American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-13, Issue-2, pp-154-165
www.ajer.org
Research Paper Open Access

The effect of hot water and its patterns on byproducts created from disinfectants and microbes in building plumbing systems

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ABSTRACT:*The aim of this research is to examine the impact of water heaters and various household heating situations on the generation and degradation of disinfection by-products (DBP). The study investigated the concentrations of disinfectants in hot and cold water samples collected from 18 households in Tehran, Iran. These households were fitted with either conventional water heaters or tankless water heaters. The water system examined in this research employed traditional treatment methods involving a GAC filter and residual chlorine for disinfection purposes. Furthermore, laboratory tests were carried out to assess the influence of stagnation and elevated temperature on the levels of disinfection byproducts (DBPs), employing various heating conditions (short-term and long-term heating). The field study findings indicated differences in water quality between the hot water generated by the two heater models. Specifically, the traditional water heaters resulted in higher chlorine consumption, leading to increased levels of total trihalomethanes (TTHM), dichloroacetic acids (DCAA), and chloropicrin (CP). On the other hand, the levels of dichloroacetonitrile (DCAN) and trichloropropane (TCP) were significantly degraded. The laboratory tests showed that the level of DBP in the warmed mixture is impacted by the speeds at which DBP is created and broken down. Minimal changes were observed in TTHM, haloacetic acids (HAA), and CP concentrations following brief heating, however, a significant reduction in DCAN and TCP levels was noted in the control group. Prolonged heating, however, resulted in higher levels of TTHM, DCAA, trichloroacetic acid (TCAA), and CP, but led to reduced levels of bromochloroacetic acid (BCAA) and bromodichloroacetic acid (BDCAA), as well as a significant decrease in DCAN and TCP levels.*

Date of Submission: 10-02-2024 Date of acceptance: 25-02-2024

I. INTRODUCTION

During the treatment of drinking water to remove contaminants, Disinfection Byproducts (DBPs) are produced as a result of the reaction between Natural Organic Matter (NOM) and a chemical disinfectant. These byproducts consist of both regulated disinfection byproducts (DBPs) like trihalomethanes (THMs) and haloacetic acids (HAAs), as well as unregulated DBPs including nitrosamines, haloacetonitrile (HAN), haloketones (HKs), and others (Ao et al., 2021; Gao et al., 2019). The existence of disinfection byproducts in water has the potential to create health hazards, as a number of them have been identified as possible carcinogens (Proctor et al., 2020). The world health organization (WHO) has set maximum allowable levels for total trihalomethanes (TTHMs) and five haloacetic acids (HAAs) at 80 µg/l and 60 µg/l, respectively.

Evaluating human exposure to disinfection byproducts (DBPs) poses a significant challenge because of the diverse climate conditions, spatial variables, and various exposure routes. Furthermore, aside from drinking cold water, the act of inhaling and having skin contact with hot water (such as bathing, showering, and dishwashing) can lead to notable effects as well (Lei et al., 2022; Zhang et al., 2019). Therefore, it is essential to take into account the DBP exposure levels in hot tap water when evaluating overall exposure. Research on air conditioning has shown significant changes in the concentrations of trihalomethanes (THMs), haloacetic acids (HAAs), and other DBPs when exposed to closed systems at temperatures of 50°C or higher (Dong et al., 2019). Nevertheless, numerous inquiries remain unanswered concerning the impact of prevailing residential heating methods on DBP levels. Kali et al. (2021) did not include HAAs in their study and utilized a temperature of 65°C, which exceeds the WHO's recommended temperature of 55°C for effective pathogen control (Salehi et al.,

2020). Chaves et al. (2019). investigated tap water under both open and closed heating systems at boiling point temperatures, as well as synthetic chlorinated water without residual chlorine. Wang et al. (2020) maintained consistent drying conditions at various temperatures, although the incubation mainly took place indoors without combining low and high temperatures.

Recent studies have indicated an escalation in the levels of THMs and HAAs found in the hot water systems utilized by consumers. This is primarily due to the longer time that water spends in traditional hot water systems. Ike et al. (2019) and Manasfi et al. (2017) have conducted studies that support this finding. Additionally, Carter et al. (2019) have observed similar results in simulated distribution systems. Xu et al. 2019) pointed out that the prolonged exposure of water in residential hot water systems can hasten the reaction between chlorine and NOM. It is crucial to emphasize that non-hot water samples obtained from the distribution or piping system do not provide an accurate representation of the water being evaluated for human exposure during bathing and hot water activities. This has been emphasized by Loeb et al. (2018) and Jjagwe et al. (2021).

There has been a lack of extensive research conducted on the existence of disinfection by-products in water supply, and no studies have specifically investigated the influence of various types of household heaters on water quality. In Iran, tankless water heaters have become popular. Unlike traditional tank heaters, tankless water heaters heat water only when needed, eliminating the need for a storage tank. Upon activation, the water flow detector initiates the burner, typically powered by natural gas. The water subsequently flows through a heat exchange coil and attains the desired temperature in a mere 10 seconds. Simpson et al. (2022) carried out a comparative analysis on the longevity of three different water heater models: a conventional tankless water heater lacking recirculating hot water, an on-demand tankless water heater without recirculating hot water, and a recirculating tankless water heater. The study revealed that the degradation of disinfectant (monochloramine) was minimal in bare water heaters, slightly higher in the non-recirculating tank heater, but significantly higher in the recirculating tank heater.

