

# Impact of mixing phenomenon at cross junctions on the variation of total coliform and *E. coli* in water distribution systems: experimental study

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## ABSTRACT

This study investigates factors that influence the growth and diffusion of microorganism especially total coliform and *Escherichia coli* (*E. coli*) in water distribution networks. The experiments were carried out in a laboratory distribution network where different flow directions at junctions, varying inlet flow rates, initial chlorine doses and natural organic matter were studied. Depending on the incoming flow directions, two hydraulic behaviors were observed at cross junctions: (i) incomplete mixing and (ii) perfect mixing of the fluid stream. The study shed light in to how concentration of microorganism (total coliform and *E. coli*) can vary greatly in the same water network system due to the impact of the mixing of water with different physicochemical characteristic. The results also indicate that pipe material was the main factor that influenced bacteria growth in a water distribution system.

**Key words** | *E. coli*, mixing phenomenon, SimPlate, total coliform, water distribution diffusion

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## INTRODUCTION

The goal of a water distribution network is to provide safe drinking water to the costumers, which means it must be free of pathogenic microorganisms, which is indicated by the absence of total coliform and *Escherichia coli* (*E. coli*). The presence of coliform does not necessarily imply presence of pathogens, but its presence indicates the vulnerability of the water to be contaminated by pathogens, a loss of disinfectant, intrusion of contaminated water into the potable water supply (McFeters *et al.* 1986; Geldreich *et al.* 1992; Clark *et al.* 1996; Rompre *et al.* 2002), bacterial regrowth (Le Chevallier 1990), a failure in the disinfection process, or a strong growth of biofilm in the distribution system (Dunling & Fiessel 2008). The presence of *E. coli* in water is an indication of a fecal

contamination and may imply the possible presence of disease-causing pathogens such as viruses, parasites, protozoa and helminths from improperly treated wastewater effluents, discharges from septic tanks, leaching of animal manure and storm water runoff. Pathogens such as *E. coli* 0157:H7, for example, are associated with drinking contaminated water and cause intestinal diseases. The US Environmental Protection Agency (1990), the Canadian Drinking Water Quality Guideline 'Ministère de la santé' (1996) and the World Health Organization (1994) require that no total coliforms and *E. coli* should be detected in drinking water. Although most treatment plants are able to achieve these standards, the distribution system can be a point where issues regarding pathogens can occur.

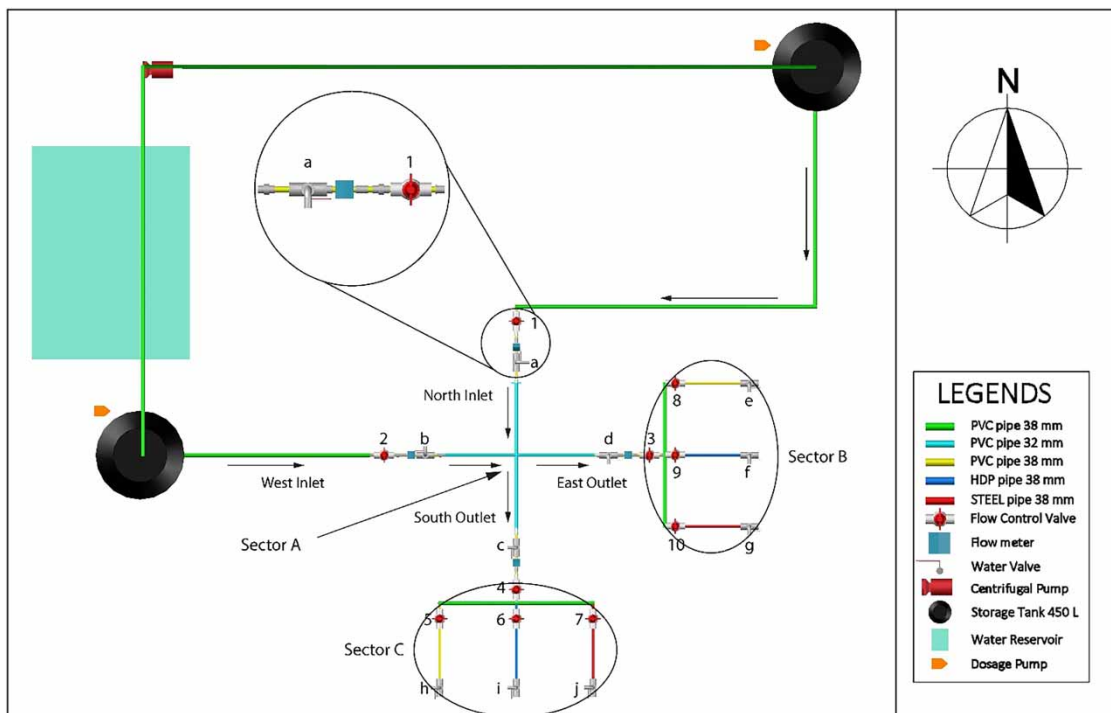
Variations in hydraulic conditions at junctions can vary the mixing conditions and hence physicochemical characteristics of water. In a previous study Mompremier *et al.* (2015) studied the impact of mixing phenomenon in the prediction of chlorine residuals in municipal water distribution systems. The results showed that free chlorine concentration could vary within the network depending on the flow direction at cross junctions and identified a larger vulnerability zone due to the impact of incomplete mixing of water with different physicochemical characteristics in some cross junctions. The impact of such hydraulic conditions on pathogens is not well understood and to the best of our knowledge there have been no previous studies that investigated the impact of flow conditions at cross junctions on the viability of total coliforms and fecal coliforms or *E. coli*. The objectives of this research are to investigate on one hand the impact of mixing phenomenon on the diffusion and growth of coliforms bacteria in the distribution network using a laboratory scale water distribution network, and on the other hand the factors that contributed to their growth in water distribution systems.

