, 6, and 8 h of time duration (as shown in Table 2). The TC and FC of the all the samples were checked before and after disinfection.

2.2.5. Disinfection by ultra violet rays

A low-pressure UV lamp G15T8 (Fig. 1), fabricated by School of Water Resources Engineering, Jadavpur University, was used to check the efficiency of UV as a sterilizing agent. The lamp was held inside quartz sleeves easing the installation. A stable high-voltage source of electricity was placed in it which resulted in a low intensity UV irradiation. The chamber was made of stainless steel with polyvinyl chloride (PVC) caps at both sides of the end. Quartz sleeves with sufficiently high transmission rates were fitted to deliver the UV energy produced by UV lamps. An indicator LED light was put to alert the operation and failure of the system with electronic ballast. Two copper elbow pipes were fitted as inlet and outlet hold up with two controlling valves.

A 10-L capacity Jar with tap was kept just above the height of UV setup, so that water can continuously flow through the tap of the water reservoir into the inlet pipe of the setup. Flow rate were controlled gradually by pressure manometer enabled in the system. 10 L of drinking water was filled in the reservoir. Sample-6 was mixed into it. Contaminated water was made to flow through the tap into the inflow of the set up with four different flow rates at 4.6, 11.1, 17.4, and 51.2 L/h. Water flowing into the chamber was exposed to the UV rays. The UV disinfected water at different flow rates was collected in sterilized sampling bottle to check the TC and FC of the disinfected water. Also, the TC and FC were done prior to the disinfection. Similarly, other two samples-7 and 8 were flown through UV setup and after disinfection; samples were collected for different flow rates. TC and FC of the disinfected water for different sample with different flow rates are shown in the tabulated results in Table 3. Contaminated water is less effective for treatment. Hence, water samples were filtered before UV disinfection [26,27].

2.2.6. Disinfection by boiling

A liter of drinking water was taken in a borosil glass beaker. Sample-6 was mixed to contaminate the

Table 2
TC, FC, and H_2S test experimental results of various modes of disinfection methods with respect to the CT

Mode of disinfection	Sample volume (pond water)	Timing (min)	Total Coliform 10–1–0.1	TC (MPN/ 100 ml)	Fecal Coliform 10–1–0.1	FC (MPN/ 100 ml)	Bacteriological test by H_2S strip
Chlorination using sodium hypochlorite (NaOCl)	10 ml/L (sample-6)	0	4–2–0	22	2–1–1	9.2	Positive
		10	2–2–0	9.3	2–0–0	4.5	Positive
		20	1–0–0	2	0–0–0	<1.8	Negative
		30	0–0–0	<1.8	0–0–0	<1.8	Negative
	50 ml/L (sample-8)	0	5–3–2	140	5–1–1	46	Positive
		10	5–3–0	79	2–3–1	14	Positive
		20	4–2–0	22	2–0–0	4.5	Positive
		30	0–0–0	<1.8	0–0–0	<1.8	Negative
Silver wire disinfection	10 ml/L (sample-6)	4 h	1–1–0	4	1–0–0	2	Positive
		6 h	0–1–0	1.8	0–0–0	<1.8	Negative
		8 h	0–0–0	<1.8	0–0–0	<1.8	Negative
		10 h	0–0–0	<1.8	0–0–0	<1.8	Negative
	30 ml/L (sample-7)	4 h	3–1–0	11	2–1–0	6.8	Positive
		6 h	2–1–0	6.8	2–0–0	4.5	Positive
		8 h	0–0–0	<1.8	0–0–0	<1.8	Negative
		10 h	0–0–0	<1.8	0–0–0	<1.8	Negative
	50 ml/L (sample-8)	4 h	4–2–0	22	3–1-0	11	Positive
		6 h	3–0–0	7.8	2–0–0	4.5	Positive
		8 h	0–0–0	<1.8	0–0–0	<1.8	Negative
		10 h	0–0–0	<1.8	0–0–0	<1.8	Negative
Copper wire disinfection	10 ml/L (sample-6)	4 h	2–0–0	4.5	1–1–0	4	Positive
		6 h	1–1–0	4	0–1–0	1.8	Positive
		8 h	0–0–0	<1.8	0–0–0	<1.8	Negative
		10 h	0–0–0	<1.8	0–0–0	<1.8	Negative
	30 ml/L (sample-7)	4 h	3–2–0	14	2–1–0	6.8	Positive
		6 h	2–0–0	4.5	1–1–0	4	Positive
		8 h	0–0–0	<1.8	0–0–0	<1.8	Negative
		10 h	0–0–0	<1.8	0–0–0	<1.8	Negative
	50 ml/L (sample-8)	4 h	4–2–0	22	2–1–0	6.8	Positive
		6 h	3–0–0	7.8	2–0–0	4.5	Positive
		8 h	1–0–0	2	0–0–0	<1.8	Negative
		10 h	0–0–0	<1.8	0–0–0	<1.8	Negative
Solar disinfection (SODIS)	10 ml/L (sample-6)	2 h	3–1–1	14	2–0–0	4.5	Positive
		4 h	0–0–0	<1.8	0–0–0	<1.8	Negative
		6 h	0–0–0	<1.8	0–0–0	<1.8	Negative
		8 h	0–0–0	<1.8	0–0–0	<1.8	Negative
	30 ml/L (sample-7)	2 h	4–2–0	22	2–1–0	6.8	Positive
		4 h	2–0–0	4.5	1–0–0	2	Positive
		6 h	0–0–0	<1.8	0–0–0	<1.8	Negative
		8 h	0–0–0	<1.8	0–0–0	<1.8	Negative
	50 ml/L (sample-8)	2 h	5–1–2	63	2–2–1	12	Positive
		4 h	2–0–0	4.5	1–0–0	2	Positive
		6 h	0–0–0	<1.8	0–0–0	<1.8	Negative
		8 h	0–0–0	<1.8	0–0–0	<1.8	Negative