Nevertheless, there have been no investigations carried out regarding the impact of various heater types on the complete range of DBPs (both controlled and uncontrolled). Within this research, samples of hot and cold water were gathered from residences equipped with two different main water heaters in a newly built residential area in Tehran, Iran. Additionally, seat warming experiments were performed as part of a supplementary study.

II. MATERIAL AND METHODS

Collecting samples from the field

Chitgar Residential Complex is located in Tehran, Iran, and consists of 28 homes spread over 6.5 acres. The majority of these homes are duplexes with similar infrastructure built at the same time. The drinking water for this community is supplied by the Tehran water treatment plant situated to the northeast of the city. The plant has a capacity to treat 6.5 million gallons of water daily. and provides an average of 2.9 million gallons per day to its 28,000 customers. The primary source of drinking water in Tehran is derived from three surface reservoirs, which contribute to approximately 90% of the total supply. The remaining 10% of the water supply is obtained from two underground sources. Since 2010, the implementation of water filtration systems, including a coarse filter (sorbent sediment) and a granular activated carbon filter, has led to a substantial decrease in the concentrations of total organic carbon and DBP within the system. Consequently, the city's DBP levels are significantly lower than the maximum contaminant level (MCL) established by the stage 2 disinfectants/disinfection byproducts (D/DBP) rule. Sodium hypochlorite is added to the filtered water before it enters the 4 million gallon tank. After leaving the tank, sodium carbonate is introduced to control the pH and manage corrosion, while zinc orthophosphate acts as a corrosion inhibitor. The residual concentration of free chlorine in the water exiting the water treatment facility varied between 1.1 and 1.3 mg/l during the duration of the research.

The study involved selecting 18 households from the Chitgarh housing estate, with 8 houses having gas "whole house" water heaters and the remaining 10 using traditional water heaters. Water samples, both cold and hot, were gathered from every residence during a 48-hour timeframe in the summer season. Sampling was conducted once per household in the early morning prior to any utilization of hot water. To reduce THMs and other DBPs, a custom threaded pair was attached to tubes by replacing the valve stem prior to sampling. After running the water for a duration of 10 minutes, samples of cold tap water were collected, ensuring that the temperature had reached a stable state. The aforementioned samples were preserved in 300 ml containers equipped with glass stoppers made of chlorine-free material. These containers were supplemented with ascorbic acid and sodium azide. Two drops of 6 M sulfuric acid were added to the liquid phase before sealing to ensure proper mixing. Once the temperature had stabilized, hot water samples were gathered to prevent any decrease in the water level within the tank. In order to tackle the bubbling problem in tap water samples, hot water samples were gathered in serum "bubble bottles" following the method outlined by Uzun et al. (2020). The cold water specimens were placed in a cooler and then taken to the UMass laboratory for analysis of disinfection

byproducts. During the collection process, on-site measurements were taken for temperature, chlorine balance, and pH levels from two wells.

Laboratory-scale experiment

A separate small-scale experiment was conducted to evaluate the influence of temperature on DBP concentrations in the water supply of Tehran. The drinking water was first treated with chlorine and then exposed to a temperature of 20°C for varying lengths of time to simulate cold tap water from different parts of the distribution system. Subsequently, these treated samples were heated to 55°C for either brief (10 minutes) or extended (24 hours) periods, representing instantaneous and storage water heating methods.

Samples were collected in large quantities from the filters of the water treatment facility in Tehran and transported to the laboratory while being kept cool with ice. The laboratory analysis was performed on a 4-liter water sample, which was then incubated at a temperature of 20°C and allowed to stabilize for a duration of 8 hours. Following this, the samples were preserved by adding monopotassium phosphate and sodium hydroxide to maintain a pH level of 8.0 ± 0.2. Chlorination was carried out using a sodium hypochlorite solution obtained from Fisher Scientific in Pittsburgh, PA, and its concentration was standardized using DPD iron titration (Method 4500-Cl F; APHA, 2005). The dosage of chlorine was adjusted to 5 mg/L in order to achieve a residual chlorine level of 0.5 mg/L after 24 hours of incubation.

The borosilicate bottles with 4-L capacity, which contained chlorine samples, were stored at a temperature of 20 °C for varying contact durations (6, 24, 48, 72, 96 hours). Following each time interval, a subsample that was not subjected to heating was obtained by transferring 300 mL to a glass bottle free of chlorine. A segment of this subsample was utilized for residual chlorine measurement, while the remaining portion was distributed into glass ampoules with ascorbic acid. After adding a drop of concentrated sulfuric acid to each flask, they were sealed for future analysis of DBPs. After gathering unheated subsamples, the remaining volume was precisely divided into plastic bottles to prevent air gaps caused by the pipe being fully installed on the floor to allow for water expansion during heating. Following this, every bottle was securely sealed and positioned in a water bath adjusted to 55°C. It required approximately half an hour for each bottle to achieve the intended temperature. At the designated time intervals (10 minutes and 24 hours), one bottle was removed from the 55°C water bath and promptly cooled in a cold water bath at 4°C. Residual chlorine levels were measured after sample collection, and the remaining samples were divided and stored, similar to the original samples, in preparation for future DBP analysis.

