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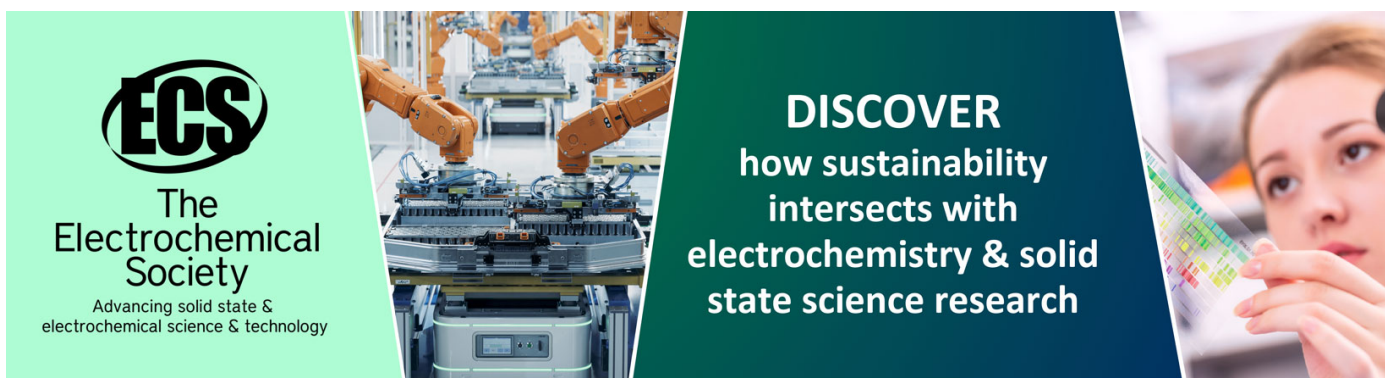
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Effects of Water-supply Pipe Materials on the Quality of Drinking Water

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Abstract: With three types of plastic water-supply pipes (PVC-U pipe, PP-R pipe and PE pipe) commonly used in the project as the object, this study designed a static soaking experiment to simulate the process of water delivery and distribution in drinking water pipe network, and selected the total organic carbon (TOC) as the comprehensive performance evaluation indicator to investigate the change in the amount and rate of release of organics in different plastic pipes over time.

1. Introduction

Inside many present buildings, PP-R hot-melt pipes are used to make the drinking water pipe network from outdoor to indoor. However, this material will slowly release organics into the water, which will directly affect the quality of drinking water^[1]. Gou Xiuli, et.al studied the effects of copper pipe, stainless steel pipe, and PP-R hot melt pipe on the quality of drinking water. The experimental results show that the overall stability of PP-R hot-melt pipes is good, but there will be a trace of phenolic organics dissolved out^[2] in the process of soaking.

However, with the improvement of sanitary standards, the effects of pipe materials on water quality will inevitably draw attention^[3-4] as various modifiers, additives and auxiliaries of plastic pipes will affect the internal organs of the human body. PVC-U pipe and PP-R pipe^[5] as well as PE pipe among common plastic pipes are most widely used in the water-supply pipe network. This paper selected these three types of pipes for comparison and analysis to study the effects of their materials on the water quality.

2. Experiment Contents

2.1. Experimental Evaluation Index

Developed countries have advanced technology and complete testing equipment, so they can detect the amounts of various toxic substances in water. Generally, therefore, they do not use the comprehensive index of organics as an indicator for the test of water quality. The measurement accuracy of TOC can reflect the more direct nature of organics, so TOC is used as a comprehensive index for evaluating organic micro-pollutants in drinking water^[6]. By studying the correlations between TOC and COD_{Mn}, as well as between THMs carcinogenicity coefficient and Ames test

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mutagenicity activity, we know that the TOC content in the terminal tap water of the drinking water pipe network is generally 1.0 to 4.0mg/L. In the advanced treatment, when the TOC content is lower than 1.0 mg/L, the generated THMs compound had a low risk of carcinogenesis, and the Ames mutagenesis test showed a negative result.

Since the Ames test is difficult to popularize, it is advisable to use certain routine indicators to evaluate the mutagenicity of drinking water. According to the survey results given by literature^[7-9], TOC has a good correlation with MA (TA98). Therefore, this index can be used to evaluate the mutagenicity of water. The following criteria are for reference:

TOC < 1.0mg/L, MA (AT98) < 2, water is negative

TOC > 1.0 mg/L, MA (AT98) > 2, water is positive.

