CATRINA (2023), 27(1): 33-43

Controlling Disinfection By-Products Using Chlorine Profile and CT Tables at EL-Nobarya Drinking Water Treatment Plant, Egypt

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ABSTRACT

The present study aims to optimize the disinfection process at the El-Nobarya water treatment plant by developing a disinfection profile and utilizing CT tables as a secondary strategy, along with enhanced coagulation (EC), to achieve a constant reduction in Trihalomethanes (THM) levels and ensure adequate pathogen removal. Temperature effect was studied as chlorine profile was calculated based on highest and lowest water temperature recorded in the plant. Plant processes configuration (baffling factor) and efficiency (log removal) role in reducing chlorine dose by increasing contact time and reducing the log removal required was also determined. The results of disinfection profile revealed that more than 30 log inactivation of *Giardia* in summer and 11 log inactivation in winter was achieved by disinfection process. The log inactivation was reduced to 8 log in summer and 2.7 log in winter consequently. THM was reduced by more than 50%, even with high temperature and natural organic matter (NOM) level. Moreover, *Giardia* cysts were completely absent in the treated water. Chlorine dose was reduced from 8 to 5-5.5 gm/m^3 with saving of 13000 EP /month. The results of the present study will help operators, consultants, and government agencies to reduce Disinfection Byproducts (DBPs) for existing, upgrading, and new water distribution systems in Egypt.
Keywords: Baffling factor; Chlorine; CT disinfection; *Giardia;* Trihalomethanes.

INTRODUCTION

The quality of drinking water is an essential factor for human health. The combination of conventional drinking water treatment and disinfection has proved to be one of the major public health advances in modern times (Chaves, 2019). Chlorine is, by far, the most commonly used disinfectant in drinking water treatment plants as it is perceived as one of the most effective, least expensive and best operator disinfectants (Wagner and Plewa, 2017; Li and Mitch, 2018). However, chlorine is very chemically reactive with natural organic matter (NOM) present in the drinking water to form a group of chlorinated organic compounds known as Disinfection Byproducts (DBPs) (Thokchom *et al*., 2020; Lau *et al.*, 2020). The presence of DBPs specially THM in drinking water has been the subject of increasing public concern since the 1970s (Ghernaout *et al.*, 2021).

DBPs regular consumption in small quantity may adversely affects human health. DBPs in drinking water exhibit high cytotoxicity, mutagenicity and carcinogenicity specially bladder, colon and rectum cancers (Wright *et al.*, 2017; Albanakis *et al.*, 2021; Qian *et al.*, 2021). Disinfection byproducts have a great influence on the growth retardation, urinary tract anomalies, spontaneous abortions, and congenital cardiac defects (Villanueva *et al.*, 2015; Plewa *et al.*, 2017; Chaves *et al.*, 2019).

Increasing the residence time, temperature, pH, free chlorine, and TOC (humic substances) enhanced the THMs formation (Mazhar *et al.*, 2020). Plewa et al. (2017) and Gougoutsa et al. (2016) concluded that the main factors affecting THMs formations were the chlorine dose and the TOC concentration. USEPA Stage 1 D/DBP RULE set maximum contamination level (MCL) of trihalomethanes (THMs) of 0.08 mg/L (USEPA, 1998). These rules obligate systems to implement a strategy for THM control if their distribution system DBP running annual average for THM concentrations greater than or equal to 0.064 mg/L (USEPA, 2006). Sophisticated treatment options such as ozonation and granular activated carbon (GAC) are not always viable, especially at smaller water treatment facilities and developing countries where both the capital costs and the need for skilled personnel to operate such processes are limited (Sun *et al.*, 2019).

Optimization of disinfection strategies must be applied to provide sufficient protection against microbial infection, and at the same time minimize DBPs (Dong *et al.*, 2021). The recently promulgated surface water treatment rule (SWTR, 1998) requires water treatment systems to inactivate at least 3-log (99.9%) removal and/or inactivation of *Giardia*, at least 4-log (99.99%) removal and/or inactivation of viruses and at least 2-log (99%) removal of Cryptosporidium. The inactivation can be achieved through disinfection, while settling, filtration, or both for removal.

Systems with high THM value are required to develop a disinfection profile for *Giardia* to estimate the inactivation percentage. If the resulting log inactivation of a plant exceed the required log inactivation for *Giardia* or viruses there may be an opportunity to reduce the disinfectant dose without affecting disinfection process (USEPA Disinfection Guidance Manual 2020; British Columbia., 2022). Because of the difficulty in measuring actual microbial inactivation, EPA developed CT tables that can be used to estimate the inactivation's achieved through chemical disinfection. The tables indicate that the log inactivation of *Giardia* and viruses corresponding to the

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operating conditions of temperature, pH, residual disinfectant concentration, and contact time (Lanchbery 2019; USEPA Disinfection Guidance Manual 2020). CT is the concentration of the disinfectant C (mg/L) multiplied by the detention time T (min). The T in each basin, pipe, or unit process is a function of the physical configuration and baffling (Lanchbery 2019; Rush 2002). Disinfection profiling and benchmarking will help ensuring that microbial protection is not compromised by any modifications to disinfection practices. The benchmark is used as a minimum level of inactivation of Giardia and Viruses that must be maintained by water systems when modifying their disinfection practice.