Fig. 1. Typical UV experimental setup fabricated by SWRE, JU.

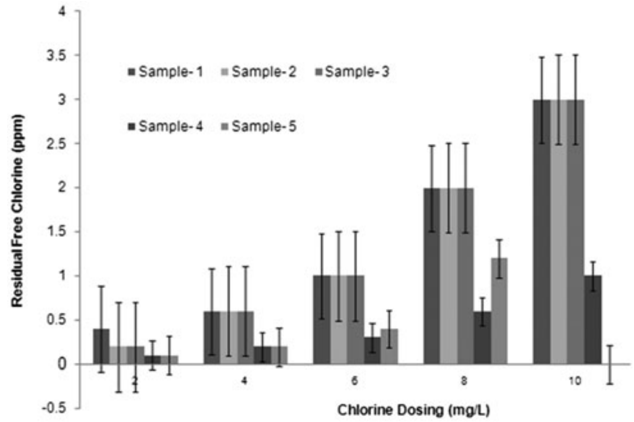

Fig. 2. Chlorine demand test using sodium hypochlorite (NaOCl) and bleaching powder $Ca(OCl)_2$ for supply water (or treated water).

water taken to check the TC and FC. Then, the contaminated water was boiled at 100˚C for different time durations 10, 5, 2, and 1 min, respectively. Sampling was done at each time interval to check for Total and Fecal Coliforms [3].

3. Results and discussion

3.1. Disinfection of water by chlorination

Sample-6 when chlorinated with 2 mg/L of chlorine showed 0.4 ppm RFC after CT of 30 min which is within prescribed limit. Sample-2 and sample-3 after chlorination with 2 mg/L chlorine showed 0.2 ppm of RFC which is also within prescribed limit. Sample-4 and 5 showed 0.1 ppm RFC after chlorination with 2 mg/L chlorine, which is below prescribed limit. Hence, chlorine demand for sample-1, sample-2 and sample-3 is 2 mg/L. Dosing with 4, 6, 8, and 10 mg/L chlorine for sample-1, sample-2, and sample-3 showed RFC more than the prescribed limit. Therefore, to sufficiently chlorinate sample-1, sample-2, and sample-3, 2 mg/L of chlorine solution may be considered adequate. Sample-4 and sample-5 were sufficiently chlorinated when 4 mg/L of chlorine was added, after CT of 30 min RFC was 0.2 ppm. On further increasing the concentration of chlorine to 6 mg/L, sample-4 was found to have RFC 0.3 ppm and sample-5 to have 0.4 ppm, which is within prescribed limit. Hence, chlorine demand for sample-4 and sample-5 is 6 mg/L. Chlorine demand for different source water is graphically represented in Fig. 2. The results inferred that the treated water or sample-1, 2, and 3 are bacteriologically better in quality than the untreated ground water, i.e. sample 4 and 5. Since, the chlorine demand of the sample 4 and 5 are greater.

