

Leaching of microplastics from PVC pipes under stagnant conditions

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ABSTRACT

The commonly used household plumbing pipes are made of polyvinyl chloride (PVC) pipes. However, there are concerns regarding their role as source of microplastics (MPs) in the water supply system. This study aimed to investigate the leachability of MPs from PVC pipes under stagnant conditions. Laboratory experiments were conducted in PVC pipes to simulate MP leaching at varying pH, chlorine doses, and stagnation times. Water samples from the experiments were tested for different water quality parameters, including MPs using standard procedures. The total organic carbon concentration in the water samples increased with stagnation period indicating that organic substances including MPs were leaching from the pipes. The concentration of leached particles as well as the MPs count increased with stagnation period. A strong correlation was found between the MPs count and the mass concentration of leached particles retained on the filter papers leading to the conclusion that most of the leached particles were MPs. Attenuated total reflectance-Fourier-transform infrared spectroscopy analysis showed peaks associated with C–Cl and C–H bonds that are typical for PVC suggesting that particles retained in the filter are likely PVC microplastics. Scanning electron microscopy coupled with energy-dispersive X-ray spectroscopy analysis identified particles that have elemental compositions like that of PVC further strengthening the conclusion that MPs were leaching from the PVC pipe.

Keywords: Microplastics; Leaching; Stagnation; Polyvinyl chloride pipes

1. Introduction

Polymeric pipes with their many advantageous attributes, such as long durability, corrosion resistance, low cost, easy installation, etc., have been increasingly used as substitutes for old metallic pipes in drinking water systems. During this development, various types of plastic pipes made of polyethylene (PE), polyvinyl chloride (PVC) and polypropylene (PP) are predominantly used in the potable water distribution networks all over the world [1]. In fact, according to estimates by the American Water Works Association (AWWA), the United States will spend nearly \$250 billion over the next few decades to mitigate and replace the metal pipes in the distribution networks [2]. In China, plastic pipes with a nominal diameter (DN) below 400 mm were proposed for urban drinking water networks and accounted for

about 80% of all the pipe materials used in water distribution systems by 2015 [1].

Despite their increasing popularity and use, there are major concerns about using polymeric pipes in the water distribution networks (WDNs). One such concern is the leaching of organic compounds, especially volatile compounds. Polymeric pipes such as PVC, polypropylene random copolymer (PPR), and PE are capable of leaching monomers, lightweight polymer units, and additives such as antioxidants, catalysts, solvents, fillers, lubricants, stabilizers, and plasticizers [1–4]. In addition, concerns about possible formation of biofilms in the inner surface of the pipes and the possibility of increased disinfection-by-products formation due to the presence of chlorine that is added to the water for secondary disinfection were observed [1]. Recently, microplastics (MPs) in the WDNs has become an important topic of concern among researchers [5].

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MPs are generally defined as plastic fragments smaller than 5 mm. The recent introduction of the term “nanoplastics (NPs)” for sizes <100 nm in any of their dimensions establishing a lower limit to these particles. However, literature shows that there exist discrepancies on the definition of MP sizes [6]. MPs are commonly categorized as primary and secondary based on their origin, with the majority being secondary. Primary MPs are manufactured in size <5 mm. They are found in skin care products such as microbeads, textiles, and medicines. Secondary MPs, on the other hand, are formed through the disintegration of larger plastics. This disintegration can occur due to various processes such as solar UV induced photo-degradation, thermal reactions, hydrolysis, or microbial biodegradation [6].

MPs can also be categorized by their form, commonly in fibers, fragments, and spherical beads, as well as by their chemical composition, for example, PE, low-density PE (LDPE), PE terephthalate (PET), polyacrylates (PA), and so on. MPs in water can be divided into many groups depending on the characteristics, describing a diversified class of materials that includes a wide range of polymer types, particle sizes, shapes, and chemical formulations [6].

The environmental and health impact of MPs in the marine and aquatic environment has been well documented in literature [7–10]. MPs can also negatively affect human health. Owing to the cumulative effect of NPs and MPs, even low concentrations of MPs may accumulate in the secondary organs of the human body, damaging the immune system and cells. MPs may also release contaminants and pathogenic bacteria that were initially adsorbed onto their surfaces, causing secondary pollution [11]. MPs can be regarded as vectors or sinks for hydrophobic organic chemicals (HOCs) in aqueous environments owing to their strong hydrophobicity. Many field and laboratory studies have proved that MPs can associate a range of environmental contaminants such as polychlorinated biphenyls, polycyclic aromatic hydrocarbons, pharmaceuticals, and perfluorinated surfactants. Chemical additives (e.g., bisphenol A, phthalates, and flame retardants) blended intentionally during the manufacture of plastic pipes are of increasing concern as they might be released from the plastic into the environment [12].