EL-Nobarya water treatment plant employs enhanced coagulation (EC) to reduce THM levels in treated water. However, during periods of high temperature and NOM concentration, THM levels exceed the limit of 80 µg/L. Based on a literature review, it has been found that there are no reported studies on developing and applying a chlorine profile with scientific basis and guidance steps (CT tables) in Egyptian water treatment plants. Consequently, the aim of this study is to optimize the disinfection process in the plant as a secondary strategy alongside EC by using CT tables. This method ensures a consistent reduction in THM levels (not exceeding 64 µg/L), avoids implementing expensive methods for THM control, and guarantees sufficient pathogen removal.

MATERIALS AND METHODS

Plant description

This study was performed from August to December 2020, in EL-Nobarya water treatment plant, EL-Nobarya city, Egypt. The capacity of the plant is 2160 m^3/h and it supplies drinking water to EL-Nobarya city and the surrounding village. The treatment system of this conventional plant comprises of coagulation (using of aluminum sulphate) followed by 2 rectangular sludge pulsator clarifies where flocculation and sedimentation take place in the same basin, five rapid sand filtration and contact tank followed by rectangular clear well. The raw water intake (EL-Nobarya canal) is about 2 Km away from the plant. Typical alum dose of 60-70 mg/L is used.

Chlorine injection and sampling points

The plant uses two constant injection points out of 5 points available in the plant, the prechlorination point at the raw water intake and the contact tank point. Chlorine is measured in five locations in the plant and at the first customer outside the plant resulting in six disinfection segments. Disinfection Segment 1 starts at the prechlorination injection point and ends at the monitoring point prior to the coagulation basin (Figure 1). Disinfection Segment 2 starts at the chlorine monitoring point before the coagulation (flash mixer) and ends at the monitoring point after sedimentation. Segment 3 starts at the end of sedimentation tank and extends to the residual chlorine monitoring point after filtration unit. Disinfection Segment 4 starts at chlorine injection point at the beginning of the contact tank and ends at the monitoring point at the entry of the clear well. Disinfection Segment 5 starts at the chlorine monitoring point at the entry of the clear well and ends at the end of the clear well. Disinfection segment 6 starts at the chlorine monitoring point at the end of the clear well and ends prior to the first customer. Residual chlorine is measured at the end of each segment.

Experimental setup

The present study aims to optimize the disinfection process in EL-Nobarya water treatment plant to control the high level of THM. To judge the effectiveness of the disinfection process, CT calculation and chlorine profile were determined as a crucial step.

CT and log inactivation calculation steps

The following steps according to the disinfection profiling and benchmarking technical guidance manual (USEPA, 2020) were applied to calculate CT and log inactivation in the disinfection segments of the plant.

Step 1: Detention time calculation

The theoretical detention time (TDT) was calculated according to the following equation:

$$TDT = V/Q$$

Where, TDT is the theoretical detention time (min); V is the volume based on low water level (m^3), and Q is the Peak flow (m^3/hr.).

While, the actual detention time *(T)* was calculated according to Eq.:

$$T = TDT \times BF$$

Where, BF is the baffling factor (measure of short circuiting). The BF classifications are represented in Table (1).

Step 2: Actual CT achieved in the plant calculation

The actual CT of the plant for each disinfection segment under actual operating conditions (i.e., C x T) was calculated as the following:

$$CT\ actual = C \times T\ (min/L)$$

Where, C is the concentration of the residual disinfectant measured during peak flow (mg/L), and T is the actual detention time (min).

Step 3: Giardia lamblia log inactivation calculation

Step 3-A: CT99.9 determination using EPA tables and WTP information

The CT required for 3-log Giardia inactivation (CT3-log, *Giardia*) and/or 4-log virus inactivation (CT4-log, virus) was chosen from the SWTR CT Tables based on the temperature of the water. Choosing the pH column, corresponding to the plant water pH. The selection of the correct row is based on the residual chlorine concentration recorded at the end of the segment. Moving across this raw, and down the PH column allow the required CT value to be determined (min mg/L).

Step 3-B: Giardia lamblia log inactivation calculation

Estimated log inactivation for Giardia and/or viruses for each disinfection segment was calculated using the following equations:

$$Segment\ log\ inactivation\ of\ Giardia = 3.0 \times CT\ actual / CT3\text{-}log,\ Giardia$$

$$Segment\ log\ inactivation\ of\ viruses = 4.0 \times CT\ actual / CT4\text{-}log,\ viruses$$

Step 4: Plant log inactivation calculation

Plant log inactivation is the sum of the segments log inactivation of Giardia or viruses.