In Fig. 3, for sample-6, residual chlorine (ppm) was found to be 0.2 ppm when 2 mg/L chlorine solution was applied for chlorination. Hence, chlorine demand is 2 mg/L for sample-6. Sample-8, residual chlorine obtained was 0.3 ppm, when treated with 8 mg/L of

Table 3
TC, FC experimental results of UV disinfection method with respect to varying flow rates

Mode of disinfection	Sample volume (pond water)	Flow rate (L/h)	Total Coliform 10–1–0.1	TC (MPN/100 ml)	Fecal Coliform 10–1–0.1	FC (MPN/100 ml)
UV Disinfection	10 ml/L (sample-6)	4.6	0–0–0	<1.8	0–0–0	<1.8
		11.1	0–0–0	<1.8	0–0–0	<1.8
		17.4	0–0–0	<1.8	0–0–0	<1.8
		51.2	0–0–0	<1.8	0–0–0	<1.8
	30 ml/L (sample-7)	4.8	0–0–0	<1.8	0–0–0	<1.8
		12.0	0–0–0	<1.8	0–0–0	<1.8
		16.6	0–0–0	<1.8	0–0–0	<1.8
		50.8	0–0–0	<1.8	0–0–0	<1.8
	50 ml/L (sample-8)	4.5	3–1–0	11	1–0–0	2
		11.7	3–1–1	14	1–1–0	4
		17.1	3–1–1	14	2–0–0	4.5
		50.2	4–2–1	26	3–0–0	14

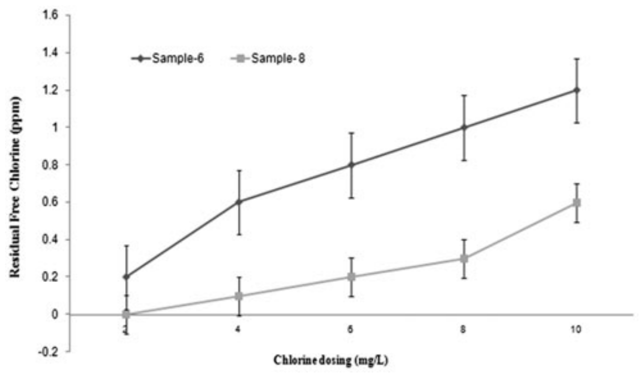

Fig. 3. Chlorine dosing using bleaching powder $Ca(OCl)_2$, (mg/L).

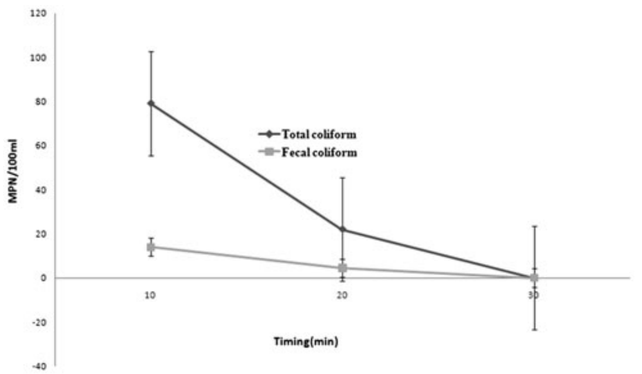

Fig. 5. Efficiency of sodium hypochlorite as chlorine disinfectant of sample-8.

chlorine. The chlorine demand for sample-8 was higher than sample-6. For, chlorinating sample-8 sufficiently, 8 mg/L chlorine was found adequate as the RFC after CT was 0.3 ppm, which is within prescribed limit.

Chlorination of contaminated sample-6 and sample-8 by sodium hypochlorite (NaOCl) was done for time duration of 30 min. TC and FC of the contaminated raw water was checked after 10, 20, and 30 min time duration of chlorination. Bacteriological test of the contaminated water was also checked by H_2S strips (Figs. 4 and 5).

