Pipe Material Influence On Variable Formation Of Chlorine Disinfection By-Products In Water Supply Networks

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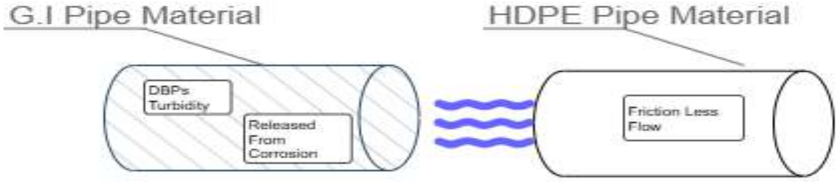
Abstract Well-known, prominent two-chlorination disinfectant byproducts (DBPs), i.e., Trihalomethanes (THMs) and Trihaloacetic Acids (THAAs), emerge in drinking water when reacting with other constituents in water. The chlorination of water nowadays crucial step in water supply infrastructure, yet the production of chlorine-generated DBPs has emerged as a critical public health issue. The pipe nature used for water supply is considered an important factor for the manipulation in the production of Chlorine DBPs. This study validates the pipe nature effect in the production of Chlorine DBPs by using the two types of pipe, i.e., Galvanized Iron (G.I.) and High-Density Polythene (HDPE). When the chlorinated water comes in contact with the surface of two different nature pipes, fluctuating results were seen. These findings certainly contribute to the contrast between the generation of prominent DBPs formation under the known two supply mediums. Overall results from this study revealed that the G.I pipe nature contributes more to the chlorine DBPs production as compared to the HDPE pipe nature.

Key Words :Chlorination Disinfectant by Products, Water Distribution Nature, GC -MS (ECD)

Graphical Abstract



Comparative Flow Between Pipe Media

1 . Introduction

In this modern era, drinking water disinfection attempts are considered a critical public health measure, effectively preventing waterborne disease by removing pathogenic microorganisms[1].Chlorination is one of the practical yet least expensive methods to deactivate microorganisms and is a feasible agent for ensuring the control of developmental activities in the supply network [2]. A free chlorine residual is generally maintained up to a maximum of 0.2 mg/L, which must be maintained in the distribution network because it reduces the likelihood of further contamination. [2].Dissolved organic matter in water is a complex natural element present in water due to anthropogenic activity and is known as the main cause of the production of chlorine DBPs in water.[3].The study by [4] found that the most prevalent group among DBPs is THMs, THAAs.

Distribution Systems (WDS) impacts a huge role in the secondary formation of DBPs, which may lead to the risk of excessive DBPs generation while passing through WDS [5]. Meanwhile, the complex environment of pipe nature will affect the further reaction between residual chlorine and organic matter. Different countries use different pipe materials for drinking water transportation according to the supply and regulations cast iron pipe is the most widely used pipe material but cast iron pipe easily corrodes and produces iron, accelerating DBPs formation [6]. Compared to other pipes, galvanized steel pipes showed a higher rate of chlorine decay, which means producing more DBPs[6]. Besides hydraulic shock, which can lead to the release of microplastics in plastic pipes, and the release of the microplastics may contribute to DBPs formation, which further deteriorates the water quality[7]. [8] found that biofilm from 2 years-usage pipes increased the concentration of THMs and THAAs to 59.5-123 μg/L and 35.1-51.6μg/L, respectively, which were higher than that of new pipes. Volatile chlorinated hydrocarbons are found to be carcinogenic, and the USA (EPA) has regulated 0.005mg/L as the minimum permissible contamination level of these volatile chlorinated hydrocarbons[9].Moreover, the transformation factors of DBPs formation in WDS in the WDS (e.g., pipe materials, deposits, and biofilms) are not single and synergistic for the formation[5].

For the quantification of THMs and HAAs formation[10]conducted experiments for pipe setups like [11]in which 56 days were selected for the investigation of the DBPs development under-maintained chlorination dosages during the whole experiment. The purpose of the study done by was[12]to investigate firstly the effect of initial chlorine dose, under different pipe materials, and secondly, the analysis of the occurrence and transformation of DBPs in a water distribution system after booster chlorination. The DBPs were measured for each sample by Gas Chromatography Mass Spectrometry equipped with an electron capture detector (GC -MS(ECP)). The reason for using GC-MS(ECD) in most DBPs studies is high sensitivity to halogens. To the best of our knowledge, there has been no reference to comparative studies investigating prominent DBPs for the most commonly used water supply pipes, which are of iron and plastic nature.