Analytical methods

All analysis was conducted in the Central laboratory of Beheira water Company, Beheira, Egypt. The laboratory analyses were in accordance with protocols recommended in standard method (APHA, 2017). All chemicals were of analytical reagent grade, purchased from Sigma-Aldrich (USA), and the solutions were prepared with ultra-pure water produced using a Millipore Super-Q plus water system (Millipore, USA). THM samples were taken using 40 ml glass bottles sealed with Teflon septum cap. The bottles were filled slowly to overflowing so that no air was included with the samples. The reducing agent (sodium thiosulfate) is added to all samples to stop the formation of additional trihalomethanes after sample collection and to eliminate the possibility of free chlorine reacting with impurities in the extraction solvent to form interfering organo-halides. Water samples were then preserved with sulfuric acid at pH < 2. THMs were measured by GC-MS (Thermo-Quest, USA) equipped with a 30 m × 0.25 mm × 0.25 µm DB-1701 column (J&W Scientific, USA), ECD detector and a quadruple analyzer. The samples for TOC were taken using amber glass containers with a volume of 120 ml having a screw cap with a Teflon septum. Water samples were preserved with sulfuric acid to maintain a pH below 2 and kept at <20 °C during shipment. Dissolved organic carbon (DOC) was measured in pre-filtered samples using a Total Organic Carbon (TOC) analyzer (Tekmar-Dohrman Apollo 9000), while glass-fiber filters of pore size 0.45 µm were employed for filtration. The pH was determined by a pH meter (Thermo Scientific, Orion Star A111). Turbidity of water was assessed via a turbidimeter instrument (Hach model 2100N), and free chlorine levels were measured using the N,N-diethyl-phenylene-diamine (DPD) powder pillow photometric method as described in APHA, 2017.

For *Giardia* cysts determination, plastic cubitainers with a capacity of 10 L were utilized. Each collected water sample underwent filtration through nitrocellulose membrane filters measuring 47 mm in diameter and having a pore size of 0.45 µm by employing stainless steel vacuum filter holder Sartorius SM from Göttingen, Germany. Next, each membrane was inverted face-to-face on the surface of non-nutrient agar plates seeded with living *E.coli* bacteria before being incubated at an optimum temperature of approximately30°C for up to15 days to examine for living cysts formation after which results are recorded accordingly.

RESULTS AND DISCUSSION

Enhancing coagulation was one of the primary strategies utilized at EL-Nobarya treatment plant to manage THM formation. However, due to high levels of TOC and temperatures in the water source, this strategy became even more critical in effectively managing THM formation and reducing their concentrations in treated water. THM concentrations were over the USEPA's (1998) limit which recorded 80 µg/L (Durmishi *et a*l., 2012; Albanakis *et al.*, 2021). Thus, disinfection optimization (disinfectant dose, and contact time) was applied as a second crucial strategy for further control of THM level. In general, the concentration of DBPs espec-ially THMs formed during chlorination increased with longer contact time and higher applied dose of free chlorine (Li *et al*., 2018). Therefore, chlorination time and applied dosage of disinfectant should be reduced as much as possible (Phanutda *et al*., 2019).

Disinfection process in EL-Nobarya plant takes place in the coagulation, flocculation and sedimentation basins, filters, and clear well, as well as in all the associated piping (Figure 1). Therefore, the accurate estimation of the disinfection time and dosage is important to achieve the microbial safety (Wols et al., 2010).

Bafling factor and contact time in EL-Nobarya plan

Table 1 summarize baffling factor for the different disinfection segment/process in the plant according to the configuration of each segment and the intrabaffles. These segments vary in shape between pipes and rectangular basin. The theoretical detention time, which is the volume (V, m^3) divided by the peak flow rate (Q, m^3/hr.), is not the real contact time. The effective contact time is often less than assumed due to various arrangements of inlet and outlet structures of the clear tank and varying level of short circuiting (Lanchbery, 2019).

The contact time (T) in each basin, pipe, or unit process is a function of the physical configuration and baffling. The actual contact time is estimated through multiplying the theoretical detention time by baffling factors or estimated through conducting tracer studies (Table 2). The minimum volume in the storage tank and the maximum flow rate out of the storage tank were employed to ensure that the actual detention time was not overestimated. For safety, contact time in pipes between each process will not be taken into account. The total actual contact time of the plant was 282 min.

Table (1): Baffling classification, according to the USEPA, (1991), and baffling factor for conventional water treatment processes at EL-Nobarya plant .

Baffling condition	T_{10}/T	BF/treatment† processes	Baffling description
Unbaffled (mixed flow)	0.1	0.7/1	None, agitated basin, very low length to width ratio, high inlet and outlet flow velocities.
Poor	0.3	0.7/2	Single or multiple unbaffled inlets and outlets, no intrabasin.
Average	0.5	0.5/3	Baffled inlet or outlet with some intra-basin baffles.
Superior	0.7	0.7/4	Perforated inlet baffle, serpentine or perforated intrabasin.
Perfect (plug flow)	1	1/5	Very high length to width ratio (pipeline flow), perforated inlet, outlet, and intra-basin baffles

Treatment Process:1, Flocculation/sedimentation; 2, Filtration; 3, contact tank; 4, clear water well and 5, Pipe.