3.2. Disinfection of contaminated water by sodium hypochlorite NaOCl

The results presented in Fig. 4 illustrate that 20 min of CT was sufficient to destroy the FC totally from sample 6 using NaOCl. For complete destruction of TCs using NaOCl, 30 min CT was found sufficient; chlorine demand found for sample-6 was 2 mg/L. For sample-8, chlorine demand found was 8 mg/L. From Figs. 4 and 5, it is well understood that NaOCl can efficiently destroy the Fecal and TCs from contaminated pond water (i.e. sample 6 and 8) within a CT of 30 min.

3.3. Disinfection of contaminated water by bleaching powder ($Ca(OCl)_2$)

Chlorination of sample-6 and sample-8 was also done by bleaching powder ($Ca(OCl)_2$) for time duration of 30 min. Chlorine demand obtained for the samples were found to be 4 and 8 mg/L, respectively. TC and FC of both samples were checked after 10, 20, and 30 min of chlorination. Bacteriological test of the contaminated water was also checked by H_2S strip test. Results in Figs. 6 and 7 indicates that for both sample-6 and 8 CT of 30 min were needed for complete eradication of TC and FC using as ($Ca(OCl)_2$) disinfectant. Hence, bleaching powder is considered an efficient

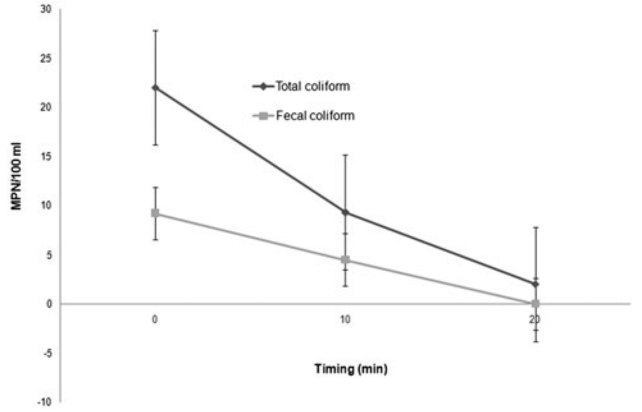

Fig. 4. Efficiency of sodium hypochlorite as chlorine disinfectant of sample-6.

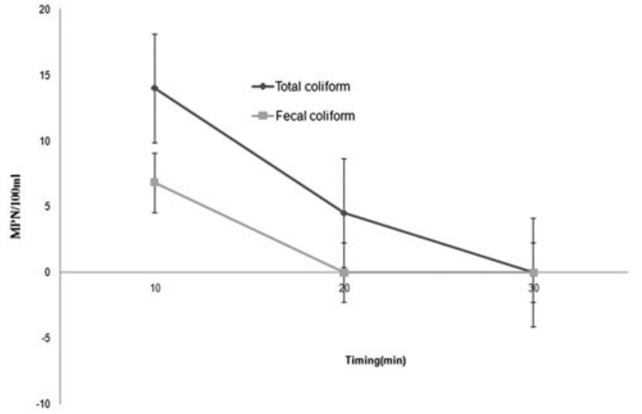

Fig. 6. Efficiency of bleaching powder as chlorine disinfectant of sample-6.

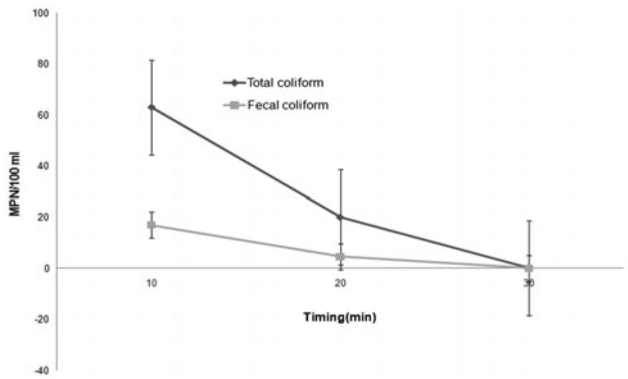

Fig. 7. Efficiency of bleaching powder as chlorine disinfectant of sample-8.

disinfectant that could reduce the TC and FC from contaminated pond water.