The presence of MPs from the open seas to deep oceans, river, lakes, the water column, sediments, reservoirs, tertiary systems, freshwater bodies, portable water and discharge from wastewater treatment plants (WWTPs) has been widely reported [5–10]. The presence of MPs in all stages of drinking water treatment plant and water distribution network including pipe scales was also reported in literature [11,13]. Removal of MPs using different water treatment unit processes were also addressed in previous studies [14,15]. In addition, Chu et al. [11] noted the increased presence of MP particles in pipe scale samples compared to that in the water samples. The predominant MP particles in pipe scales were smaller in size than those found in the water samples. They also noted a significant reduction in the number of MPs entering the tap, thus providing direct evidence for the strong adsorption of MPs onto pipe scales. Other studies have also shown that MP contamination prevails in drinking water. Orb Media, a nonprofit journalism organization, tested drinking water from five continents and found that

83% of the drinking water samples were contaminated by MPs [7].

Despite the implications for human health, limited research has been carried out on MPs in drinking water, and previous studies focused primarily on MPs in freshwater used for drinking water production rather than on the water directly consumed. Only a few studies focused on the quantification of MPs in potable water. The reported results in these studies vary by nearly 6 orders of magnitude. Comparison of these results is challenging because samples of drinking water samples originated from different sources (ground- or surface water) and the different techniques used to identify and quantify MPs ranging from simple visual inspection to state-of-the-art micro-Fourier-transform infrared (μ FTIR) and micro-Raman analysis [16].

A significant source of MPs in the water distribution system is the pollution of raw water with effluent from wastewater treatment plants. Even though wastewater treatment plants can remove 95%–99% of MPs, the large volume of sewage released into fresh water leads to MP pollution of fresh water. Moreover, in the treatment plant and distribution system, MPs may be generated from chemicals used for coagulation and degradation of membranes used for water treatment and leaching of plastic pipes and fittings [11].

Mortula et al. [17] conducted a study on the leachability of MPs from different types of plastics (i.e., PVC, PP) under different pH conditions. There were more types of plastics that were studied (such as PET, LDPE, HDPE, PS, PC). The study was conducted on small pieces of different types of plastics using a modified toxicity characteristics leaching procedure (TCLP) test. The results indicated that significant MP leaching occurred under acidic and basic conditions. Leaching was also observed under neutral conditions, though at a lower rate. Nevertheless, the leachability of MPs from plastic pipes used in WDNs and its significance is not well studied.

PVC is one of the most commonly used materials in household plumbing pipes around the world. It provides advantages for small diameter pipe markets. PVC pipes are known for their stability and reliability for usage in household plumbing. However, water flows through these pipes only when end users open the tap. Specifically, water remains stagnant for most of the night as people sleep. The leached MPs can accumulate during this period. So, water that is used for the first-time in the morning may contain a significant number of leached MPs. However, there are no such studies investigating MP leaching in stagnant water. Most research on MPs in the WDNs tend to focus on the quantification and characterization of MPs [18]. There is a gap in research for finding the role of leaching from pipes used in the WDN, especially under stagnant conditions. In addition, research is necessary to investigate the factors that affect the leaching of MPs from pipes under stagnant conditions. This study is novel in its attempt to investigate leachability of MPs from PVC pipes under stagnant conditions using laboratory-based experiments.

The leachability of MPs from plastic pipes under stagnant condition in the WDN is the focus of this study. Various factors can affect the leachability of MPs from pipes that make up a typical WDN. Some of these factors may be but are not limited to water temperature, pH level, chlorine level, and the amount of time that the water is left stagnant.

The objective of this study is to investigate the leachability of MPs from PVC pipes under stagnant conditions using a laboratory-based experiment. It also attempts to determine the significance of leaching as a source of MPs in the WDN.

2. Materials and methods

2.1. Materials

PVC pipes with internal diameter of 40 mm and length of 1 m with end caps on either side were used in this study as shown in Fig. 1. A total of 27 pipes were used in this study. The pipes were procured locally from the hardware stores. However, these pipes are not new and have been used previously only once for one set of stagnant water experiments.

2.2. Experimental procedure

The experiment aimed to identify the MP leaching of PVC pipes under varying pH, chlorine dose and stagnation times. Tap water at room temperature was used in the study to simulate the water quality in the stagnant pipes of typical WDNs. The water sample was divided into three batches and their pH was adjusted to 6.5, 7.0 and 7.5 using diluted sodium hydroxide and sulfuric acid. These pH levels were chosen as they represent the typical range of pH in many WDNs. Each batch was then divided into three parts and diluted sodium hypochlorite was added to the samples to attain three different initial chlorine concentrations of 0.5, 1.0 and 1.5 mg/L. These initial chlorine doses were taken based on the expected residual chlorine levels in WDNs. Water treatment plants aim to deliver water at the consumer end with a chlorine concentration of 0.2–0.5 mg/L. However, it may be necessary to maintain higher levels of residual chlorine in some parts of the distribution system to ensure the minimum residual chlorine concentration throughout the entire system. The concentration of chlorine in drinking water supplied to customers should be below the World Health Organization guideline value of 5 mg/L [19]. Each sample set was then poured into three separate PVC pipes until they were filled. The pipes underwent varying stagnation durations: 5, 8.5, and 12 h. The durations were selected to simulate households where water may stagnate in the pipes over

short, medium, and long periods on an average day. The 12-h stagnation period is typical of households where the residents spend their days at work (9–10 h) and on commute (2–3 h). By combining these factors, 27 samples that have different pH, chlorine level and stagnation duration were achieved.