Our study was conducted in District Mardan (geographic coordinates between 34°05`N-34°32`N and 71º48`E-72°25`E), one of the central districts of Khyber Pakhtunkhwa province of Pakistan. Samples were selected for chlorine dosage of 0.2mg/L, 1.8mg/L and 2.4mg/L specifically for Galvanized Iron (G.I.) nature pipe media and High Density Polythene (HDPE) nature pipe for identification and quantification in the study area. Each sample was investigated under controlled chlorine dosages. A prototype experimental lab setup was built to replicate a vast water supply network flow in G.I. and HDPE for the uninterrupted water flow in distribution pipes under controlled conditions. The two main chlorination disinfectant by-products, specifically THMs and THAAs, were investigated for quantification under GC-MS equipped with (ECD).

1. Materials and Method

a. Chemicals and Reagents

Chlorine granular powder, i.e. Calcium Hypochlorite was obtained from the Water Quality Labs Public Health Engineering Department KP, Pakistan. Two DBP standardization chemicals, i.e., chloroform and trihalo acetic acids, were purchased from standard sales in Pakistan. Separating chemicals for separation of solute and solvent ethyl acetate(separator) as a liquid-liquid separation was obtained from the Public Health Engineering Department KP. Distilled water was obtained from the Public Health Engineering Department KP, Pakistan Water Quality Labs. Fluorescence spectrometry was performed in the Central Resource Laboratory (CRL) at the University of Peshawar, KP.

b. Sampling Site

For coherent sampling, we use a multi-staged random sampling for all water zones of district Mardan Region, Pakistan's second-largest district of KP Province. For the water samples, water from the ground source was selected, and the pumping water system elevated head tank or overhead reservoirs were utilized to give head elevation and distribute to the consumers. Groundwater, or tubewell, was the intake source for all inputs. The groundwater potential of almost every groundwater source was below 90-120m, while the static water level was about 18-30m. For most areas, the area used G.I pipe is used for hilly areas, and the HDPE pipe nature for flat regions. This study mainly used the GI nature pipe and HDPE pipe for water conveyance.

c. Setup

To accomplish the aim of the study, the lab model pilot-scale water distribution system was prepared for different chlorine dosages, which contain loops made of G.I nature and HDPE nature as shown in Figure 1. Each loop's length was approximately 1.5-3m, and the diameter of the pipe was kept 25mm. The loops were provided with ball valves, elbows, unions, and sockets to investigate water behavior and control water pressure and velocity. They have also been used to divert water flow in the required direction. The velocity flow of the water was controlled between 0.2m/s to 1.8m/s. A 0.3 HP centrifugal pumping machine was also installed for the continuous water flow. In the distribution network, 0.189m^3(50 Gallons) of water reservoir receives samples directly from the site. Special attention was paid to grab samples of water from different zones to monitor temperature and exposure to sunlight by using the Public Health Engineering Department KP Mobile water quality testing laboratory. Before running the water sample in the pilot scale laboratory distribution system, the system was washed with ultrapure water for 30 minutes to clean any leftover residue. The methodology of the distribution network comprises four components, i.e., flushing, adjusting parameters, chlorination dosages, and sampling. After washing with clean water, samples were added to a reservoir of 0.189m^3(50 Gallons) and given a suction by pumping matching. The water flow from each loop, flow, and velocity were uniform and uninterrupted, so mixing particles may have equal opportunities when chlorine dosages are added. After ensuring the flow was uniform, chlorine dosages were added in weightage of 0.2 mg/L, 1.8 mg/L, and 2.4 mg/L, respectively, for each turn. Identification and quantification of THMs and THAAs were achieved for different dosages of chlorine added.