From the above results, it can be concluded that sodium hypochlorite and bleaching powder both are effective against TC and FC (FC). Maximum time taken for removal of TC and FC is 30 min in both cases.

3.3.1. Disinfection by chlorination

In this disinfection process, 30 min of CT was found to be sufficient for complete removal of Total and Fecal Coliform from contaminated pond water.

3.3.1.1. Disinfection by silver. In this disinfection process, Table 2, implicit that FC of sample-6 was reduced to <1.8 MPN/100 ml after 6 h of contact with silver wire H_2S strip presence–absence test also showed negative result for bacteriological contamination consequently. Sample-7 showed reduction in TC from 9.3 MPN/100 ml to <1.8 MPN/100 ml after 8 h of contact with silver wire. H_2S strip presence–absence test, showed negative result for bacteriological contamination consequently. Sample-8 showed same results as sample-7. TC and FC was reduced to <1.8 MPN/100 ml after 8 h, H_2S strip presence–absence test, was also negative within a CT of 8 h. The results of bacteriological tests implicates that 6 h CT was sufficient to treat sample 6. However, sample 7 and 8 showed reduction in TC and FC after 8 h. The tests inferred that on an average 8 h of contact with silver wire can totally remove the pathogenic bacteria from contaminated water.

3.3.1.2. Disinfection by copper. After 8 h of contact with copper wire, sample-6 and sample-7 showed reduction in TC and FC to <1.8 MPN/100 ml. H_2S strip presence–absence test, also showed negative result after duration of 8 h. Nonetheless, sample-8 needed longer time to remove contaminants. TC and FC was reduced to <1.8 MPN/100 ml after CT of 10 h. H_2S strip presence–absence test also showed negative result for bacteriological contamination after 10 h. The overall pathogen removal efficiency of copper wire was found to be 8–10 h. Table 2, implicit that, removal of TC and FC of water sample-6 and sample-7 requires CT of 8 h on an average.

3.3.1.3. Solar disinfection (SODIS). Table 2, implicit that sample-6, require 4 h for reduction of TC and FC. H_2S strip presence–absence test also showed negative result for bacteriological contamination after 4 h. Sample-7 and sample-8 required 6 h for complete disinfection of TC and FC. H_2S strip presence–absence test was negative for bacteriological contamination after 6 h. Hence, SODIS may be considered an efficient, low cost and effective method of disinfection.

3.3.1.4. Disinfection by ultra violet light. From Table 3, it implicit that sample-6 requires minimum flow rate of 4.6 L/h to remove TC and FC by UV treatment. Sample-7 requires 4.8 L/h of minimum flow rate for effective removal of TC and FC. Sample-8 was not successfully treated with UV as it was highly contaminated. Therefore, the observation infers that, highly contaminated sample requires filtration before UV treatment. The test results interpret that reduced flow rate enables more efficient treatment by UV radiation and also longer the exposure time, greater is the chance for destruction of pathogen. Hence, UV ray disinfection system may be very effective for low contaminated water but it is less effective for highly contaminated water.

Table 4
TC, FC, and H_2S test experimental results of disinfection by boiling with respect to the CT

Mode of disinfection	Sample volume (pond water)	Timing (min)	Total Coliform 10–1–0.1	TC (MPN/100 ml)	Fecal Coliform 10–1–0.1	FC (MPN/100 ml)	H_2S strip test
Disinfection by boiling	10 ml/L (sample-7)	10	0–0–0	<1.8	0–0–0	<1.8	Negative
		5	0–0–0	<1.8	0–0–0	<1.8	Negative
		2	0–0–0	<1.8	0–0–0	<1.8	Negative
		1	0–0–0	<1.8	0–0–0	<1.8	Negative

3.3.1.5. Disinfection by boiling. TC and FC for different time duration is shown in Table 4. It is observed that contaminated water sample-6 was fully disinfected after 1 min of full boiling at 100˚C. The results showed total absence of TC and FC from the contaminated water sample.