## MATERIALS AND METHODS

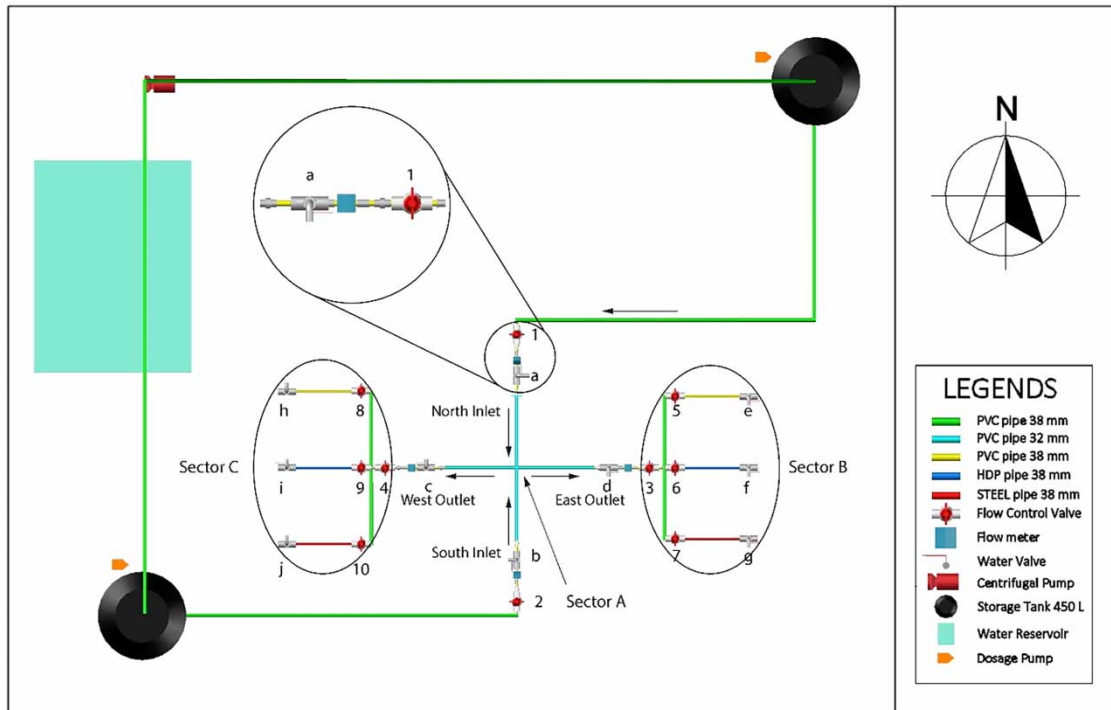
### Experimental setup and preparation

In order to study the impact of mixing phenomenon, residence time and pipe material on the growth and diffusion of total coliform and *E. coli*, a series of experiments were carried out in a laboratory network system. The experimental setup was divided into three sectors:

1. Sector A consisted of a cross junction pipe system with two inlets and two outlets:  
Scenario 1: Inlets – North and West; outlets South and East (Figure 1).  
Scenario 2: Inlets – North and South; outlets East and West (Figure 2).
2. Sector B consisted of three different pipe materials (supplied from the East outlet of sector A in scenario 1 and 2).
3. Sector C consisted of three different pipe materials (supplied from the South outlet in scenario 1, and the West outlet in scenario 2).