2.3. Analytical methods

Upon completion of the stagnation period, water samples from each pipe were analyzed using standard and established analytical methods for evaluation of water quality [20]. The pH of the water samples was measured using a pH probe (Oakton pH 11 series, Vermont Hills, Illinois, USA). The conductivity of the water samples was measured using a conductivity meter (Oakton Con 11 series, Vermont Hills, Illinois, USA). The HACH DR/890 Colorimeter (Loveland, Colorado, USA) was used to measure the total chlorine residual in the samples according to the DPD method. Total organic carbon (TOC) was analyzed using the HACH LCK 385 Cuvette Test (Dusseldorf, Germany) (range 3–30 mg/L of TOC) on the HACH DR5000 Spectrophotometer (Dusseldorf, Germany). Measurement TOC concentrations can be used as a tool to investigate leaching of organic compounds from polymeric pipes [2]. Methods of using TOC to quantify MPs and NPs were illustrated in previous research work [21,22]. The methods involve concentration MPs and NPs and particulate organic matter (POM) using membrane filtration; and treatment of samples through various procedures to remove interference of organic compounds that could affect the TOC reading. In this study the TOC of the water samples was measured without any filtration and treatment.

Filtration and microscopic detection are commonly used techniques for identifying and quantifying MPs [23–25]. Accordingly, microplastics analysis was done using visual observation under 40x dissecting microscope (KERN Optics OSE417, Balingen, Germany). The entire volume of water from each pipe was vacuum filtered through a gridded cellulose acetate filter paper (47 mm diam., 0.45 µm pore size). Afterwards, the filter paper was air dried inside a desiccator for at least 24 h (Fig. 2). The mass of the dried filter paper was measured to determine the mass gained from the particles retained on it. The filter paper was then observed under the



Fig. 1. Polyvinyl chloride pipes set-up.

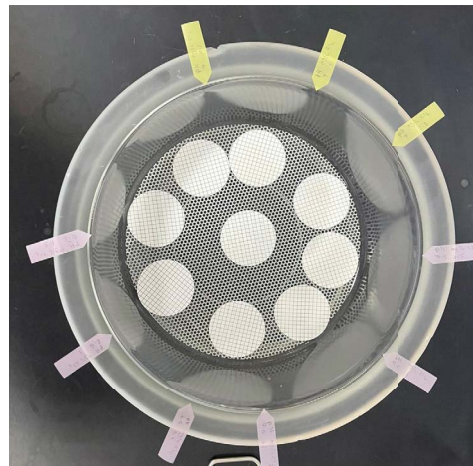


Fig. 2. Filter papers dried in desiccator.

microscope to identify and count the MPs (Fig. 3). As a standard practice, a part of the gridded filter paper was selected and the number of MPs on that part of the grid was used to determine the number of MPs across the entire filter paper.

2.4. Characterization of microplastics

The Fourier-transform infrared spectrometry (FTIR) analysis is one of the most used and robust methods to identify and characterize synthetic plastics [26]. FTIR is generally used for homogeneous particles and mixtures. FTIR analysis of MPs involves the selection of individual plastic particles and sample preparation. In samples that are heterogeneous, the use of micro-FTIR image scanning is recommended [27]. The difficulties of sample preparation can be solved with the use of attenuated total reflectance-Fourier-transform infrared spectroscopy (ATR-FTIR) which requires very little sample preparation.

Selecting individual MPs from filter papers is challenging due to the size of the particles. Furthermore, collecting enough particles to cover the diamond crystal window of the ATR is almost impossible. In this study, the filter papers were directly analyzed using Thermo Scientific Nicolet iS5 (Madison, Wisconsin, USA) FTIR with iD7 ATR accessory to characterize the type of plastics retained on the filter paper. The analysis was conducted on the filter papers from the samples with the highest chlorine concentration (i.e., 1.5 mg/L).

Application of scanning electron microscopy coupled with energy-dispersive X-ray spectroscopy (SEM-EDX) as a tool to characterize the morphology and elemental composition MPs was reported in the literature [28]. SEM-EDX provides detailed information on the elemental composition of microplastics with additional information on the inorganic additives they contain. The presence of chlorinated MPs can be easily confirmed using this method. A previous study [29] indicates that PVC particles show strong chlorine peak in the EDX spectra. In another study [30], SEM analysis of a virgin PVC in an ultrafiltration membrane exhibited 74.9% carbon, 10.4% oxygen, and 14.7% chlorine. On the other hand, fouled membrane showed significantly less content of chlorine with its composition dropping down to 2.4%. Degradation of material due to aging and the associated leaching of organic compounds also results in alteration of chemical properties of PVC [31,32].

In this study, SEM-EDX analysis was carried out to evaluate the surface characteristics and the elemental makeup of the particles retained on the surface of the filter papers. A total of nine filter paper samples representing the longest stagnation period, that is, 12 h were analyzed under the SEM-EDX.