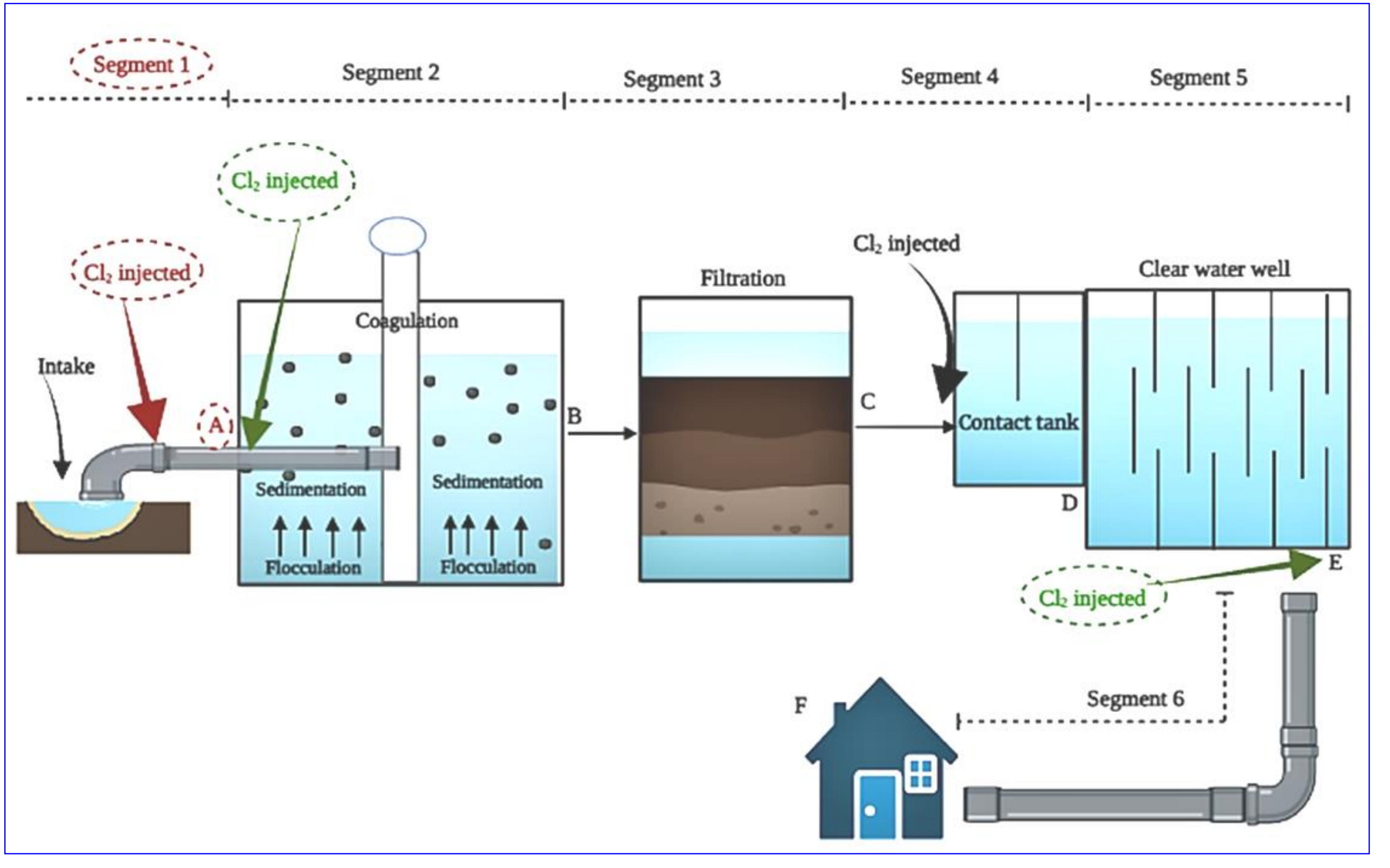


Figure (1): The schematic diagram shows the EL-Nobarya water treatment plant before and after changing chlorine injection points. A, B, C, D, E, and F are residual chlorine monitoring points.

( ), Disinfection segment, chlorine injected and monitoring points canceled from the plant;

( ), The modified chlorine injected points.

both *Giardia* and viruses, CT tables should be applied in all surface and ground water systems. One of the main concerns is how to judge the chlorine dose used in the plant whether it is high or low, to ensure disinfection and trying to control THM (Wols, *et al.*, 2010). The disinfection profile for the plant can be developed using operating conditions such as flow rate, chlorine doses and residuals, water levels in tanks, and data on water quality (such as temperature, pH, and turbidity). The study found that free chlorine, which is typically used to inactivate *Giardia*, can also be effective at killing viruses. To determine the appropriate disinfectant dose needed to achieve water treatment goals, CT values were obtained from CT tables (USEPA, 1991) corresponding to a 3-log removal of *Giardia* (CT required), and recorded CT values were calculated based on residual chlorine levels at different points in the treatment process and their duration (CT achieved). The total inactivation ratio recorded 11.49 and 3.77 for 10 and 25^{o}C, respectively. However the total log inactivation achieved 34.47 and 11.30 for 10 and 25^{o}C, respectively (Table 3). If total log inactivation exceeded the required level for *Giardia*, reducing disinfectant doses may be considered as an option.