**Figure 1** | Schematic description of the experimental distribution network for scenario 1 (sector A inflows at 90°).



**Figure 2** | Schematic description of the experimental distribution network for scenario 2 (sector A inflows at 180°).

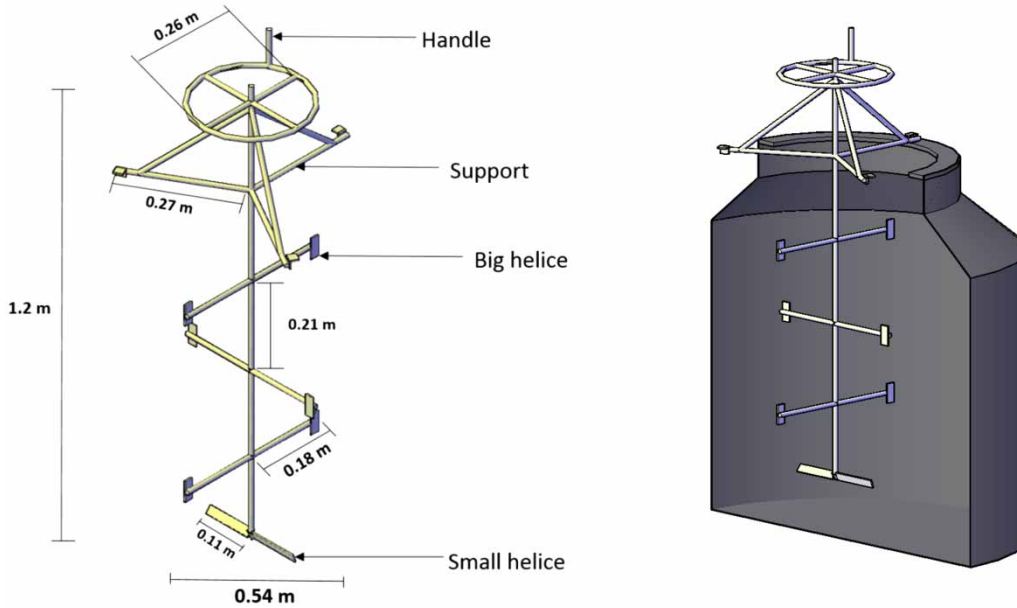
Three pipe materials were used: steel galvanized, polyvinyl chloride (PVC) and high density polyethylene (HDPE). The network used pipes of diameter 32 and 38 mm (pipe diameters of each segment are shown in the schematic diagrams).

The system also included the following:

- (a) A water reservoir (2.12 m<sup>3</sup> capacity).
- (b) Two storage tanks (450 L capacity each) at an elevated position for gravity flow.
- (c) Four flow meters (CZ300s model Contazara S.A, Spain) located at each inlet and outlet of the cross junction (sector A) to measure instantaneous flow rate in the system. To ensure the precision of the measurement, a relative error was calculated for each test, a margin of error of 5% was considered acceptable.
- (d) Ten flow control valves (labelled 1–10). One valve at each inlet and outlet of sector A and three valves at the entrance of sectors B and C were used to change the operating condition of the system.
- (e) Ten water valves (labelled a–j). One at each inlet and outlet of sector A and three at the exit of sector B and C were used to collect water samples.
- (f) Two dosing pumps (BL3-12, HANNA instrument, Mexico) were to control the chlorine concentration released from the storage tank.
- (g) An advanced system (CL763, B&C electronics, Italy) that detects chlorine concentration in the range of 0.1–20 mg/L was installed in sector A (at inlets and outlets). This equipment is designed for inflow continuous measurement of residual chlorine in solution. A different chlorine measurement method was used in sectors B and C.
- (h) A data logger (EI-USB-4, Lascar electronics, USA) connected to each controller and a PC for analysis.

Schematic diagrams of the experimental distribution network for scenario 1 and scenario 2 are shown in Figures 1 and 2, respectively.