2.2. Experimental Materials

The three types of pipes used in this study were polyethylene (PE) pipe, unplasticized polyvinyl chloride (PVC-U) pipe and polypropylene random copolymer (PP-R) pipe respectively. All the pipes were uniformly bought from a local building materials market. PVC-U pipe is composed of amorphous thermoplastic resin made of vinyl chloride monomer which has been subject to polymerization reaction, and certain additives (such as stabilizers, lubricants, fillers, etc.). It has excellent corrosion resistance^[10-11]; PP-R is a new type of environmental protection pipe material; PE is the abbreviation of polyethylene. The three pipe numbers and specifications are shown in Table 2.1.

Table 2.1 Specification of experimental tubing samples

No.	Material	Specification
NO.1	PVC-U	DN63
NO.2	PP-R	DN63
NO.3	PE	DN63

All pipe sections used in this study were uniformly machined to the sections with the length of 30cm, as shown in Figure 1.

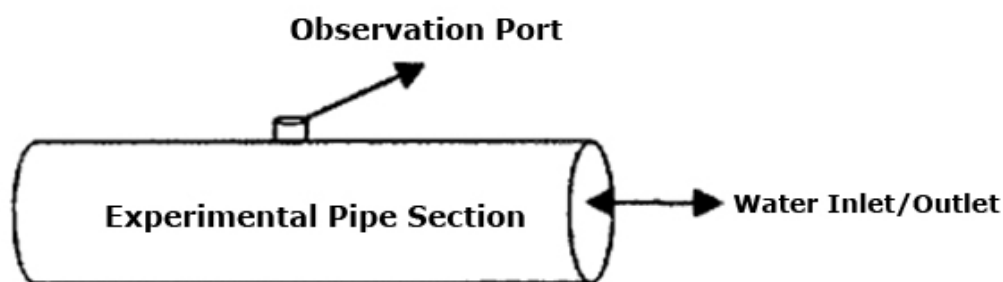


Figure 2.1 Simulation of Static Soaking Experiment

2.3. Static Soaking Experiment Method

In this study, the static immersing method was designed according to the requirements of the *Standard for Hygienic Safety Evaluation of Equipment and Protective in Drinking Water* (GB/T17219-1998)^[12].

(1) Preparation of Soaking water and Sample Pretreatment

The soaking water was prepared according to National Standard GB/T17219-1998: The 0.04mol/L anhydrous sodium bicarbonate solution, 0.025mol/L sodium hypochlorite solution, 0.04mol/L anhydrous calcium chloride solution and deionized water (resistance rate > 10MQ·cm) were prepared in

proportion to be the soaking water with a pH of 7.8 to 8.0, effective chlorine of 2mg/L and hardness of 100mg/L soaking water. The soaking water was prepared on the same day as required by the experiment. The TOC value of newly-prepared soaking water was about 0.1-0.2 mg/L.

After the experimental pipe sections were machined as shown in Figure 2.1, they were cleaned with tap water internally and externally, and rinsed continuously for 30 minutes under running direct drinking water and then rinsed three times with distilled water. Both ends of the pipe sections were plugged tightly with the clean rubber plugs covered with clean PTFE. Immediately after that, the pipe sections were filled with the newly-prepared soaking water for soaking.

(2) Soaking Process

The experimental soaking process includes two modes. In the first mode, the situation that the water flow in the water supply pipeline was continuously updated slowly was simulated: In the constant-temperature incubator set at room temperature ($25 \pm 5^\circ\text{C}$), the pipe sections filled with soaking water were put in and protected from light. 24h later, the samples were taken for testing and immediately refill the pipe sections with soaking water to continue soaking, and a total of 7 soaking cycle of testing (24h per cycle) were performed. For this mode, the 7 soaking cycles of experiment must be conducted continuously, and could not be interrupted. In the second mode, the areas such as water network terminals of water supply pipelines where the water retention time is long were simulated: In the constant temperature incubator set at room temperature ($25 \pm 5^\circ\text{C}$), the pipe sections filled with soaking water were put in and protected from light. Different soaking durations were adopted, namely 24h, 48h, 72h, 144h and 240h. In addition, each soaking experiment corresponded to a blank control experiment: Clean glass bottles of the same volume were filled with the newly-prepared soaking water, sealed and placed under the same conditions as the pipe sections filled with soaking water. Three parallel experiments were required for the soaking experiments of each type of pipe sections in this study.