Analytical method

Residual chlorine in the field was quantified using the N,N-diethylphenylenediamine (DPD) colorimetric method, employing a Hach field kit (model CN-70). Temperature and pH were measured using a portable meter (AP85) from Fisher Scientific. In vitro, four THMs containing chlorine and bromine (THM4), dihaloacetonitrile (DHAN), chloropicrin (CP), and 1,1,1-trichloropropanone (TCP) were quantified through liquid/liquid extraction using pentane and analyzed using electron-gas chromatography with detection (GC/ECD) as per USEPA method 551.1. Nine haloacetic acids (HAA9) were examines through liquid/liquid extraction using methyl tert-butyl ether (MTBE), followed by derivatization with acidic methanol and analyzed using GC/ECD according to USEPA Method 552.2. The analysis of total organic carbon was conducted using a commercial TOC analyzer (TOC-VCPH, Shimadzu) through the high-temperature combustion method.

III. Results and Discussions

Field sampling

The specimens of cold waters collected in Tehran during July 2023 have temperatures ranging from 18 to 22 degrees Celsius. The outlet temperature of the tankless water heater was initially set at 55℃ at the factory to prevent burns, but during our on-site measurements, it ranged from 50 to 60℃. The outlet pipe of a tankless water heater appears cooler in comparison to the room temperature, whereas the outlet pipe of a conventional water heater becomes warm as a result of heat transfer from the heated tank. However, despite these disparities, there were no notable discrepancies in temperature among the water samples obtained from different types of heaters. Slight alterations in TOC, pH, and UV-254 levels were observed between hot and cold tap water. The quality of both purified water and tap water is succinctly presented in Table 1.

Chlorine residue

The breakdown of chlorine in tap water primarily occurs due to the interaction with natural organic compounds. Age of water, presence of dissolved reactants (e.g., natural organic matter, sulfides, iron ions), and reactants in pipelines can affect chlorine reduction in the distribution system (Mantilla-Calderon et al., 2019). The life span between plants and water for model houses in Chitgarh housing complex is basically the same and ranges from 24 hours to 96 hours. The sampled homes had a residual chlorine content ranging from 0.23 to 0.52

mg/L in their cold water. Figure 1 illustrates that homes with tank water heaters experienced a substantial decrease in residual chlorine levels in their hot water, while homes without tank heaters only saw a moderate reduction.

Table 1: The water quality of the finished water in the Tehran water supply system

TOC (mg/L)	Finished water	Cold tap water	Hot tap water
	0.95	0.90 (0.11)*	1.02(0.12)*
DOC (mg/L)	0.79	-	-
UV-254 (cm^{-1})	0.007	-	-
SUVA (L/mg/m)	0.6	-	-
pH	6.49	7.55 (0.018)*	6.56(0.026)*
Temperature (°C)	18	21.2(0.96)*	49.2(1.98)*
		Significant test outcomes of Delta value Δ for the disparity between two categories of water heaters	
		P value	Significant or not
Cl_2 residuals (mg/L)	1.03	0.00001	Yes
DCAA (µg/L)	6.20	0.0019	Yes
TCAA (µg/L)	5.75	0.397	No
BCAA (µg/L)	1.54	0.0638	No
BDCAA (µg/L)	0.56	0.23651	No
TTHMs (µg/L)	21.58	0.05	Yes
CP (µg/L)	BDL^{Δ}	0.00763	Yes
TCP (µg/L)	0.35	0.003437	Yes
DCAN (µg/L)	2.37	0.0000002141	Yes

*: The standard deviations are represented within the brackets.
-: BDL: Below detection limit.
$^{\Delta}$: Cl_2 o DBPs discrepancy between the cold and hot tap water in the area.

Residual chlorine depletion due to thermal decomposition, such as its reaction with water or disproportionation, is highly improbable since sodium hypochlorite remains stable at around 50 °C (Lee et al., 2019). Instead, the main cause of residual chlorine loss is the rapid reaction between residual chlorine and NOM and other solutes present in water. Prolonged exposure to high temperatures can render standard tank heating systems more susceptible to this chlorine depletion. In the scenario of a house equipped with both a tank heater and a substantial fireplace, the increased levels of residual chlorine in hot water appear to be a result of excessive hot water usage prior to sampling.

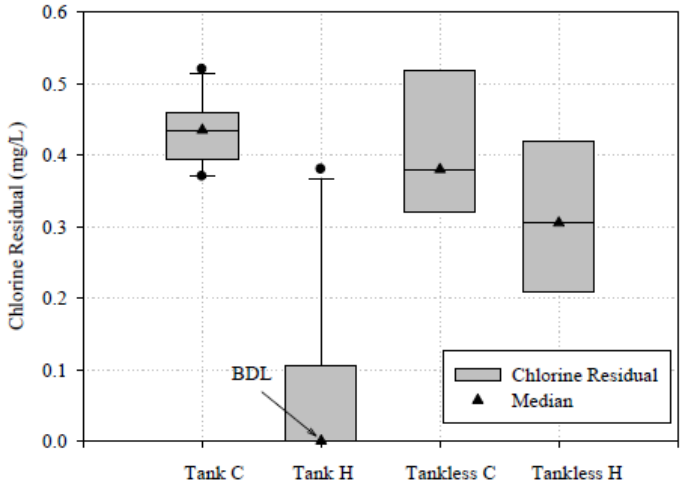

Figure 1: Chlorine residual levels were measured in the cold (C) and hot (H) tap water of residences equipped with tank and tankless water heating systems. The detection limit for chlorine residual was set at 0.02 mg/L, with levels below this threshold considered as below detection limit (BDL).