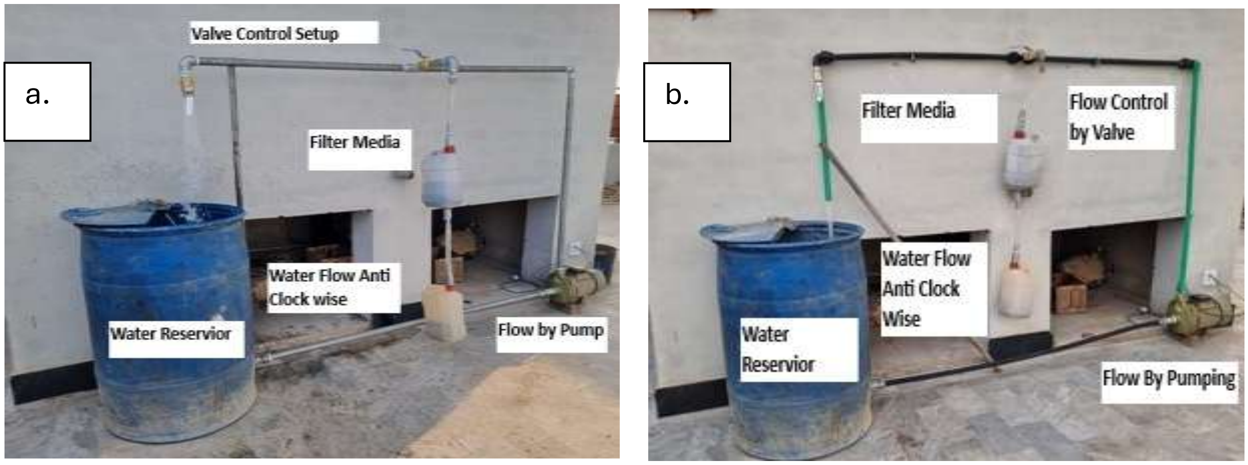


Figure 1 Schematic of Experimental Setup (a. Setup for G.I nature b. Setup for HDPE nature)

To determine THMs and THAAs already recommended by EPA 555.1[13]GC-MS (ECD) laboratory model of (GCMS-5977B AGILENT TECHNOLOGIES USA)was used. The column was fused silica capillary DB-1,30m × 0.32 mm i.d. × 0.25µm film thickness. The Gas used was helium (99.99% pure) as a carrier and nitrogen(99.99%) as makeup gas. The analytical equations were used as protocol.

$\mathrm{TTHMs} + \mathrm{THAAs} = \text{promient chlorine DBPs}$ Equation 1

$$\text{Concentration in Extract} = \frac{\text{Measured Peak area}}{\text{Peak area of Internal Standard}}\ \text{X}\ (\text{m} + \text{b}) \qquad \text{Equation 2}$$

$$\text{Cw} = \frac{\text{Ce X Ve}}{\text{Vw}} \qquad \text{Equation 3}$$

2. Results and discussion

a. Fraction of DBPs in selected zones under controlled dosages

To obtain occurrence results of Chlorine DBPs [12]made a sequence-wise batch supply of chlorine dosage for the water distribution network model and observed the production weightage/variations accordingly against chlorine-controlled dosages supplied. The analysis was conducted in a stepwise phase, i.e., initially for 0.2mg/L, then 1.8mg/L, and then 2.4mg/L for both pipe nature. For the initial control dosage of 0.2 mg/L, the production of DBPs, specifically THMs and THAAs, was not seen in the obtained chromatogram for both of the nature of the pipe medium. Other than chlorine DBPs elements with retention were traced out . The reason for non-identified THMs and THAAs was the meager presence of chlorine residual and negligible residual chlorine rate.

Then a 1.8mg/L chlorine dosage rate sample was taken to investigate the availability of two chlorine DBPs, i.e., THMs and THAAs, for both G.I. and HDPE pipe nature pipe. Initially, for the G.I. pipe GC-MS sample analysis, 11 elements were traced out in a chromatogram. In contrast, subject DBPs, one element, Trichloromethane was recognized at 1.532 mins with Peak Number 4 with a molecular weight of 119 g/mol and having mass spectrometry area of 3029057 as shown with peak in Figures 2. After the G.I pipe nature HDPE passed water sample was investigated under GC-Mass. For searching for chlorine DBPs, the sample was investigated under GC.MS (ECD) for about 8-9 hours and it couldn't be discovering any halogenated Chlorine DBPs but rather any of their family members.