Chlorine profile for EL-Nobarya plant

Data needed for the profile are considered constant in the plant all over the year. The only variable parameter in the profile of EL-Nobarya plant is the temperature which changes seasonally. Two chlorine profile were made depending on water temperature recorded in the plant, the first profile represents the maximum water temperature (30 ^{o}C) and the second represent the lowest water temperature (11 ^{o}C). Summary of the two profile calculations is presented in Table (3). The CT calculations below are based on worst-case operating conditions (e.g., maximum and minimum water temperature, maximum pH, maximum flow rate, minimum clear well volume, and minimum free residual chlorine in each segment).

From the two profiles, the plant achieved more than 30-log removal of *Giardia* in summer and 11 log removal in winter by disinfection alone. Difference in log inactivation between summer and winter revealed the great effect of temperature on chlorine used as a disinfectant against microorganisms such as *Giardia* and viruses. WHO (2017) reported the high reactivity and efficiency of chlorine at high temperatures. In addition, lower pH resulting from enhanced coagulation due to acidic alum allows decreasing chlorine dose, since chlorine is more effective at lower pH values. CT value under pH column of 7.5 in EPA CT table was used in the subsequent process in the plant rather than pH column of 8 used in the prechlorination segment. The maximum log inactivation was observed in the clear well in winter and summer (8.6 and 26.2) due to high chlorine dose and contact time (Table 3). The prechlorination disinfection segment demonstrated 0.65 log inactivation during winter and 1.9 log inactivation during summer, achieving the intended purpose of controlling microbiological growth for subsequent processes while also improving coagulation and reducing tastes and odors. Additionally, if necessary, this process can provide additional inactivation credits.

It is noteworthy that the benchmark log at the plant was lowest during winter with a value of 11.3.

Table (2): The actual contact time of the disinfection segments in EL-Nobarya plant.

Disinfection segment	Process unit	Peak flow (m^3/hr)	Volume (m^3)	TDT[†] (min)	BF	Contact time (min)
Segment 1	Prechlorination	2340	1000.4	25	1	25
Segment 2	Flocculation& Sedimentation	2340	1976	50.6	0.7	35.5
Segment 3	Filtration	2340	615	15.7	0.7	11
Segment 4	Contact tank	2340	1550	39.7	0.5	19.8
Segment 5	Clear well	2340	10303	264	0.7	184.8
Segment 6	Pipe	2340	241	6.2	1	6.2

[†]TDT is the theoretical detention time.

Effect of treatment process efficiency on *Giardia* log removal

EL-Nobarya plant is a conventional filtration system, the turbidity of filtered water is less than or equal to 0.3 NTU in the measurements taken every day. The turbidity of filtered water never exceeds 1 NTU at any time. Thus, 2.5-log of *Giardia* can be removed through sedimentation and filtration process (USEPA, 1991). The required log inactivation for *Giardia* by the disinfectant should only be 0.5-log as the total log requirement for *Giardia* set by USEPA is 3 log. The total ratio of inactivation recorded 11.49 and 3.77 for 10 and 25^{o}C, respectively (Table 3). Meanwhile, the total log inactivation recorded 34.47 and 11.3 in winter and summer, respectively.

Optimizing chlorine dose through disinfection profiling and benchmarking

Modifying chlorine injection points (contact time)

Based on the above profiles calculations the chlorine dose and contact time can be reduced safely (Table 3). THM formation increases with increased disinfection contact time (Qian *et al.*, 2021). According to USEPA disinfection guidance manual (2020) water systems using pre-disinfection might consider moving the point of disinfectant application further into the plant treatment train to reduce the contact time between DBP precursors and the disinfectant(s). Eliminating prechlorination completely in a treatment plant and using an injection point after the sedimentation basin is not feasible, as prechlorination is conventionally used to control the formation of biological slime in treatment plants.

In the plant, three injection points (Figure 1) were used instead of two. The first two injection points were at the flash mixer and contact tank, where primary disinfection occurred. The third point was at the end of the clear well to provide secondary disinfection and prevent high doses with long contact times. Disinfection Segment 1 starts at the chlorine injection point before the coagulation (flash mixer) and ends at the monitoring point after sedimentation. Disinfection Segment 2 starts at the end of sedimentation tank and extends to the residual chlorine monitoring point after filtration unit.

Disinfection Segment 3 starts at chlorine injection point at the beginning of the contact tank and ends at the monitoring point at the entry of the clear well. Disinfection Segment 4 starts at the chlorine monitoring point at the entry of the clear well and ends at the end of the clear well. Disinfection segment 5 starts at the chlorine monitoring point at the end of the clear well and ends prior to the first customer.