4. Conclusion

Effective CT sufficient to lower down the viable counts, by various modes of treatment are as follows: boiling-1 min < chlorination-30 min < UV treatment-1 h < SODIS-6 h < silver wire-8 h < copper wire-8–10 h. Disinfection of water using chlorine, completely killed or inactivated the pathogens within 30 min. Chlorine is very easily available in the market and it takes very less time to disinfect the water. Disinfection of water using chlorine is routinely followed in municipality areas and water supply systems but the main problem with this disinfection method is that the byproducts formed during chlorination that are very harmful for health [28,29]. So it has to be used with precautions. Disinfection of water by silver and copper shows remarkable destruction of pathogens within 8 h. These methods are quite simple, operational cost is minimal and can be easily performed. The disadvantage of this process is the longer duration of time needed for efficient disinfection and the high cost of silver and copper. Disinfection of water by solar radiation (SODIS), destroy the pathogens within 6 h. This method is completely free and effective but it is completely weather-dependent. Disinfection of water using UV rays ensures pathogen removal completely though this method has certain disadvantages. Firstly, it is very much complicated and costly. Secondly, exposure time must be sufficient and the flow rate must be slow enough to provide proper contact with the bacterial cells. However, the advantage is that it is 100% efficient in pathogen removal from less contaminated and less turbid water. It is most commonly used in the households. Disinfection of water by boiling may inactivate the pathogens completely within a minute after the temperature reaches 100˚C. It is also a very easy process but is not recommended for large scale water treatment. It also consumes much more fuels. Hence, the operational cost is much higher. Nonetheless, boiling is efficient and faster compared to other methods. It is an alternative to all the costly water treatment processes for household water disinfection. Nowadays, it is practiced in almost many rural places where people are out of reach of safe drinking water.

5. Recommendation for future use

With the advancement of technologies, the disinfection by UV radiation evolved out as one of the efficient method. It has become very popular and is also commonly used in many households. Nevertheless, the silver and copper disinfection method should be encouraged because it is of low operational cost and is affordable for many families. Disinfection method by SODIS should also be encouraged in the rural areas as it is completely free. Disinfection using chlorine should be avoided as its byproducts are very harmful for health.

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References

[1] M.W. LeChevallier, Au. Kwok-Keung, Water Treatment and Pathogen Control. Process Efficiency in Achieving Safe Drinking Water, WHO Drinking Water Quality Series, IWA Publishing, Geneva, 2004.
[2] Metcalf & Eddy, Wastewater Engineering: Treatment, Disposal and Reuse, third ed., McGraw-Hill, New York, NY, 1991.
[3] T. Clasen, C. McLaughlin, N. Nayaar, S. Boisson, R. Gupta, D. Desai, N. Shah, Microbiological effectiveness and cost of disinfecting water by boiling in semi-urban India, Am. Soc. Trop. Med. Hyg. 79(3) (2008) 407–413.
[4] V.J. Pereira, R. Marques, M. Marques, M.J. Benoliel, M.T.B. Crespo, Free chlorine inactivation of fungi in drinking water sources, Water Res. 47(2) (2013) 517–523.
[5] S.B. Somani, N.W. Ingole, N.S. Kulkarni, Disinfection of water by using sodium chloride (NaCl) and sodium hypochlorite (NaOCl), J. Eng. Res. Stud. 2(4) (2002) 40–43.
[6] S.B. Somani, N.W. Ingole, Alternative approach to chlorination for disinfection of drinking water—An overview, Int. J. Adv. Eng. Res. Stud. 1(1) (2011) 47–50.
[7] D.V. Halem, H.V.D. Laan, S.G.J. Heijman, J.C.V. Dijk, G.L. Amy, Assessing the sustainability of the silver-impregnated ceramic pot filter for low-cost household drinking water treatment, Phys. Chem. Earth, Parts A/B/C 34 (2009) 36–42.
[8] M. Hindiyeh, A. Ali, Investigating the efficiency of solar energy system for drinking water disinfection, Desalination 259 (2010) 208–215.