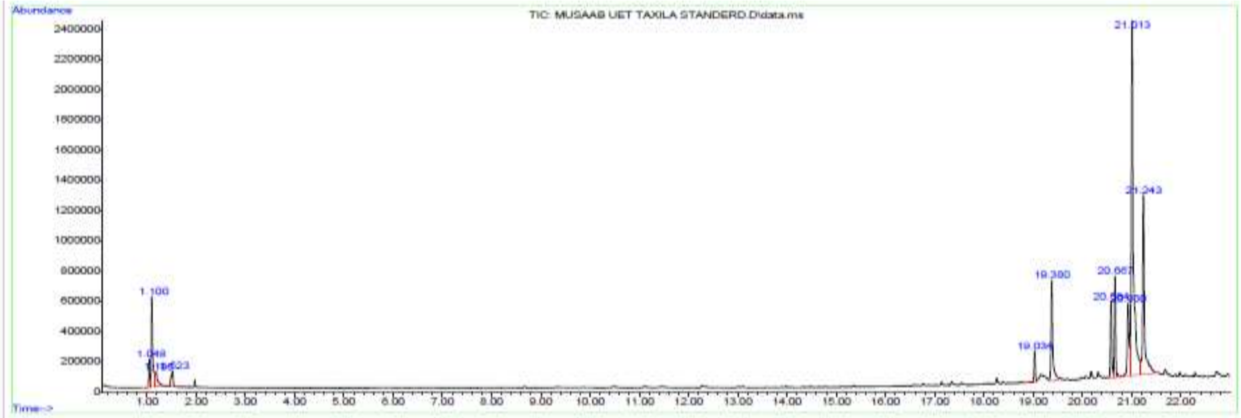


Fig 2 Chromatogram of 1.8mg/L Chlorine Dosage for G.I pipe nature

Now we enhance chlorination to 2.4mg/L. Now both the G.I nature pipe and HDPE water passed sample were investigated. Now initially G.I pipe water samples were investigated under GC-MS for which both focused halogens family members including THAAs and THMs were traced with peak number 2 at 4.452 mins as shown in Figure 3. Other than these focused hydrocarbons the remaining traced elements with retention .For the HDPE nature sample, we traced both DBPs in the form of trichloroacetic acid and trichloronitromethane at peak no 2 with a retention time of 4.340 mins as shown in Figure 4 .The detection of these DBPs in the HPDE sample underscores the material potential role as a source or mediator of DBPs formation in the water system.