Trihalomethanes

Residual chlorine loss due to thermal decomposition, such as reaction with water or disproportionation, is highly unlikely as sodium hypochlorite remains stable at around 50 °C (Ghernaout et al., 2019). Instead, it is mainly caused by the rapid reaction of residual chlorine with NOM and other solutes found in water. Prolonged exposure to high temperatures can increase the susceptibility of standard tank heating systems to this chlorine loss. In situations where a residence has both a tank heater and a large fireplace, the higher levels of residual chlorine in hot water appear to be a result of excessive hot water usage before sampling.

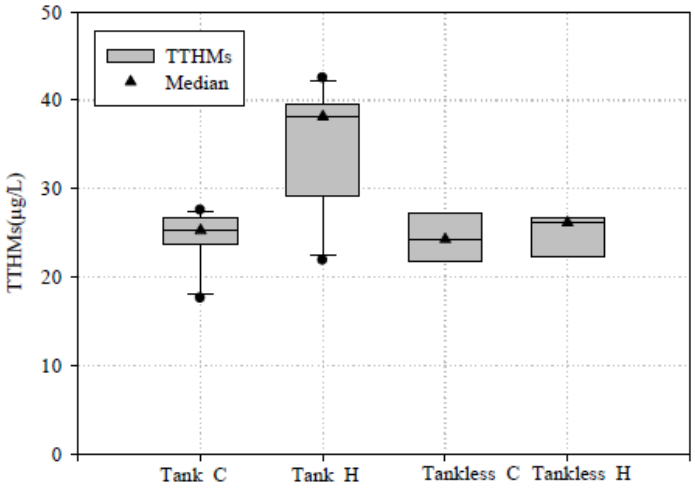

Figure 2: TTHMs were detected in the cold (C) and hot (H) tap water samples collected from residences equipped with Tank and Tankless water heating systems

Other neutral DBPs (DCAN, CP, TCP)

Figure 3 depicts the presence of three neutral disinfection byproducts (DBPs) - dichloroacetonitrile (DCAN), chloropyrene (CP), and 1,1,1-trichloropropanone (TCP) - in cold and hot water. The concentration of DCAN was discovered to be nearly as distinct as that of chlorinated haloacetonitrile. This similarity was observed in all cold water samples and hot water samples from tankless systems. However, the concentration of DCAN in hot water was considerably lower compared to traditional tank water heating systems. Conversely, a slight increase in TCP concentration was observed in hot water heaters from tankless water heaters. It is important to note that DCAN can be degraded by natural catalysts, as reported by Sun et al. (2018) and Yang et al., 2018). In the presence of residual chlorine, the concentration of DCAN initially increases and then decreases due to spontaneous decomposition, as observed by Bangia et al. (2020). Fu et al. (2017) discovered that DCAN can be converted to dichloroacetamide (DCAM), which undergoes rapid hydrolysis in the absence of free

chlorine, forming dichloroacetic acid (DCAA). Therefore, the disruption of DCAN may contribute to the observed increase in DCAA in hot water systems, albeit to a lesser extent. On the other hand, chloropyrene has not been detected in tap water or hot water from tankless heaters. The presence of chloropyrene in hot water samples from traditional tank water heating systems suggests that high temperatures enhance its production rather than its degradation. The case of trichloropropanone is similar to that of DCAN, with slightly lower TCP levels in hot water samples from tankless water heaters. In contrast, significant TCP loss was observed in hot water samples from traditional tank water heating systems.