[9] K.M. Johnson, M.R.A. Kumar, P. Ponmurugan, B.M. Gananamangai, Ultraviolet Radiation and its germicidal effect in drinking water purification, J. Phytol. 2(5) (2010) 12–19.
[10] K.S. Manja, M.S. Maurya, K.M. Rao, A simple field test for the detection of faecal pollution in drinking water, Bull. World Health Org. 60 (1982) 797–801.
[11] APHA Report, Standard Methods for Examination of Water and Wastewater, twenty-second ed., American Public Health Association, Washington, DC, 2012.
[12] BIS Report, Indian Standard Drinking Water-Specification (Second Revision), IS-10500:2012, New Delhi.
[13] EPA Guidance Manual, Alternative Disinfectants and Oxidants-Ultraviolet Radiation, USA, 1999, p. 346.
[14] EPA Victoria, Australia, Guidelines for Environmental Management Disinfection of Treated Wastewater, September 2002, Publication 730.
[15] S. Bishankha, D.R. Bhatta, D.R. Joshi, T.P. Joshi, Assessment of microbiological quality of chlorinated drinking tap water and susceptibility of gram negative bacterial isolates towards chlorine, J. Sci. Eng. Technol. 9 (2013) 222–229.
[16] M.J. Casteel, C.E. Schmidt, M.D. Sobsey, Chlorine disinfection of produce to inactivate hepatitis A virus and coliphage MS2, Int. J. Food Microbiol. 125 (2008) 267–273.
[17] I. Hashmi, S. Farooq, S. Qaiser, Chlorination and water quality monitoring within a public drinking water supply in Rawalpindi Cantt (Westridge and Tench) area, Pakistan, Environ. Monit. Assess. 158(1–4) (2009) 393–403.
[18] S.J. Gaffey, C.E. Bronniann, Effect of bleaching on organic and mineral phases in biogenic carbonates, J. Sediment. Petrol. 63 (1993) 752–754.
[19] World Health Organization (WHO) Report, Technical Notes for Emergencies Technical Note No. 11 Draft revised 7.1.05, 2005, Geneva, Switzerland.
[20] M. Izadi, A. Sabzali, B. Bina, N.A.J. Jafari, M. Hatamzdeh, H. Farrokhzadeh, The effects of incubation period and temperature on the hydrogen sulphide (H_2S) technique for detection of faecal contamination in water, Afr. J. Environ. Sci. Technol. 4(2) (2010) 084–091.
[21] R.T. Noble, D.F. Moore, M.K. Leecaster, C.D. McGee, S.B. Weisberg, Comparison of total coliform, fecal coliform, and enterococcus bacterial indicator response for ocean recreational water quality testing, Water Res. 37 (2003) 1637–1643.
[22] D.S. Blanc, P. Carrara, G. Zanetti, P. Francioli, Water disinfection with ozone, copper and silver ions, and temperature increase to control Legionella: Seven years of experience in a university teaching hospital, J. Hospital Infect. 60 (2004) 69–72.
[23] H. Haider, W. Ali, S. Haydar, S. Tesfamariam, R. Sadiq, Modeling exposure period for solar disinfection (SODIS) under varying turbidity and cloud cover conditions, Clean Technol. Environ. Policy 16(5) (2014) 861–874.
[24] T.S. Saitoh, H.H. El-Ghetany, A pilot solar water disinfecting system: Performance analysis and testing, Solar Energy 72(3) (2002) 261–269.
[25] R. Meierhofer, S. Luzi, M. Wegelin, Does the reuse of PET bottles during solar water disinfection pose a health risk due to the migration of plasticisers and other chemicals into the water? Water Res. 42 (2008) 5054–5060.
[26] M. Guo, H. Hu, J.R. Bolton, M.G. El-Din, Comparison of low- and medium-pressure ultraviolet lamps, photo-reactivation of *Escherichia coli* and total coliforms in secondary effluents of municipal wastewater treatment plants, Water Res. 43 (2009) 815–821.
[27] S.A. Brownell, A.R. Chakrabarti, F.M. Kaser, F. Reygadas, M.J. Lang, L.G. Connelly, R.L. Peletz, D.M. Kammen, K.L. Nelson, Assessment of a low-cost, point-of-use, ultraviolet water disinfection technology, J. Water Health 6(1) (2008) 53–65.
[28] G. Hua, D.A. Reckhow, Comparison of disinfection byproduct formation from chlorine and alternative disinfectants, Water Res. 41 (2007) 1667–1678.
[29] M. Nieuwenhuijsen, M. Toledano, N. Eaton, J. Fawell, P. Elliott, Chlorination disinfection byproducts in water and their association with adverse reproductive outcomes: A review, Occup. Environ. Med. 57 (2000) 73–85.