In order to obtain a homogeneous mixture of tap water and chemicals (natural organic matter and chlorine), a manual mixer was installed at each storage tank (see Figure 3).



**Figure 3** | Schematic drawing of a manual mixer.

## Experimental procedure

This study involved two scenarios that simulate different inflow directions as water enters sector A. In scenario 1, the flow entered sector A at 90° (from North and West) whereas in scenario 2 flow entered sector A at 180° (North and South).

To carry out the experiments, tap water from the 2.13 m<sup>3</sup> reservoir was pumped to the elevated storage tanks using a 4HME200 centrifugal pump. K-Tonic solution (1.15 g/mL) which is a mixing of six compounds such as total nitrogen, urea nitrogen, K<sub>2</sub>O water-soluble potassium, extract of total humic carbon, humic acid carbon and fulvic acid carbon was used as the contaminant agent.

An amount of 2.73 mL of K-Tonic solution was added to the North storage tank, which resulted in total organic carbon (TOC) of 0.76 mg/L. Then 3.13 mL of the same solution (K-tonic solution) was added to the West storage tank to obtain a TOC concentration of 0.87 mg/L. About 4.66 and 6.13 mL of sodium hypochlorite solution (at 13%) was

added to the West and North storage tanks, respectively, which resulted in corresponding chlorine concentrations of approximately 1.35 and 1.77 mg/L. The solutions in each tank were mixed using a manual mixer as described earlier. The experiment extended for about 24 hours. Initial concentrations of chemical parameters for scenarios 1 and 2 are presented in Tables 1 and 2 respectively.

The first goal of the experiments was to study the behavior of the incoming flows (North and West in scenario 1, North and South in scenario 2) before leaving the cross junctions (sector A). Scenario 1 provides varying inflows, varying chlorine and NOM (natural organic matter) concentrations. Prior to that, flow control valves 1 and 2 (of sector A) were maintained partially opened (approximately 50 and 75% respectively) to provide flow rate of 0.50 and 1.14 L/s at North and West inlets, respectively (Table 3). Flow control valves (from 6 to 10 of sectors B and C) were totally opened.

Instantaneous flow rates were measured at each inlet and outlet of sector A using the flow meters. Free chlorine concentrations were also measured at each inlet and outlet

**Table 1** | Initial concentrations of chemical and biological parameters in storage tanks (scenario 1)

Sampling points	Chlorine mg/L	K-tonic solution (mL)	Temperature (°C)	Turbidity (NTU)	Residence time (h)	TOC (mg/L)	Total coliforms (CFU)	<i>E. coli</i> (CFU)
North storage tank	1.77	3.13	19.3	1.2	6.0	0.87	0.0	0.0
West storage tank	1.35	2.73	18.9	0.9	6.0	0.76	0.0	0.0

**Table 2** | Initial concentrations of chemical and biological parameters in storage tanks (scenario 2)

Sampling points	Chlorine (mg/L)	K-tonic solution (mL)	Temperature (°C)	Turbidity (NTU)	Residence time (h)	TOC (mg/L)	Total coliforms (CFU)	<i>E. coli</i> (CFU)
North storage tank	1.06	1.80	19.8	1.1	6.0	0.51	0.0	0.0
West storage tank	1.70	2.05	18.1	1.6	6.0	0.57	0.0	0.0

**Table 3** | Flow and water quality parameters at inlets and outlets of sector A for scenario 1

Sampling points	Flow rate (L/s)	Chlorine (mg/L)	pH	Temperature (°C)	Turbidity (NTU)	TOC (mg/L)	Total coliforms (CFU)	<i>E. coli</i> (CFU)
North inlet	0.50	0.70	7	19.3	1.2	0.87	0.0	0.0
West inlet	1.14	0.35	7	18.9	0.9	0.76	0.0	0.0
South outlet	0.72	0.37	7	18.6	1.0	0.40	0.0	0.0
East outlet	0.92	0.53	7	18.6	1.1	0.69	0.0	0.0

of sector A. Triplicate samples were collected at the each location (inlets and outlets) and analyzed for turbidity, pH, and temperature, free chlorine TOC, total coliform and *E. coli*.