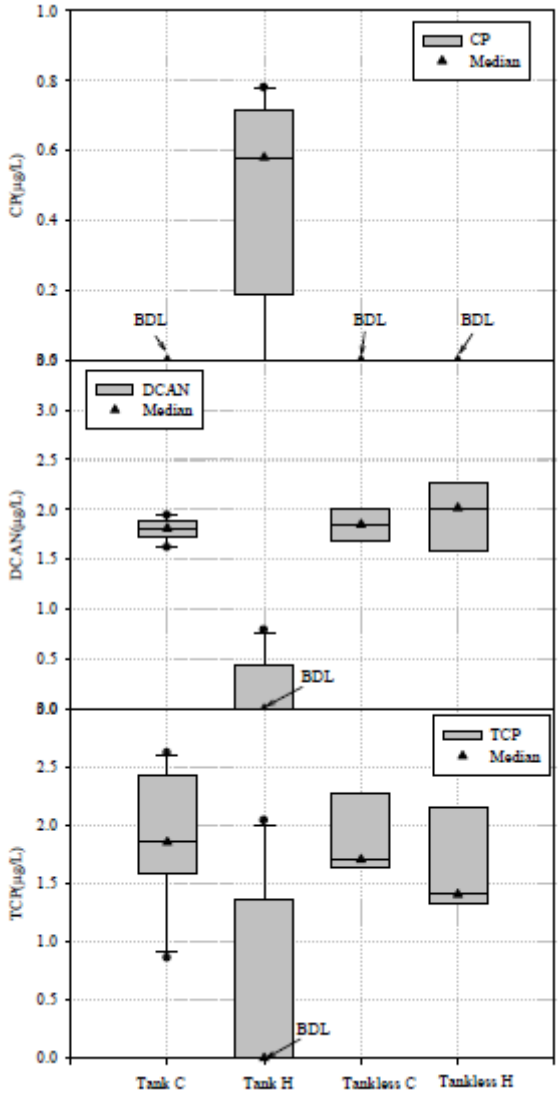

Figure 3: The concentrations of CP, DCAN, and TCP were measured in both cold (C) and hot (H) tap water samples collected from residences equipped with either Tank or Tankless water heating systems. The detection limits for DCAN, CP, and TCP were found to be 0.05, 0.03, and 0.11 μg/L, respectively, with BDL indicating concentrations below detection limits.

Haloacetic acids

The first step taken in these aquatic environments effectively kept HAA5 levels below the MCL of 60 μg/L established by the USEPA (Figure 4). Among the HAA9 species, only DCAA and TCAA were observed in specimens collected from residential areas. Tap water from traditional hot water tank systems exhibited higher levels of DCAA compared to the cold water obtained from the identical sampling sites. Nevertheless, the variance was not noteworthy in the majority of model residences that were outfitted with tankless heating systems. On the other hand, regardless of the heating system type, TCAA levels in cold water and hot tap water were similar in most production sites. Despite lacking approval from the US EPA, BCAA and bromochloroacetic acid (BDCAA) have garnered attention and analysis for their potential benefits compared to chlorinated alternatives (Jiang et al., 2020). There were slight differences in BDCAA levels observed between

cold and hot tap water samples in residences equipped with tankless water heaters (see Figure 4). Nevertheless, a significant reduction in BDCAA levels was noted in hot water samples collected from households equipped with conventional water heaters. The thermal decomposition of BDCAA occurs more rapidly than TCAA, leading to the formation of bromochloromethane at a first-order rate of 0.234 days at 50 °C (Young et al., 2018). Therefore, the overall decrease in BDCAA levels in tank water systems can be attributed to the rapid degradation caused by slight changes in trihaloacetic acid as a whole (i.e., the apparent influence of the most stable member, TCAA). As can be seen in Figure 4, BCAA levels in tap water remained consistent across all household samples. The slight increase in BCAA levels observed in domestic hot water and tank systems may reflect the corresponding increase seen in the more prevalent DCAA.

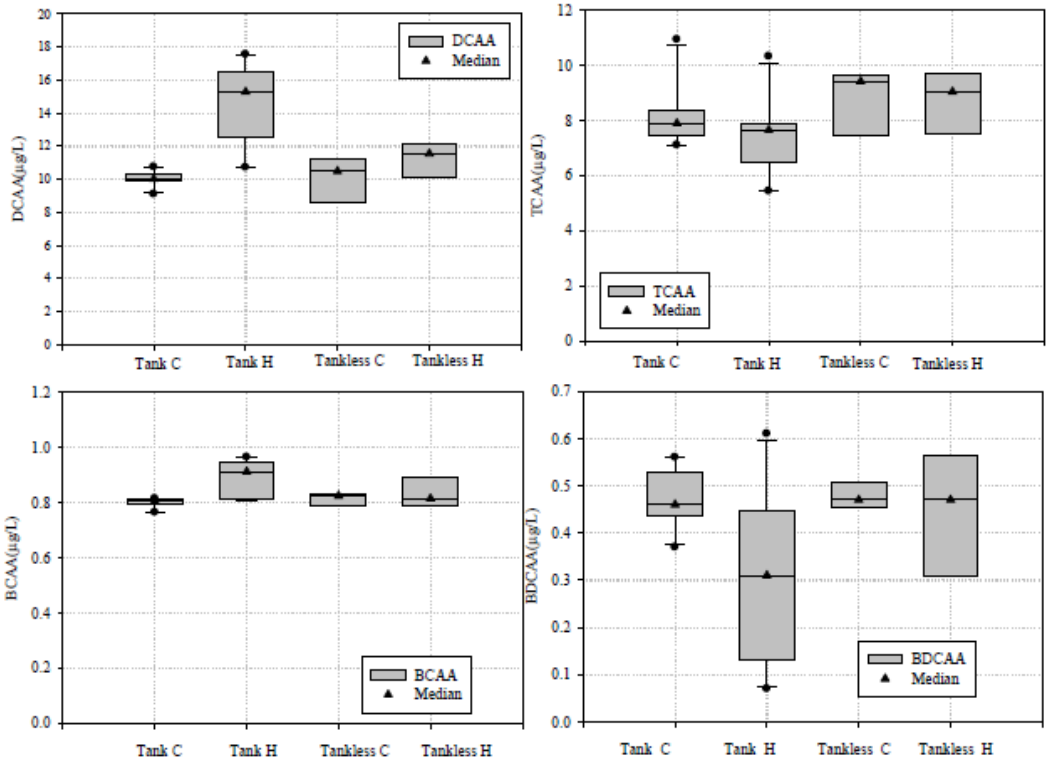

Figure 4: Haloacetic acids were detected in both cold and hot tap water samples collected from residences equipped with Tank and Tankless water heating systems.