3. Results and discussion

3.1. Microplastic analysis

For samples with a stagnation period of 5 h, no microplastics were detected on the filter papers. Nevertheless, the final mass of the filter papers increased. This could be due to other suspended particles in the water or due to residual moisture on the filter papers. As the stagnation time increased, the mass retained on the filter papers also increased for most of the samples. The increase in mass of particles retained on the filter papers could be attributed to MPs leaching from the pipes. Since there were no MPs detected in the filter papers with a stagnation period of 5 h, they were used as blank samples for developing correlation between number of MPs and mass of MPs. For samples with other stagnation durations, the mass of leached particles was calculated as the mass retained on the filter paper minus the mass retained on the blank sample. Fig. 4 shows the mass concentration of leached particles retained (after blank corrections) on the filter papers for varying pH level, initial chlorine dose, and stagnation period.

Further, the relationship between the concentration of leached particles and the number of MPs counted under the microscope was investigated. A plot of MPs count vs. the concentration of leached particles shows a linear relationship (Fig. 5). The high value of coefficient of correlation ($R^2 = 0.96$) indicates that the leached particles responsible for increasing the mass were mainly MPs.

3.2. Other water quality analysis

Changes in other relevant water quality parameters such as conductivity, residual chlorine and TOC during the stagnation period were measured. These variations could be either due to the chemicals added for adjusting the pH and chlorine level, or because of chemical/physical interactions between the water and the PVC pipe.

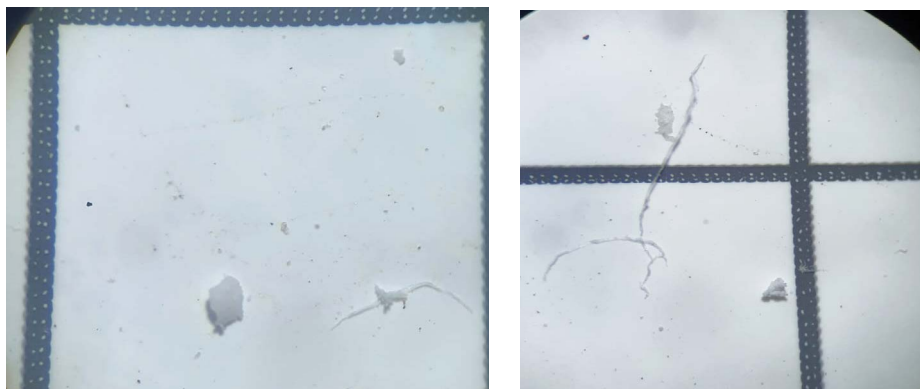


Fig. 3. Examples of microplastics observed under microscope.

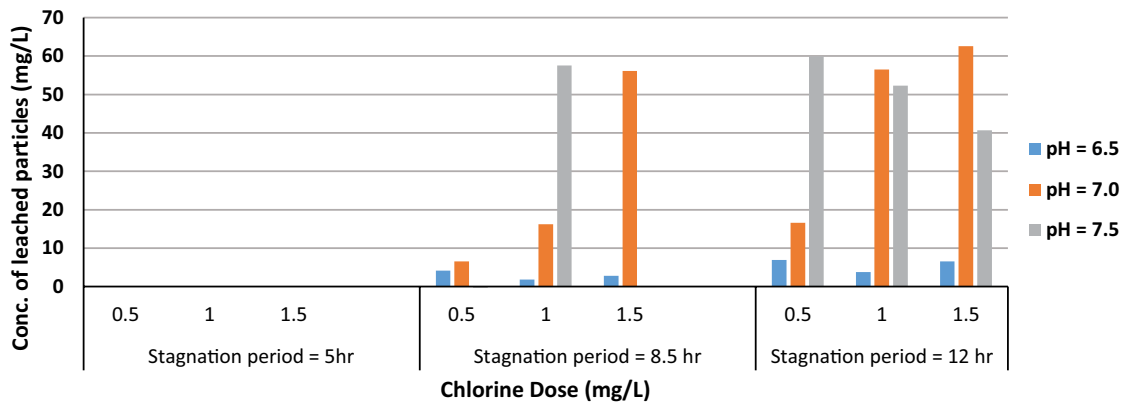


Fig. 4. Variation of concentration of leached particles retained on filter paper as a function of initial pH, chlorine dose and stagnation period.

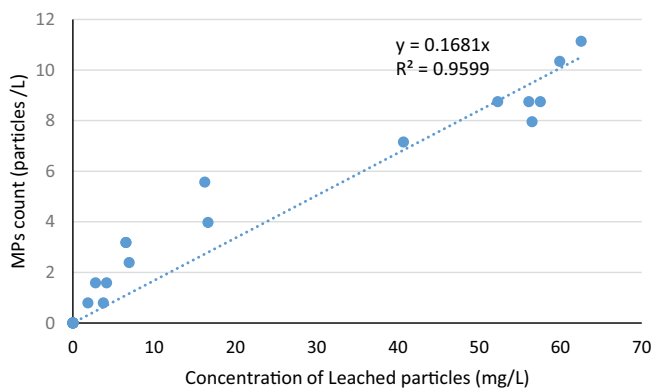


Fig. 5. Relationship between microplastics count and concentration of leached particles.