Chlorine dose adjustment

The desired residual chlorine is the amount of residual chlorine required after satisfying the chlorine demand (break point). To achieve this, the residual chlorine at the end of the sedimentation basin should be reduced as much as possible to reach a level between 0.2 and 0.3 mg/L, instead of being maintained at higher levels such as 0.6-0.8 mg/L. Dose of 0.4-0.5 mg/L will be applied at the end of the contact tank as it is the minimum dose available in the CT tables. Another profile for the new chlorine dose and disinfectant segments will be carried out before being applied on the plant to ensure that the disinfection process will not be affected. The profile calculations for both high and low temperature are displayed in Table (4). The results revealed that 8-log removal of *Giardia* was reported at high temperature and 2.7 log inactivation with the lowest temperature, so the doses can be used safely on the trial. Figure (2) illustrates the log inactivation before and after disinfection optimization compared to the required log removal of 0.5 log.

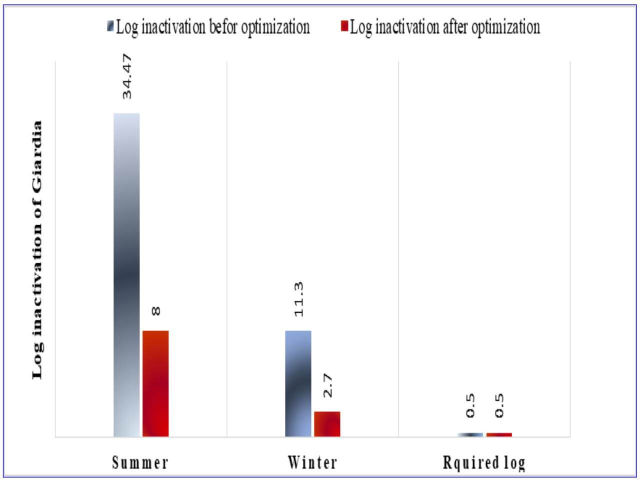
Effect of applying new profile on THM level

Samples for THM analysis after applying the new disinfectant profile were taken once a week covering a period from September to December 2020. Chlorine dose was reduced from 8 to 5-5.5 mg/L divided on the three injection points. Flash mixer dose was 2.5 mg/L led to a residual chlorine concentration of 0.2-0.3 mg/L (after satisfying chlorine demand -break point) and the contact tank point with dose of 0.6-0.8 mg/L given free residual chlorine at the end of the clear well of 0.4-0.5 mg/L. Finally, the secondary disinfectant point dose was 2 mg/L to ensure that free residual chlorine will reach the end of the long net at least 0.2-0.5 mg/L (WHO, 2017). The results in Table (5) showed sharp, simultaneous and constant reduction in THM level.

All THM values were below 64 µg/L which reveals the effect of chlorine dose on THM formation. The same trend was also reported by Chavesa *et al*. (2019) and Albanakis *et al*. (2021) who observed a linear dependency between the chlorination dosage and THM formation. It was also noted that the higher the TOC concentration, the higher the THM level. These results were also confirmed with other reported data by Richardson *et al*. (2015) and Sillanpaa *et al*. (2018). In addition, the impact of chlorine was found to be more significant than that of enhanced coagulation. For instance, trihalomethanes (THMs) did not exceed 52 µg/L even when there were high levels of natural organic matter (NOM) at 9.7 mg/L and temperatures as high as 28°C. In contrast, using enhanced coagulation with high total organic carbon (TOC) concentrations and elevated temperatures often resulted in THM levels exceeding acceptable limits.

The increase in THM level in sample No. 4 (Table 5) was attributed to two reasons: 1) the secondary disinfectant point was restored to the traditional point in the beginning of the contact tank, 2) error in preparing alum tank concentration resulted in a decrease in the injected alum dose (35 mg/L instead of 60 mg/L) and there was no EC applied. And this is obvious from low percent removal of TOC (13%). Gougoutsa *et al*., (2016) observed that the main factors affecting THMs formations were the chlorine dose and TOC. In sample No. 10, the flash mixer and secondary disinfectant points were out of service due to a maintenance action in both points. Therefore, prechlorination and contact tank points were used. Dose of 2.8 mg/L rather than 0.8 mg/L was injected in the contact tank point. This clearly assures the undoubted role of chlorine dose and contact time on THM formation (Saidan *et al*., 2013; Zhou *et al*., 2019).

Biological test for *Gardia* Lamblia in treated water was carried out to ensure water safety after reducing chlorine dose and contact time. The results revealed complete absence of *Gardia* cysts in all samples (Table 5).



Figre (2): *Giardia* Log inactivation before and after disinfection optimization compared to the required log removal.

Table (3): Water characterization, water flow, BF, disinfection contact time, calculated actual CT and log *Giardia* inactivation during different segments along disinfection process for EL-Nobarya plant at 10 and 25°C.