Five minutes later, flow control valves 5, 6 and 7 as well as water valves e, f, and g of sector B were closed. Flow control valves (8, 9, 10) and water valves (h, i, j) of sector C were also closed at the same time. Thus, water was stagnated in sectors B and C. Once a period of time of 18 hours was completed, three samples were collected from pipe segments of each sector for analysis of water quality.

As shown in Figure 2, in scenario 2, a different configuration was investigated to assess mixing phenomenon at cross junction. The experimental setup consisted of a cross junction with two inlets (North and South) at 180 instead of 90°. This scenario also provided varying inflows, varying chlorine and TOC concentrations (see Table 8). Experiments were carried out using the same procedures as described in scenario 1. However, flow control valves 1 and 2 (sector A) were maintained partially opened (approximately 50 and 65%) to achieve a flow rate of 0.50 and 0.84 L/s at the North and South inlets, respectively.

## Analytical methods

### Temperature and pH measurement

A 350 mercury thermometer (Lauka, USA) was used to measure water temperature and a M530P (Pinnacle series, USA) unit was used for pH measurement.

### Free chlorine measurement

Determination of free chlorine of samples from sectors B and C was performed using the Iodometric titration according to standard methods for the examination of water and wastewater (Greenberg *et al.* 1991). In this case chlorine concentration was calculated using Equation (1):

$$mgCl = \frac{(A \pm B) \times N \times 35450}{mL.sample} \quad (1)$$

where A is mL titration for sample; B is mL titration for blank; N is normality of Na<sub>2</sub>S<sub>2</sub>O<sub>3</sub>·5H<sub>2</sub>O.

### Turbidity and total organic carbon determination

Turbidity was measured using a turbidimeter (2100A, HACH, Mexico). TOC analysis was carried out based on catalytic combustion at 720 °C using a TOC-L CSH (Shimadzu Corporation, Germany).

### Enumeration of bacteria

Microbial analyses for total coliform and *E. coli* were performed using the SimPlate method (IDEXX Laboratories 2015). In this method, 10 mL water samples were added to a media tube which contained multiple enzyme substrates. Once dissolved, the contents of the tube were poured into the center of the plate base. Then, the plate was covered and gently swirled to distribute the sample into all the

wells. Excess sample was drained in the absorbent pad. Plates were incubated for 24 hours at 35 °C. Once the incubation time was completed, total coliform and *E. coli* counts were determined by counting the wells with changed color. Colored wells indicated the presence of total coliforms, and colored wells with fluorescence exposed to a UV (ultra-violet) light (6-watt, 365-nm) indicated the presence of *E. coli*. Finally, the number of positive wells were referred to the SimPlate conversation table and the number of coliform bacteria in the sample were determined. Microbial analyses were performed in triplicates.

## RESULTS AND DISCUSSION

### Scenario 1

#### Sector A

Several studies showed that flows entering a cross junctions could show different behaviors (Chávez et al. 2005; Ho et al. 2007; Austin et al. 2008; Ho & O'Rear 2009; Mompremier et al. 2015). While in some cases complete mixing may be observed, in other cases mixing is incomplete. In scenario 1 (Inflows from North and West), flow at the North inlet was blocked by the incoming water from the West, which had greater flow (Table 3). This forced some of the flow (from the North inlet) to get pushed across the junction and exit through the East outlet. This resulted in only slight mixing and had an impact on water quality characteristics at outlets as summarized below.

*Effects of incomplete mixing.* Because of the incomplete mixing, physicochemical characteristics of the water varied from one section to another in the same experimental setup. In the case of sector A, levels of disinfectant at the East and South outlets were different. In general, water in the East outlet had higher values of free chlorine, TOC levels and turbidity that corresponded to the higher level of these parameters in the North reservoir. This is due to the fact that water in the East outlet contained mostly water from the North inlet and only a slight mix from the West inlet. In the case of free chlorine concentration the East outlet (0.53 mg/L) had a higher concentration than the South outlet (0.37 mg/L). This

was even higher than the West inlet (0.35 mg/L), but lower than the North inlet (0.7 mg/L). Similarly TOC and turbidity levels at the East outlet were higher (0.69 mg/L, 1.1 NTU (nephelometric turbidity unit)) compared to the South outlet (0.4 mg/L, 1.0 NTU). Water temperature and pH values were, however, similar at both outlets.

In this scenario microbial analysis resulted in the absence of total coliform and *E. coli*. This may be attributed to the high concentration of free chlorine in section A, which ranged from 0.35 to 0.67 mg/L, could have resulted in complete disinfection.