Out of the four haloacetic acids (HAAs) examined in this research, solely dihaloacetic acids (DCAA and possibly BCAAs) exhibit comparable traits to THMs (specifically, elevated levels in hot water reservoirs), whereas trihaloacetic acids (TCAA and BDCAA) do not. Variations in the characteristics of these two groups may be attributed to variances in precursor origins, development, and breakdown rates (e.g., Shen et al., 2016). Previous research has indicated significantly elevated levels of HAA5 in hot spring water in comparison to cold spring water (Malato et al., 2016). Liu et al. (2020) observed a slight rise in HAA5 in a distribution system that utilizes chloramine as the final disinfectant during winter and spring. It is crucial to emphasize that this study examines both total haloacetic acids and individual haloacetic acids. Typically, the hydrophobicity of DCAA precursors is lower compared to TCAA precursors, leading to noticeable differences in the formation kinetics (Lin et al., 2020). As a result, there may be noticeable variations in outcomes between TCAA and DCAA. Additionally, the presence of chlorine degradation in hot water tanks may promote the growth of thermophilic bacteria within these tanks and the connected pipelines (Ji et al., 2016). The capacity of bacteria obtained from water distribution systems to break down halogenated acetic acids has been demonstrated (Huang et al., 2018). The thermophilic dehalogenase (L-HADST) demonstrates activity and the ability to break down halogens at temperatures above 50°C, as reported by Carter et al. (2019). However, there is no evidence of specific organisms in domestic hot water systems responsible for the biodegradation of disinfection byproducts (DBP). Furthermore, studies have shown that TCAA is not biodegradable by various cultures (Kali et al., 2021), indicating that substantial amounts of TCAA are unlikely to decompose in warm water environments. The minimal disparity in TCAA levels between cold and warm water samples could be attributed to the existence of competing formation mechanisms between TCAA and THM formation. Mantilla-Calderon et al. (2019)

proposed that the production of THM and THAA is primarily driven by competing processes, specifically hydrolysis and oxidation. Lower levels of chlorine could potentially decrease the formation of TCAA.

Significance examination of field data

A study was conducted to evaluate the statistical significance of water heaters on water quality parameters by utilizing paired t-tests on residual chlorine and DBP concentrations in hot and cold water from two distinct water heating systems. The findings are detailed in Table 1. A p value greater than 0.05 was utilized as the threshold to signify the absence of a significant distinction. The paired t-test outcomes verified that the variances in residual chlorine, DCAA, TTM, CP, TCP, and DCAN concentrations between hot water and cold water from conventional water heaters were significantly different from those of tankless heaters. Nevertheless, changes in TCAA, BCAA, and BDCAA concentrations were not considered significant.

Laboratory scale experimentation

During the bench-scale testing, factory processed water that did not contain any chlorine was utilized. The analysis presented in Table 1 reveals that the water in Tehran, after processing, possesses a remarkably low concentration of organic carbon and a specific UV value of 254 (SUVA). This indicates the presence of a naturally hydrophilic NOM (non-organic matter) that remains unaffected by dense tannins or lignin.

Different incubation periods at ambient temperature were evaluated to indicate varying water retention times in the distribution network. Short-term heating (10 minutes) and long-term heating (24 hours) were employed to simulate heating scenarios for non-demand hot water systems and tank systems. In Figure 5, the generation of TTHM and residual chlorine during incubation and heating is depicted. Chlorine residuals rose during the 4-day incubation period at 20°C. Short-term heating led to a slight rise in chlorine consumption during each environmental incubation period. Storing the samples in a refrigerator for 24 hours led to a decrease in residual particulate matter to 0.6 mg/L or less. The production of TTHM raised with longer reaction times throughout incubation at around 20°C. A slight increase in TTHM levels was observed after 10 minutes of heating. However, after a continuous period of 24 hours of heating, the TTHM level rose from 2.5 to 4.9 compared to samples that were not heated.

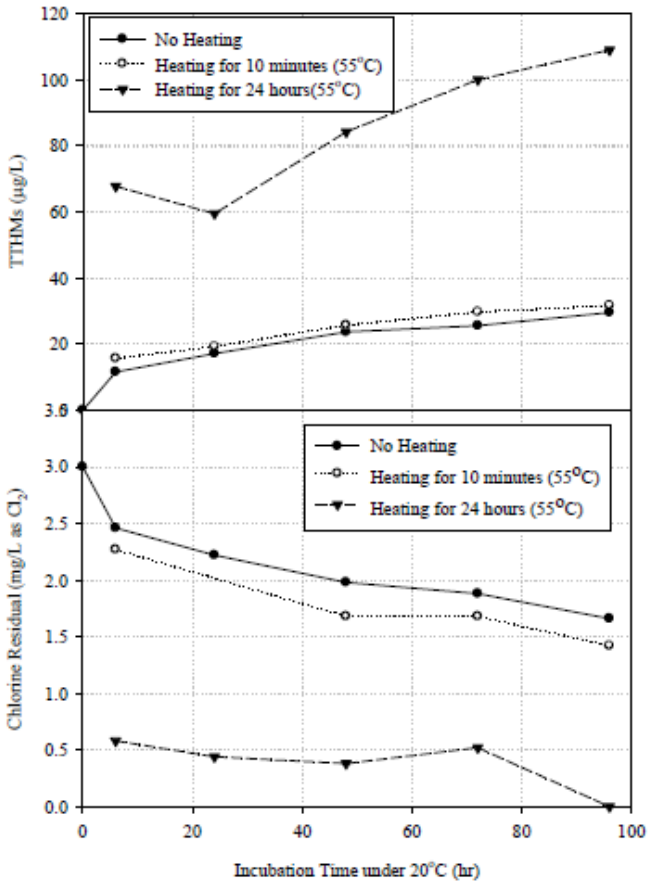

Figure 5: The generation of TTHMs while heating is time-sensitive, with the pH level set at 8± 0.2.