The conductivity of the water samples at the end of the stagnations did not show significant change. The lowest and highest conductivities were measured to be 1,039 and 1,083 $\mu\text{S}/\text{cm}$, respectively. The tap water conductivity before any pH adjustment and addition of chlorine was 1,067 $\mu\text{S}/\text{cm}$.

cm. It was important to measure the final conductivity to observe if there were significant changes to the water quality after the completion of the stagnation period. Fig. 6 summarizes the conductivity of the water samples at the end of the stagnation period. It can be concluded that even with the differences in the pH and the chlorine dose, there was little change in the conductivity of the water samples. Therefore, MP leaching did not have any effect on the conductivity of the water samples.

Analysis of residual chlorine in the water samples indicates that the total chlorine level dropped in all samples except for two (i.e., stagnation period of 12 h, pH 7.5, 0.5 mg/L and pH 6.5, 1 mg/L) that showed an increase in the residual chlorine as shown in Fig. 7. The fluctuation can be because the commercial grade sodium hypochlorite used in this study may not be homogenous in nature. Generally, total chlorine levels decreased after each stagnation period. A possible explanation could be the reaction between chlorine and organic compounds leaching from the pipe. However, the decrease in chlorine levels were not consistent with the leaching of MPs. It indicates that chlorine alone is not the deciding factor for the leachability of the MPs from PVC pipes.

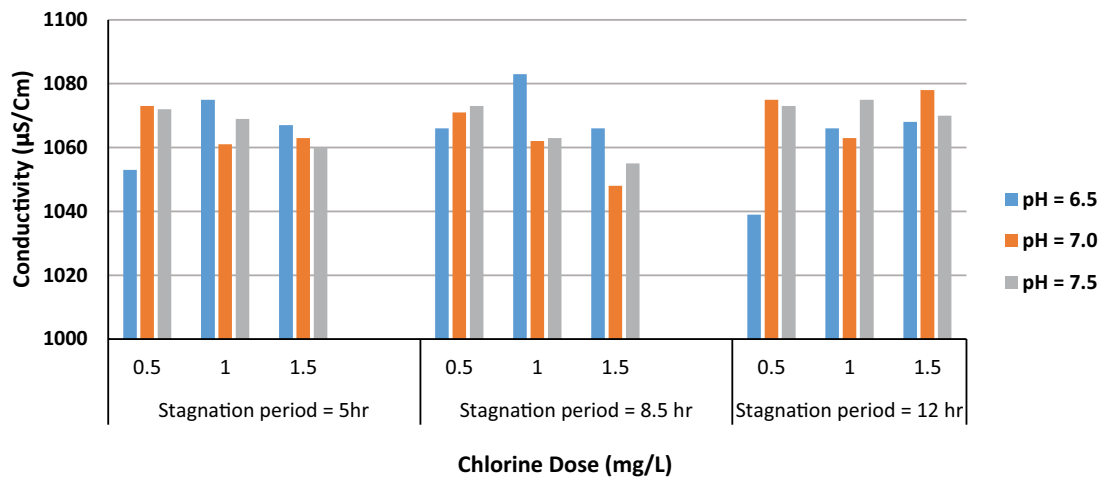


Fig. 6. Variation of conductivity as a function of initial pH, chlorine dose and stagnation period.

In this study the TOC of the water samples was measured without any filtration and treatment. TOC analysis results showed that the organic carbon content increased with increase in the stagnation duration (Fig. 8). The TOC of the blank was 3.84 mg/L. The highest TOC values (ranging between 7.5 and 9.07 mg/L) were recorded in the samples that stagnated for 12 h. These results could not be taken as a direct indication of an increase in MPs due to expected interferences from other organic compounds. However, increments in TOC as compared to the blank sample could be considered as an indication of leaching of organic substances and plastics from the pipe.

3.3. Characterization of microplastics using ATR-FTIR

The use of ATR-FTIR can be inconclusive if the diamond crystal window of the ATR is not completely covered with MPs retained on the filter paper. FTIR is generally used for homogeneous particles and mixtures. Small MPs present in the filter paper may not always provide strong spectral reflectance.

For each stagnation period, three samples with the highest chlorine dose (i.e., 1.5 mg/L) at the three different initial pH levels were chosen for the ATR-FTIR analysis. The results of the ATR-FTIR analysis are shown in Fig. 9. The spectral reflectance graphs were grouped based on the stagnation period. The graph shows the spectral reflectance for the three samples with different pH levels. Samples from stagnation period of 5 h were excluded from

the analysis because no microplastics were detected on the filter papers visually under the microscope.

Fig. 9a shows the spectral reflectance of samples representing stagnation period of 8.5 h with varying pH values. The spectral reflectance for pH 6.5 and pH 7.0 were very similar with almost overlapping peaks, whereas that for pH 7.5 was different. On the other hand, the spectral reflectance for the samples representing detention time of 12 h (Fig. 9b) showed similar patterns for pH levels 7.0 and 7.5. The results for pH level of 6.5 was like that of the other samples but the peaks were much smaller. The wavenumbers at which peaks occurred and the spectral signature patterns, especially between wavenumbers 500 and 2,000 cm^{-1} , were similar in both sets of samples.