#### Sector B

Studies in section B were aimed at understanding the effect of pipe materials on microbial and chemical characteristics. Samples from sector B (which comes from the East outlet of sector A) were collected after an incubation period of 18 hours and analyzed for chemical and biological parameters. The results indicate that the organic content (TOC) and total coliform counts in the HDPE and steel pipes increased over the 18 h period due to the reaction with the pipe material and NOM in the water. Results for scenario 1 (sector B) are presented in Tables 4 and 5 respectively.

The growth of total coliforms in these pipes (especially in steel pipe) could be attributed to the decay of chlorine over time as indicated by the significantly reduced residual chlorine concentration. Characklis & Marshall (1990) showed that biofilms can contribute to the loss of disinfectant residuals and increase bacterial levels in a distribution

**Table 4** | Water quality parameters for samples from different pipe materials in sector B for scenario 1

Sampling points	Chlorine (mg/L)	pH	Temperature (°C)	Turbidity (NTU)	TOC (mg/L)
<b>Initial water quality characteristic of sector B</b>					
	0.53	7	18.6	1.1	0.69
<b>Final water quality characteristic of sector B</b>					
PVC pipe	0.00	7	18.3	1.1	0.98
HDP pipe	0.27	7	19.0	1.1	3.29
Steel pipe	0.00	7	18.5	1.2	1.08

**Table 5** | Total coliforms level in sector B for scenario 1

Sampling points	Total coliform Sample 1 (CFU)	Total coliform Sample 2 (CFU)	Total coliform Sample 3 (CFU)	Mean	Standard deviation	Total coliforms (CFU)	<i>E. coli</i> (CFU)
PVC pipe	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HDP pipe	10	8	12	10	2.0	10.0	0.0
Steel pipe	40	38	42	40	2.0	40.0	0.0

system. This impact of pipe material on biofilm level has been studied by many researchers. Clark *et al.* (1994) performed experimental study using coupons consisting of various pipe materials representative of those found in distribution. Generally, the ranking of biofilm concentration was polyethylene > PVC > cement. A similar study by Holden *et al.* (1995) found that the highest level of biofilm was observed in cast iron pipes. However, in this study, new pipes were used and had not been installed in any water distribution system. Thus, the increase of total coliforms might be due to the reaction of chlorine with the pipe material itself. As can be seen, the results from our study indicate that chlorine interacted differently with different pipe material. For example in PVC and steel pipes there was no chlorine residual at all while in the polyethylene pipe residual chlorine was reduced by 50%. Some researchers (Powell *et al.* 2000) studied chlorine decay in water distribution systems. They reported that pipe material, diameter, initial chlorine concentration, and corrosion are the main factors which control wall chlorine decay. However, since the level of residual chlorine decreased, bacterial regrowth in water distribution systems can occur (Lee 2013). Our results indicated that, in addition to accelerating the chlorine decay, the pipes materials may have also contributed to the growth of bacteria. The highest growth of total coliform (40 CFU/mL) was observed in the steel pipe followed by polyethylene pipe with 10 CFU/mL. In PCV pipe, however, no coliform bacteria was detected despite the absence of chlorine. This could be explained by the fact that microbial growth is related to surface properties of pipes. Norton & Le Chevallier (2000) stated that iron pipes supported more diverse microbial population than PVC pipes. The differences in water quality (growth of coliform bacteria) in different pipes may be due to the release of organic compounds by the pipes material (especially steel and HDPE pipes). Zhang & Liu (2014)

investigated organic compounds migration from polymeric pipes into drinking water under long retention times. Their experiment results showed TOC release from all pipes increased significantly over time. However, polyethylene pipes showed the highest TOC concentrations among all tested pipe materials in this study. These results corroborated with those obtained in our study. As can be seen in Tables 6 and 9, the ranking of TOC concentration was polyethylene > steel > PVC.

### Sector C

Flow to this section comes from the South outlet of section A whose water quality characteristics are shown in Table 3. Analysis results of samples from this sector are shown in Tables 6 and 7 respectively.