The rapid production of TTHM during the initial stages of chlorination is often associated with the quick-reacting NOM sites (Zhang et al., 2019). Uzun et al. (2020) demonstrated that chloroform production increases quickly at the start, in any case of temperature. It is widely recognized that the reaction rate escalates with higher temperatures. Nevertheless, when the heating process began halfway through the total chlorine contact time, a brief heating period (10 minutes) did not have a significant impact on the formation of trihalomethanes due to the prior consumption of fast-reacting NOM sites. 1. The rise in TCAA levels following 24 hours of heating ranged between 31% and 66%. However, with the increase in reaction time, it was anticipated that there would be a decrease in the formation of additional TTHM due to the reduction in residual chlorine over an extended period of incubation. During the process of incubation at room temperature, it is possible for certain halogenated byproducts to accumulate without being identified. These byproducts have the potential to react with residual chlorine, resulting in the formation of extra trihalomethanes when exposed to higher temperatures. The minor factor, although likely, could be the thermal decarboxylation of trichloroacetic acid, which may also contribute to the rise in THMs (Jjagwe et al., 2021).

Figure 6 depicts an escalation in the levels of DCAA and TCAA as time progresses, with BCAA and BDCAA reaching their peak at approximately 48 hours. The presence of low bromide content in the water resulted in minimal levels of BCAA and BDCAA. Short-term heating did not lead to significant alterations in the concentrations of DCAA and TCAA. Following 24 hours of heating, the DCAA tripled in specimens with 24 and 48-hour incubation periods, and doubled in specimens with 72 and 96-hour incubation periods. The rise in TCAA levels following 24 hours of heating ranged between 31% and 66%, which was lower in comparison to TTM and DCAA. Field observations indicated no significant variance in TCAA concentration between cold and warm water due to residual chlorine in the field. The chloroform pathway is favored under alkaline conditions. A considerable decrease in BDCAA and BCAA was observed after 24 hours of heating. The first-order dissolution rate constants for BDCAA and BCAA at 50°C were 2.6×10-6 s-1 and 1.5×10-6 s-1, respectively. This reduction was less evident for shorter ambient incubations, possibly due to chain formation at shorter incubation times.

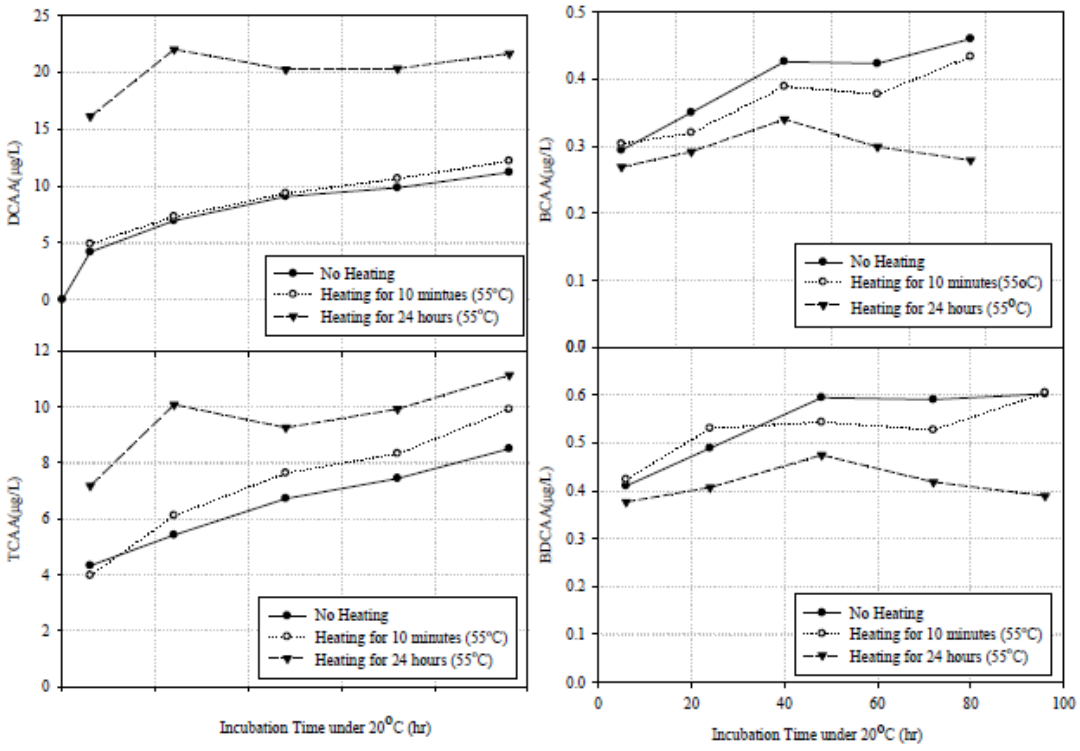

Figure 6: The formation of haloacetic acids during the heating process is influenced by time and is dependent on it. This phenomenon occurs at a pH level of 8± 0.2.