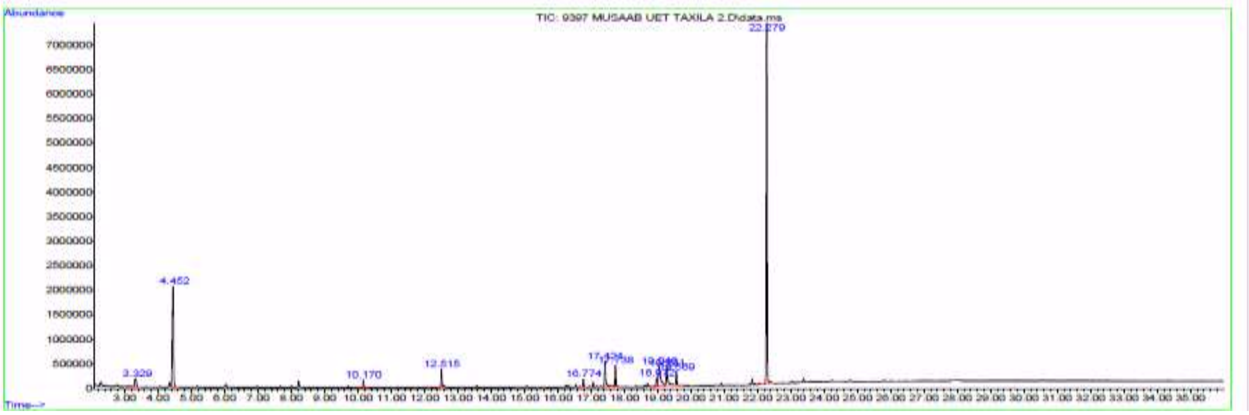


Fig 3 Chromatogram of 2.4mg/L Chlorine Dosage for G.I pipe nature

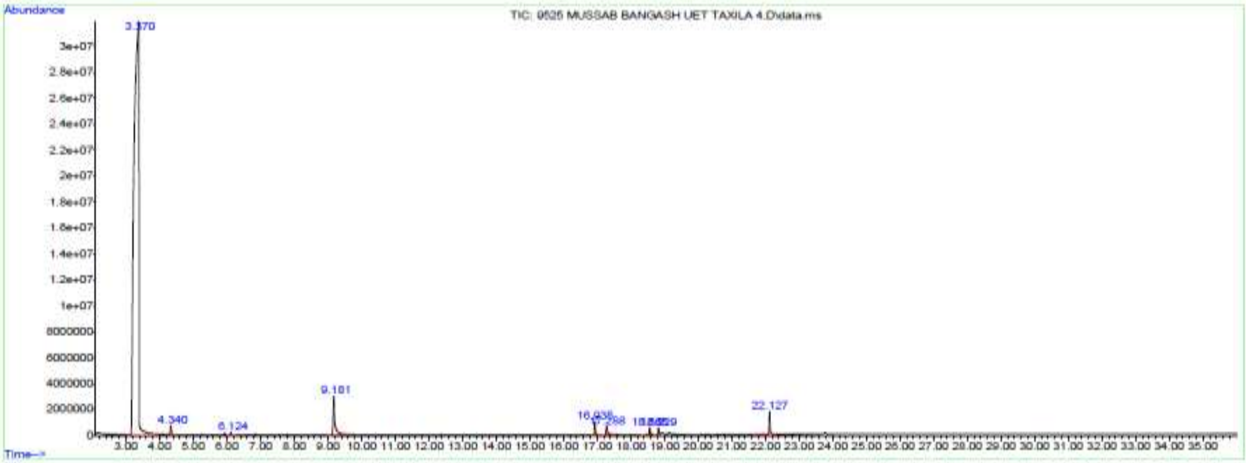


Fig 4 Chromatogram of 2.4mg/L Chlorine Dosage for HDPE pipe nature

However, for G.I passed water sample it has been found that for chlorine dosage of 2.4mg/L about 0.212mg/L THAAs were quantified and about 0.199mg/L THMs were found after running under a controlled dosage and for 1.8mg/L chlorine in same G.I pipe medium about 0.193 mg/L THMs were quantified now similarly for HDPE pipe medium for chlorine dosage of 2.4mg/L about 0.2mg/L THAAs were quantified and about 0.167 mg/L THMs were found as shown in Figure 5.

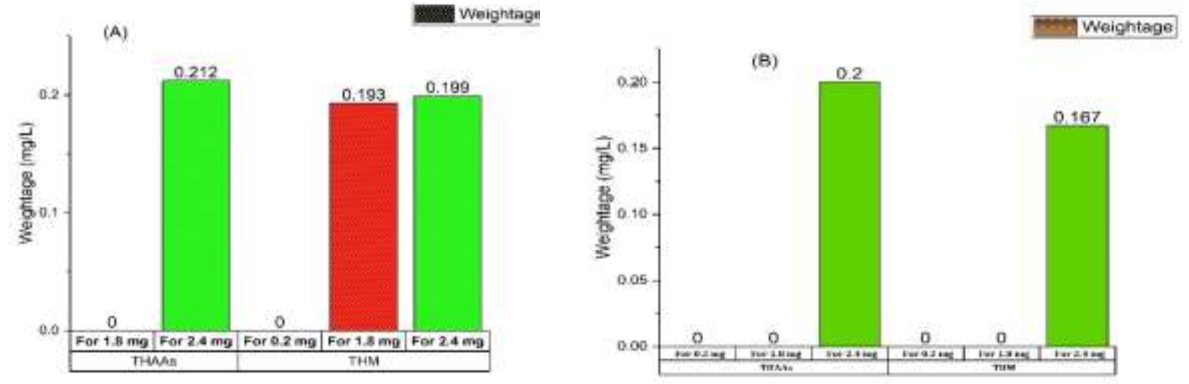


Fig 5 Chlorine DBPs obtained weightage in GI passed medium pipe .b Founded THAAs and THMs for different chlorine dosages in HDPE.

3. Conclusions

The following conclusions were obtained in the investigation of the water sample.

- The production of chlorine DBPs, specifically THMs and THAAs shows the behavior of enhancement in occurrence while increasing chlorine dosage under controlled conditions for each nature of pipe.
- The material properties of G.I pipes such as the tendency to corrode, release metal ions, and trap organic matter contribute to the higher formation of chlorine DBPs compared to HDPE pipes, which are less contributive towards chlorine DBPs production.
- Optimum usage of chlorine content in the water supply can contribute to balance disinfection effectiveness with minimum DBP formation.

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