The results indicate that total coliform counts were detected in the HDPE and steel pipes. The total coliform counts in this sector were higher compared to that of section B (76 CFU/mL in still pipe, 62 CFU/mL in HDPE). This can be explained by the lower initial chlorine concentration coming out of the South outlet compared to the East outlet (0.37 versus 0.53 mg/L) as shown in Table 3. In all the pipe sections, however, no *E. coli*

**Table 6** | Water quality parameters for samples from different pipe materials in section C for scenario1

Sampling point	Chlorine (mg/L)	pH	Temperature (°C)	Turbidity (NTU)	TOC (mg/L)
<b>Initial water quality characteristic of sector B</b>					
Initial data	0.37	7	18.6	1.0	0.40
<b>Final water quality characteristic of sector B</b>					
PVC pipe	0.0	7	18.3	1.1	0.80
HDP pipe	0.1	7	18.3	1.0	1.75
Steel pipe	0.0	7	18.1	1.1	1.01

**Table 7** | Total coliforms level in sector C

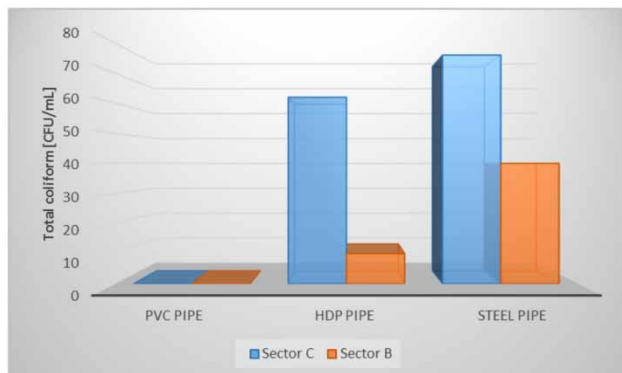
Sampling point	Total coliform Sample 1 (CFU)	Total coliform Sample 2 (CFU)	Total coliform Sample 3 (CFU)	Mean	Standard deviation	Total coliforms (CFU)	<i>E. coli</i> (CFU)
PVC pipe	0.0	0.0	0.0	0.0	0.0	0	0.0
HDP pipe	58	64	62	61.33	3.05	62.0	0.0
Steel pipe	76	76	80	77.33	2.30	76.0	0.0

were detected. Comparison of total coliform bacteria growth in sections B and C is shown in Figure 4. The results indicate that even at low residual chlorine concentration, PVC pipes did not show microbial growth. The results are important for water distribution management where the need for either boosting the chlorine residual or reducing hydraulic detention time in such sections would be necessary to ensure a microbiologically safe drinking water supply.

## Scenario 2

### Sector A

Table 2 shows water quality parameters in the storage tanks where the inflow water to sector A (cross junctions) originated. In this scenario water entered the junction from the North and South inlet pipes where the incoming flows struck against each other and exited through the West and East outlets. These flow regimes resulted in a perfect mixing condition where the resultant water quality parameters in each outlet was similar (Table 8). In a previous

**Figure 4** | Total coliform bacteria growth for scenario 1 in sectors B and C.

study, we observed that complete mixing was achieved for two varying opposing inflows due to the collision of the fluid stream (Mompremier et al. 2015). During the experiments, it is observed that the incoming flows collided in the junction; provoked turbulence along the impinging interface then exited through the outlet pipes. Free chlorine concentrations in both outlets were equal. Similar configurations have been studied by Ho & O'Rear (2009), where junctions consisting of two opposing inlets with equal and unequal pipe sizes; different combination of flow rates were investigated and yielded results equivalent to perfect mixing.

Thus, the physiochemical characteristics of the water in sectors B and C were similar. Free chlorine concentration at the East and West outlets were 0.88 mg/L each. TOC at both outlets were about 0.53 mg/L. As in the case of the first scenario, no total coliform and *E. coli* bacteria were detected in both outlets, which can be explained by the high concentration of residual chlorine present.

### Sector B

Contrary to sector A, coliform bacteria was detected in sector B after 18 hours of stagnation (Table 9). However, coliform bacteria was measured only in the steel pipe segment and the amount was 7.6 times lower to the one obtained in the same pipe material in sector C (scenario 1) and 4 times lower than the amount measured in sector B (scenario 1). The decline of bacteria levels may be attributed to the perfect mixing at cross junction. Since the initial level of disinfectant (0.88 mg/L) was higher in this sector than those measured in sectors B and C in scenario 1 (0.37 and 0.53 mg/L), the sector could maintain free chlorine concentration above 0.2 mg/L in PVC and HDPE pipe segment and had less coliform occurrence. However, since chlorine decay is faster in steel pipe, chlorine reached its minimum