FTIR analysis results with characteristics peaks at various wavenumbers were reported in literature. Silva et al. [33] reported peaks for C–H bond at 2,911; 1,254 and 959 cm^{-1} ; CH_2 groups at 1,333 cm^{-1} and C–Cl bond 836 cm^{-1} for pure PVC. Another study [34] showed results with peaks for CH_2 –Cl at 1,426 cm^{-1} ; CH–Cl at 1,254 cm^{-1} ; C–H at 960 cm^{-1} ; and C–Cl bond at 831, 691, and 615 cm^{-1} for pure PVC. A previous study conducted to investigate degradation of PVC [31] identified peaks at wavenumbers 620, 630 (C–Cl) and 1,250 cm^{-1} (C–H) for virgin PVC pellets. Two new peaks that increased with degradation time: one at 1,595 cm^{-1} that implies the formation of C=C bonds and one at 1,735 cm^{-1} which shows formation of ester carbonyl (–COO–) were observed. The variations that exist between reported results could be due to purity of samples, sample preparations,

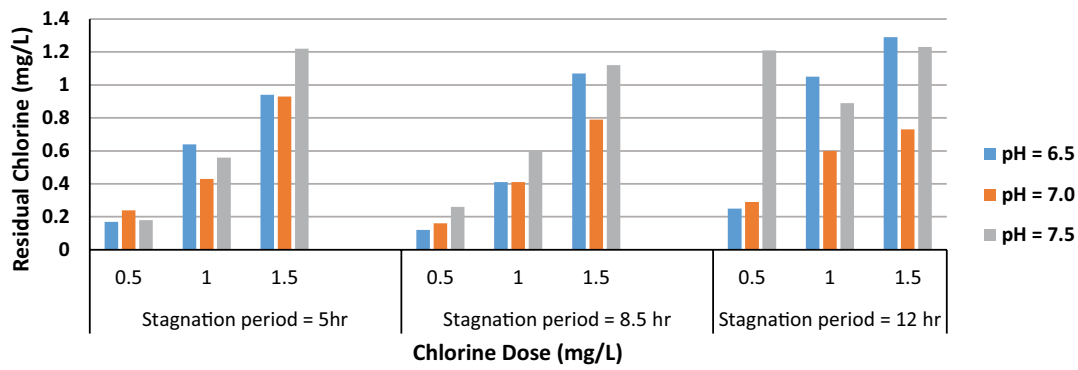


Fig. 7. Variation of residual chlorine as a function of initial pH, chlorine dose and stagnation period.

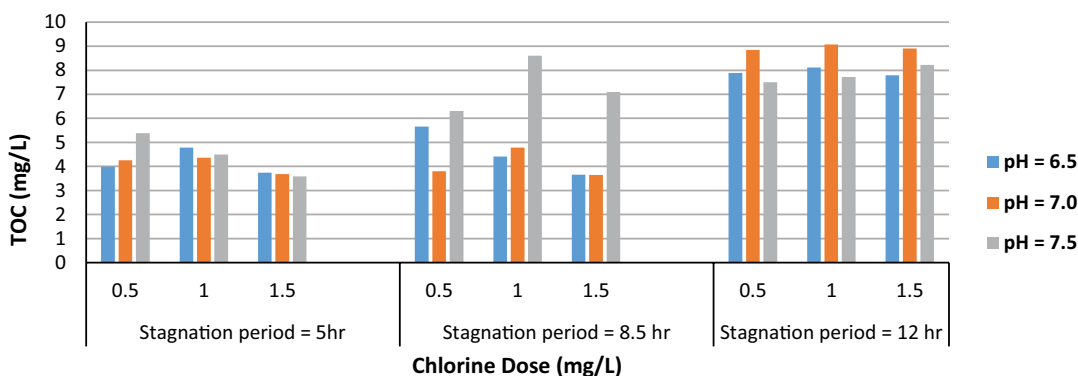


Fig. 8. Variation of total organic carbon as a function of initial pH, chlorine dose and stagnation period.