Figure 7 demonstrates how the duration of incubation affects the creation of CP, DCAN, and TCP. Initially, the concentration of CP in the incubation water at room temperature began at a slow rate of 0.04 µg/L and steadily rose to 0.12 µg/L. Following a 10-minute heating period, there was a moderate uptick in CP concentration. Conversely, after a 24-hour heating period, there was a substantial increase in CP concentration, raising the final concentration from 3.7 to 7.8. This finding contradicts the study conducted by Wiesel and Chen

in 1994, where they observed no change in CP concentration during 8 hours of heating in a hot solution. Nevertheless, our benchtop results align with our field study, which detected substantial amounts of SP in warm water but not in cold samples. In the majority of drinking water samples, SP concentrations are typically minimal and fall below the detection limit (~0.16 µg/L; Fu et al., 2017). Of concern is the fact that prolonged heating can result in a notable rise in CP levels, which is problematic given that this group of compounds is considered toxic by DBP (e.g., Carter et al., 2019). The DCAN increases with longer incubation periods, peaking at 48 hours. Brief heating results in a rise in DCAN for specimens with smaller incubation times, while it decreases the concentration for specimens with ambient incubation times. Dichloroacetonitrile is unstable in water environments and can decay, particularly in alkaline environments (Ghernaout et al., 2019). Higher temperatures accelerate the degradation of DCAN (Malato et al., 2016). Therefore, the existence of DCAN relies on the balance between the speed of its creation and its breakdown. A significant amount of DCAN was lost after 24 hours of heating. Trichloropropanone, following an initial rapid formation, degrades over time at pH 8. Short-term heating speeds up TCP degradation, reducing its concentration from 40% to 67%. The level of TCP was found to be very low after 24 hours of heating.

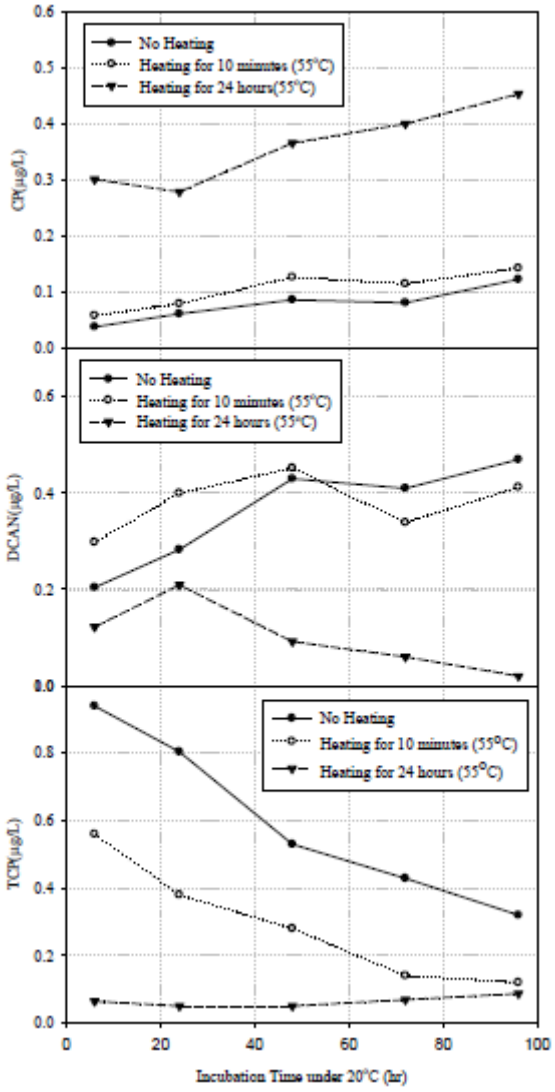

Figure 7: During the heating process (pH=8± 0.2), the formation of CP, DCAN, TCP, and DCP is time-dependent.

IV. CONCLUSION

The findings of this research indicate that DBP has the ability to greatly impact the temperature of household drinking water. Storing hot water over an extended period of time without regulating the temperature has minimal to no effect on the DBP configuration profile. On the other hand, if hot water is stored for an extended period of time using tank water heaters, it can result in the production of substantial amounts of

trihalomethanes and haloacetic acid when the water still contains residual chlorine. The presence of residual chlorine is also associated with the rise in TCAA levels in hot water, especially when combined with high temperatures. However, if the cold tap water already contains residual chlorine, there will not be a significant increase in TCAA levels after consuming water from a water heater. The installation of a faucet in your water heater can substantially enhance your CP. The abundance of DCAN is determined by the competition between its formation and degradation. After short-term heating, there is a rise in DCAN, whereas following long-term heating, a significant decline in DCAN concentration is observed. The stability of TCP diminishes with incubation time and temperature. In general, varying temperatures and temperature patterns can result in diverse DBP patterns. Therefore, as tankless water heaters gain popularity, researchers must take this into consideration when assessing human exposure to DBPs.

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