**Table 8** | Flow and water quality parameters at inlets and outlets of sector A for scenario 2

Sampling points	Flow rates (L/s)	Chlorine (mg/L)	pH	Temperature (°C)	Turbidity (NTU)	TOC (mg/L)	Total coliforms (CFU)	<i>E. coli</i> (CFU)
North inlet	0.50	0.60	7	19.8	1.1	0.51	0.0	0.0
South inlet	0.84	1.05	7	18.1	1.6	0.57	0.0	0.0
West outlet	0.68	0.88	7	17.3	1.2	0.52	0.0	0.0
East outlet	0.66	0.88	7	17.5	1.2	0.53	0.0	0.0

**Table 9** | Total coliforms level in sector B

Sampling point	Total coliform Sample 1 (CFU)	Total coliform Sample 2 (CFU)	Total coliform Sample 3 (CFU)	Mean	Standard deviation	Total coliforms (CFU)	<i>E. coli</i> (CFU)
PVC pipe	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HDP pipe	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Steel pipe	12	8	10	10	2.0	10	0.0

value (0 mg/L) only in this segment. However, only 10 CFU/mL was recorded. *E. coli* bacteria analysis was negative in samples collected in all the system. Water quality parameters are presented in Table 10.

### Sector C

Experimental results in sector C are presented in Tables 11 and 12. Just as sector B, total coliform were enumerated by the technique earlier described (SimPlate). Positive total coliform sample was recorded only in the steel pipe segment. As seen earlier, the same level of total coliform (10 CFU/mL) was recorded in sector B due to perfect mixing in sector A earlier explained.

As can be seen, water quality characteristics measured in both sectors in different pipe material were almost

similar. A slight difference was observed in some parameters such as chlorine concentration in PVC pipe (0.01 mg/L), TOC concentration in HDP pipe (0.02 mg/L). Mixing phenomenon is perhaps the most important controlling factor influencing microbial diffusion in water distribution systems.

### CONCLUSIONS

This study investigated chemical and microbial water quality at junctions that had incoming flows from different directions (90 and 180°). It also studies the effect of pipe material on water quality over time. The study showed that incomplete mixing at cross junction (for inflows at 90°) could lead to a heterogeneous diffusion of chlorine and

**Table 10** | Water quality parameters for samples from different pipe material in sector B for scenario 2

Sampling point	Chlorine (mg/L)	pH	Temperature (°C)	Turbidity (NTU)	TOC (mg/L)
<b>Initial water quality characteristics</b>					
	0.88	7	17.5	1.2	0.52
<b>Final water quality characteristics</b>					
PVC pipe	0.25	7	18.8	1.2	1.04
HDP pipe	0.35	7	19.0	1.3	2.40
Steel pipe	0.00	7	18.9	1.5	1.35

**Table 11** | Water quality parameters for samples from different pipe materials in section C for scenario 2

Sampling point	Chlorine (mg/L)	pH	Temperature (°C)	Turbidity (NTU)	TOC (mg/L)
<b>Initial water quality parameters of sector C</b>					
	0.88	7	17.5	1.2	0.52
<b>Final water quality parameter of sector C</b>					
PVC pipe	0.24	7	18.8	1.2	1.04
HDP pipe	0.36	7	19.0	1.5	2.42
Steel pipe	0.00	7	18.9	1.3	1.35

**Table 12** | Total coliforms level in sector B

Sampling point	Total coliform Sample 1 (CFU)	Total coliform Sample 2 (CFU)	Total coliform Sample 3 (CFU)	Mean	Standard deviation	Total coliforms (CFU)	<i>E. coli</i> (CFU)
PVC pipe	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HDP pipe	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Steel pipe	8	12	10	10	2.0	10.0	0.0

organic carbon concentration which resulted in different microbiological water quality as measured in terms of total coliform. The highest level of total coliform was recorded in steel pipe, followed by HDP pipe after 18 hours of stagnation. PVC pipes did not have total coliform counts. The study showed that HDPE and steel pipes had higher total coliform counts that may be explained by the lowering of residual chlorine. In the PVC pipes no total coliforms were detected, which may be explained by the surface characteristics of the pipes. Results from this study are useful in understanding the effect of pipe configuration in distribution systems and help develop better management systems to address issues related to lower chlorine residual and increasing bacteria presence in the distribution system.

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