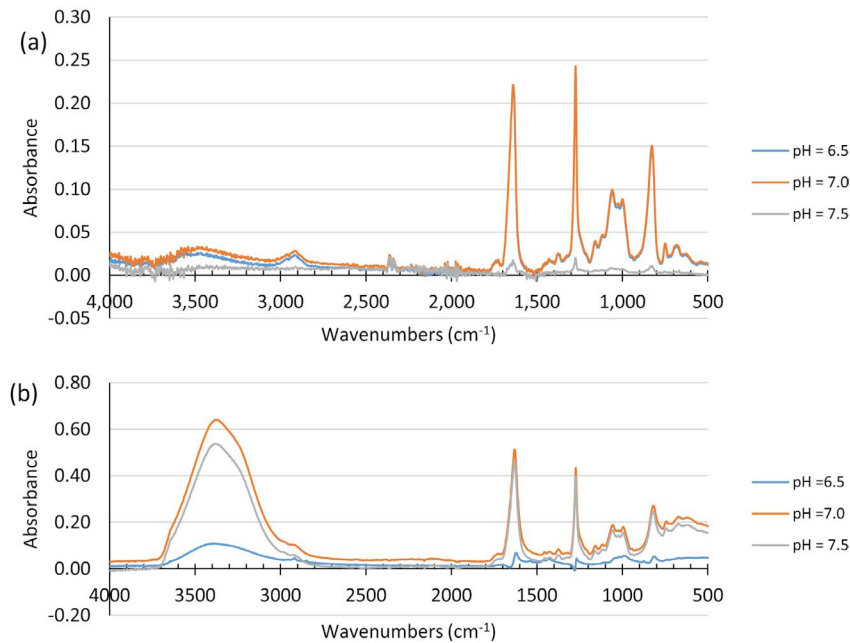


Fig. 9. ATR-FTIR spectra of filter papers from samples with varying pH and stagnation period along with spectra of polyvinyl chloride pipe: (a) stagnation period = 8.5 h and (b) stagnation period = 12 h.

Table 1
Composition of major elements in particles analyzed using SEM-EDX

SN	Sample description			Spectrum ID (Fig. No)	Composition (% weight)		
	Initial pH	Chlorine dose (mg/L)	Stagnation period (h)		Carbon	Oxygen	Chlorine
1	6.5	0.5	12	22	70.4	21.11	1.2
2	6.5	1	12	37	56.6	34.2	1.3
3	6.5	1.5	12	43	59.2	33.1	4.6
4	7	0.5	12	15 (Fig. 10a)	68.3	14.9	12.9
5	7	0.5	12	17	58.9	39.1	0.7
6	7	1	12	6	65.3	23.4	9.4
7	7	1	12	7	49.7	43.4	0.8
8	7.5	1	12	29 (Fig. 10b)	59.9	13.4	22.0
9	7.5	1	12	31	59.4	28.7	5.4
10	7.5	1.5	12	34 (Fig. 10c)	68.5	6.5	23.2

type of plasticizers used in producing the PVC, and level of degradation of the samples.

The spectra of the samples analyzed in this study show strong peaks around 830, 960–1,100 and 1,270 cm^{-1} . Even though these peaks don't exactly match the peaks reported in literature [31,33,34], they show similarity to typical peaks found in PVC corresponding to C–Cl bond, C–H bond and CH_2 groups thus suggesting the presence of PVC particles on the scanned filter papers. Other characteristic peaks at other wavenumbers were either weak or not observed. Several other peaks were also observed in the spectra of the scanned filter papers. This is to be expected because there could be other particles retained on the filter paper. Part of the filter paper may also have been scanned as the diamond crystal sample window of the ATR may not have been completely covered with MPs. Overlapping of peaks may

also have happened. Since the filter papers were air-dried, there is also a possibility of interference from the moisture on the filter papers. The non-homogeneous nature of materials collected on the filter paper surface is expected to lead to a spectral signature that is different from that of pure homogenous materials when scanned under ATR-FTIR.

3.4. SEM-EDX analysis

The surface of selected filter papers were scanned under SEM. Further, particles that were identified as potential MPs in the SEM image were analyzed using EDX to determine their elemental composition. Accounting for impurities, particles that can be identified as PVC microplastics should have a large proportion of carbon and chlorine, with a characteristic strong chlorine peak.