Disinfection segments	Residual Cl_2. Conc.(mg/L)	pH	Water temp. (ºC)		Peak flow (m^3/hr)	Volume (m^3)	TDT (min)	Baffling factor	Disinf. Contact Time (min)	CT_{actual} (CxT) (min mg/L)	CT required (min mg/L)		Inactivation ratio (Col.9/Col. 10)		log inactivation	
											Temperature (ºC)					
											10	25	10	25	10	25
Prechlorination	1.2	8	8	25	2340	1000.4	25	1	25.0	30.0	137	46	0.20	0.65	0.65	1.9
Flocculation/Sedimentation	0.6	7.5	8	25	2340	1976.0	50.6	0.7	35.5	21.3	128	43	0.15	0.49	0.45	1.48
Filtration	0.4	7.5	8	25	2340	615.0	15.7	0.7	11.0	4.4	125	42	0.03	0.1	0.1	0.30
Contact tank	3.5	7.5	8	25	2340	1550.0	39.7	0.5	19.8	69.3	166	55	0.41	1.26	1.25	3.78
Clear well	2.5	7.5	8	25	2340	10303.0	264	0.7	184.8	462.0	160	52	2.88	8.7	8.6	26.2
Pipe	2.5	7.5	8	25	2340	241.0	6.2	1.0	6.2	15.5	157	52	0.10	0.29	0.3	0.89

TDT is the theoretical detention time.

Table (4): Log *Giardia* inactivation at two different temperatures (10 and 25 °C), with a Peak flow of 2340 (m^3/hr), using a new chlorine profile disinfection at different segments along disinfection process for EL-Nobarya plant.

Disinfection segments	Residual Cl_2 conc.	pH	Temperature (°C)		Volume (m^3)	TDT† (min)	BF	Contact time (min)	CT_{actual} (CxT) (min mg/L)	CT Required (min mg/L)		Inactivation ratio (CTactual /CTrequired)		Log Inactivation	
										Temperature (°C)					
			10	25						10	25	10	25	10	25
Flocculation/ Sedimentation	0.3	7.5	8	25	1976	50.6	0.7	35.5	10.7	125	42	0.08	0.25	0.25	0.76
Filtration	0.1	7.5	8	25	615	15.7	0.7	11.0	1.1	125	42	0.02	0.02	0.07	0.07
contact tank	0.8	7.5	8	25	1550	39.7	0.5	19.8	15.84	131	44	0.12	0.36	0.36	1.08
Clear well	0.4	7.5	8	25	10303	264	0.7	184.8	73.9	125	42	0.59	1.76	1.77	5.28
pipe	2.0	7.5	8	25	241	6.2	1.0	6.2	12.4	125	42	0.1	0.29	0.3	0.89

†TDT is the theoretical detention time.

Table (5): Effect of disinfection process optimization on THM level in EL-Nobarya treatment plant (September-December 2020). Data recorded for raw total organic carbon (TOC) and residual chlorine represented in means ±SE.

Sample	Raw TOC (mg/L)	Clarifier TOC (mg/L)	Removal (%)	Residual chlorine		Temp.(°C)	THM (µg/L)	*Giardia lamblia Cysts*
				*R1 (mg/L)	**R2 (mg/L)			
1	3.8 ±0.1	2.6±0.1	31	0.2±0.1	0.4±0.1	25	35	-ve
2	4.3 ±0.1	2.8±0.1	35	0.1±0.1	0.6±0.1	25	41	-ve
3	4.2 ±0.1	2.9±0.1	31	0.3±0.1	0.4±0.1	22	39	-ve
4	5.1 ±0.2	4.4±0.1	13	0.3±0.1	2.3±0.1	22	79	-ve
5	4.6 ±0.1	3.5±0.2	24	0.2±0.1	0.4±0.1	22	40	-ve
6	7.88 ±0.1	4.8±0.1	39	0.4±0.1	0.5±0.1	20	50	-ve
7	9.7 ±0.1	5.2±0.2	46	0.2±0.1	0.5±0.1	18	52	-ve
8	7.8 ±0.2	5.8±0.1	26	0.4±0.1	0.4±0.1	18	46	-ve
9	7.1 ±0.1	4.8±0.2	3	0.3±0.1	0.6±0.1	18	47	-ve
10	6.8 ±0.1	4.7±0.1	31	0.4±0.1	2.5±0.1	17	96	-ve
11	7.6 ±0.1	4.2±0.1	45	0.4±0.1	0.5±0.1	17	50	-ve
12	5.8 ±0.2	3.8±0.2	35	0.2±0.1	0.5±0.1	16	45	-ve
13	5.5 ±0.1	4±0.1	27	0.3±0.1	0.4±0.1	15	40	-ve

TOC; Total Organic Carbon; * Residual chlorine at the end of clarifier.
**Residual chlorine at the end of clear well.

CONCLUSION

The THM level at EL-Nobarya plant was not consistently compliant with USEPA stage 1 D/DBP RULE. The concentration of THMs exceeded the limit of 80 µg/L when there were high levels of natural organic matter (NOM) and elevated temperatures. The enhanced coagulation technique that had been used in the plant previously was insufficient to maintain low and consistent THM levels. Therefore, it was necessary to apply disinfection profiles and CT tables to control THMs without affecting the disinfection process. When chlorine alone was used for disinfection, the plant achieved a 30-log removal in summer and an 11.2-log removal in winter compared to the required 3-log removal by USEPA through disinfection and treatment processes. Controlling residual chlorine levels through changing injection points resulted in a sharp, simultaneous, and constant reduction in THM levels up to approximately 40-50% removal percentage. By reducing chlorine dose and changing point of injection, log removal decreased to 8 in summer and 2.7 in winter while still maintaining a constant reduction level for THMs below regulatory limits even at high NOM concentrations or temperatures exceeding normal range.