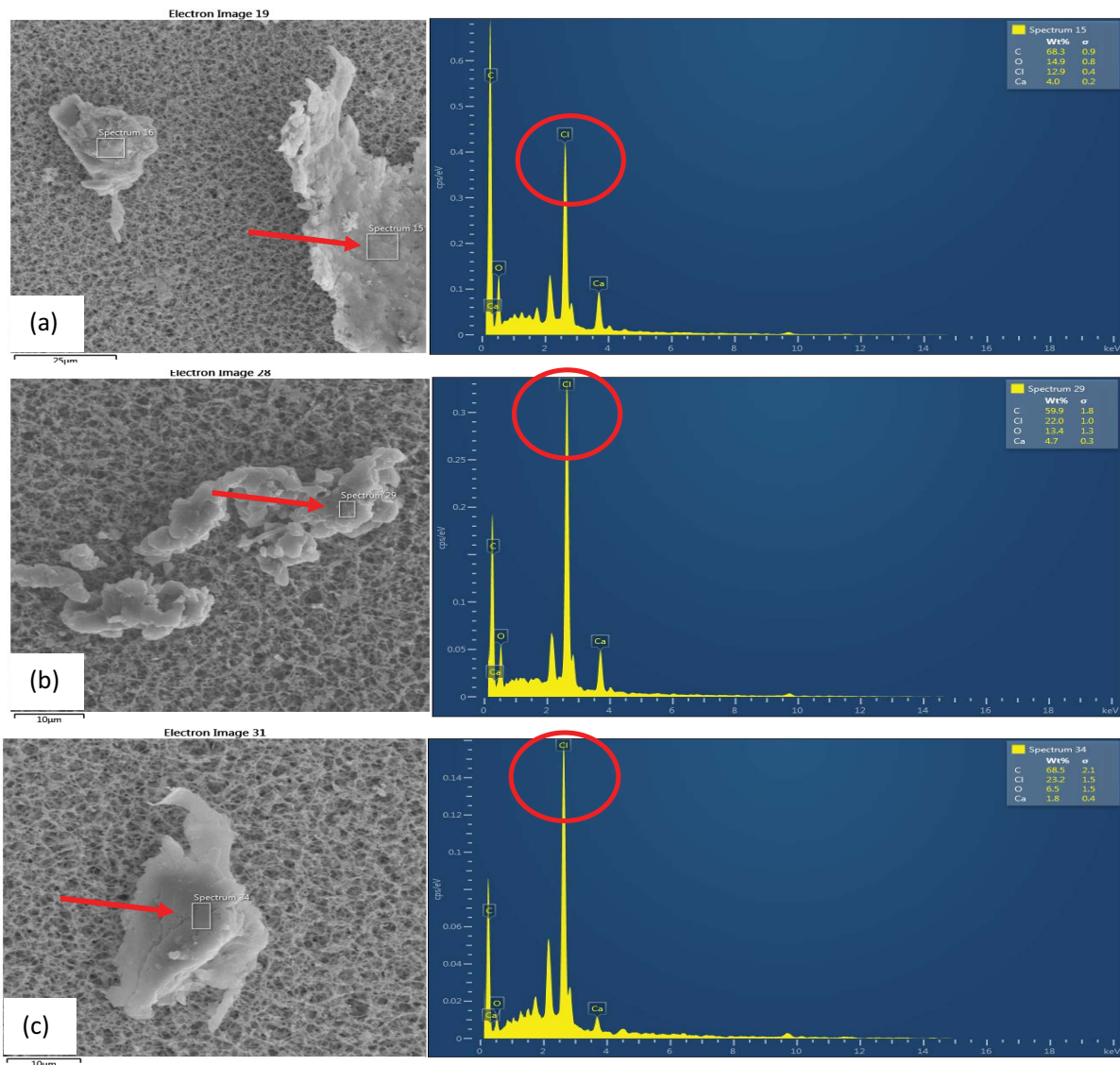


Fig. 10. Scanning electron microscopy images of particles identified as polyvinyl chloride along with their spectra. The red arrows indicate the locations on the particles surface analyzed by EDX. The red circle shows the characteristics strong chlorine peaks that indicate polyvinyl chloride particles. (a) SN 4, Spectrum ID 15, (b) SN 8, Spectrum ID 29, and (c) SN 10, Spectrum ID 34 (Table 1).

Among the particles scanned, some of them have characteristics of rust or calcium carbonate. A significant number of particles had large contents of carbon, oxygen, and chlorine. However, the composition of carbon and chlorine varies from typical PVC particles. This could be because the PVC pipes were several years old, and some segments may potentially have gone through degradation with time. Still, a few particles can be reasonably considered as PVC particles. Table 1 summarizes the composition of major elements in particles that were identified as PVC. The sizes of most of these particles ranged 5–40 μm . In addition, the elemental composition of these particles seems to be consistent with that of PVC. This can lead to the conclusion that the particles observed under the SEM-EDX were indeed microplastics of PVC. Fig. 10 shows some of the particles identified as PVC. All the three particles weren't fibrous in nature.

4. Conclusion

The study aimed to investigate the leachability of microplastics in PVC pipes under stagnant conditions. 27 PVC pipes were filled with water samples having different pH and chlorine dose and they were kept under stagnant condition for different durations. Water quality analysis results revealed that TOC increased with increase in stagnation period. The increase in TOC indicates the possibility of leaching organic substances including MPs from the pipe.

Furthermore, the water samples were filtered through cellulose acetate filter papers with 0.45- μ pore size. The filter paper was observed under the microscope to count the number of microplastics retained on the filter paper. The mass of particles retained on the filter paper was also measured after 24 h of air drying to determine the solids concentration

in the samples. When observed under the microscope, no MPs were detected on the filter papers that represent stagnation period of 5 h. Thus, these samples were taken as blank for the calculation of concentration of leached particles in the other samples. A linear relationship with strong coefficient of correlation ($R^2 = 0.96$) was found between the MPs count and the concentration of leached particles. The results indicated that the leached particles were mainly MPs.

The ATR-FTIR spectra of the samples did not exactly match the spectra of pure PVC due to interferences from other particles retained on the filter paper, moisture, and the filter paper itself. Nevertheless, the characteristic peaks for C–Cl and C–H bonds that are typical in PVC were observed. The results indicated the presence of PVC particles on the filter papers.

SEM-EDX analysis identified some of the particles on the filter paper as PVC or PVC like plastics. This leads to the conclusion that leaching happened in the pipes tested. The significance of leaching from pipes as a source of microplastics in the water distribution system as compared to other sources of microplastics should be further studied.

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