These results demonstrate that controlling residual chlorine is crucial for effectively managing THM levels during water treatment processes regardless of variations due to seasonal changes or fluctuations from source waters containing different types or amounts of NOM compounds that are prone towards DBP formation such as chloroform, bromodichloromethane etc., commonly referred as trihalomethanes (THMs).

Efficient treatment processes that remove pathogens through settling and filtration are essential in reducing disinfectant doses safely, as they can achieve up to a 2.5-log removal. For chlorine dosing, the benchmark is set at 0.5 log removal. Although the benchmark for log reduction was reduced from 11.2 to 2.7 logs in the EL-Nobarya plant, it was not decreased to the required level of 0.5 logs because free chlorine was still needed in the clarifier during both summer and winter seasons.

Furthermore, moving the flash mixer point to an in-filter point wasn't feasible since free chlorine was necessary in clarifiers for odor control, taste improvement, algae growth control, and enhanced coagulation - particularly when dealing with overloaded clarifiers - all of which require higher residual chlorine levels than what would be possible under more ideal conditions. Nonetheless, eliminating Giardia cysts completely from treated water ensured efficiency of Giardia cysts removal by using new disinfection profiles developed at this facility.

The study suggests changing primary disinfectant points seasonally according to need while avoiding early injection of secondary disinfectants can improve log removal and reduce THM levels, potentially saving costs and avoiding more expensive treatment processes at EL-Nobarya plant.

Overall this applicable study shows that EL-Nobarya plant does not require any costly or sophisticated treatment processes beyond optimizing existing methods for safe yet effective THM reduction while meeting regulatory standards. The results highlight various factors influencing THM formation should be considered during water treatment processes even if some factors contribute more significantly than others towards DBP formation such as chloroform or bromodichloromethane (THMs).

The study suggests that adjusting primary disinfectant points based on seasonal needs and avoiding early injection of secondary disinfectants can improve log removal and reduce THM levels, potentially saving costs and avoiding more expensive treatment processes at EL-Nobarya plant. The results emphasize the importance of considering various factors influencing THM formation during water treatment processes, including their relative impact towards DBP formation such as chloroform or bromodichloromethane (THMs).

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التحكم في المنتجات الثانوية للتطهير باستخدام بروفايل الكلور وجداول CT بمحطة معالجة مياه شرب النوبارية، مصر

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الملخص العربـــــي

تهدف الدراسة الحالية إلى تحسين عملية التطهير في محطة معالجة مياه الشرب بالنوبارية من خلال تطوير ملف التطهير واستخدام حساباتCT كاستراتيجية ثانية مع التخثر المعزز (EC) لتحقيق انخفاض مستمر في مستوى الترای هالو ميثان وضمان إزالة مسببات الأمراض بشكل كافٍ .وقد تم دراسة تأثير درجة الحرارة ، حيث تم حساب جرعة الكلوربناء على أعلى وأدنى درجة حرارة للماء المسجلة في محطة النوبارية. كما تم أيضا دراسة تأثير البناء التصميمى وتركيب مراحل المعالجة المختلفة (معامل الحواجز الخاص بتدفق المياة)، وكذلك كفاءة وقدرة مراحل المعالجة فى ازالة الميكروبات في تقليل جرعة الكلور. حيث تؤثر تأثيرا مباشرا على خفض جرعة الكلور المضافة عن طريق زيادة فترة التلامس وتقليل مقدار التلوث الميكروبى. كشف ملف وضع الكلور لمحطة معالجة المياه بالنوبارية أن المحطة كانت تحقق أكثر من 10-30 مره الازالة المطلوبة للجيارديا شتاءا وصيفا عن طريق عملية التطهيرفقط .تم تخفيض جرعة الكلور المضافة لتعطى من 2.7-8 مره الازالة المطلوبة. نتيجة لذلك انخفضت نسبة الترای هالو ميثان بأكثر من 50٪ حتى مع ارتفاع درجة الحرارة و المواد العضوية الطبيعية . وعلاوة علي ذلك، فقد أثبتت النتائج أيضا أن العينات المعالجة خالية تماما من Giardia cysts. وقد أدي تخفيض جرعة الكلور من 8 إلى 5-5.5 جم / مترمكعب إلي توفير شهريا حوالي13000 جنيها مصريا. ستساعد نتائج الدراسة الحالية المشغلين والاستشاريين والهيئات الحكومية المعنية بمعالجة مياة الشرب على تقليل منتجات التطهير الثانوية لأنظمة توزيع المياه الحالية والمحدثة والجديدة في مصر.