2.4. Measurement Items and Analysis Methods

(1) Determination of TOC in Water Samples

The TOC content in the water sample is relatively low, so the TOC was measured using a wet oxidation (persulphate)-non-dispersive infrared detection (NDIR) method^[13].

(2) Data Processing

From the basic conditions of the experiment, the following was obtained: the ratio between the comparative area of the pipe section and the volume of the water sample; and the soaking duration. The determined TOC value of the water sample after soaking in the pipe section was subtracted from the determined TOC value of the blank water sample, thus the concentration of the comprehensive organics precipitated from the plastic pipe was obtained. The release rate of organics in the pipe section per unit time and unit surface area can be calculated according to the following formula^[14]:

$$m = Ct^{-1}(SA/V)^{-1}$$

Where, m is the TOC release rate ($\mu\text{g}/(\text{d}\cdot\text{cm}^2)$);

C denotes the TOC concentration (mg/L);

t denotes the soaking duration (d); and

SA/V denotes the ratio between the comparative area of the pipe section and the volume of the water sample (cm^{-1}).

3. Experimental Results

3.1. TOC release characteristics of PVC-U pipe

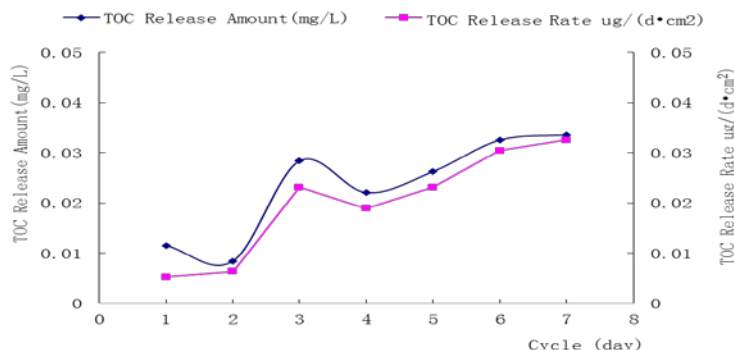


Figure 3.1 Change in TOC release amount and rate of PVC-U pipe in the first soaking mode

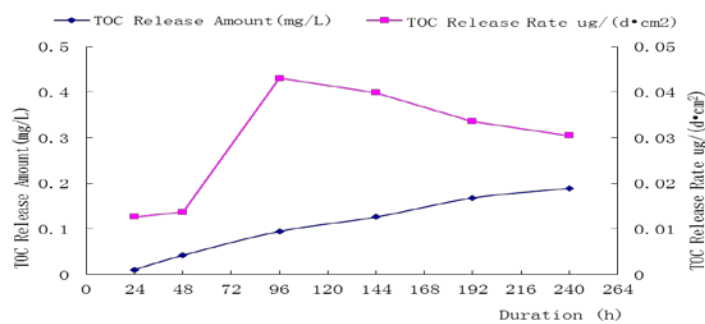


Figure 3.2 Change in TOC release amount and rate of PVC-U pipe in the second soaking mode

From Figure 3.1, the release concentration and rate of TOC from PVC-U pipe into the water were 0.034 mg/L and 0.033 $\mu\text{g}/(\text{d}\cdot\text{cm}^2)$, respectively, in the first soaking mode. The TOC concentration and release rate showed a slowly increasing trend with the increase of the soaking cycle, with slight fluctuations. From figure 3.2, in the second soaking mode, the concentration of TOC in the soaking water of the pipe section gradually increased with the soaking time, and the increase speed was slow in 48h; after 48h soaking, the TOC concentration increased rapidly; when the soaking duration was 96h, the TOC release rate reached its peak value; after 10d soaking, the concentration of TOC released from the PVC-U pipe into the water reached 0.189 mg/L. However, the TOC release rates were all at a low level (below 0.043 $\mu\text{g}/(\text{d}\cdot\text{cm}^2)$) and showed a certain fluctuation with the increase of soaking time. In the first 96h, the TOC was released rapidly and then the release rate was slightly decreased. In summary, the first soaking mode indicates that the PVC-U pipe continuously releases traces of organics into the water slowly during the water delivery. The second soaking mode indicates that the pipe section containing the dead water zone in the pipe network accumulates the organics released from the pipe, further deteriorating the water quality. In the two soaking modes, the concentrations of the released TOC varied with time, but the TOC release rates were at the same level. During the entire experiment, the concentrations and release rates of organics from PVC-U pipes were kept at a low level.

3.2. TOC release characteristics of PP-R pipe

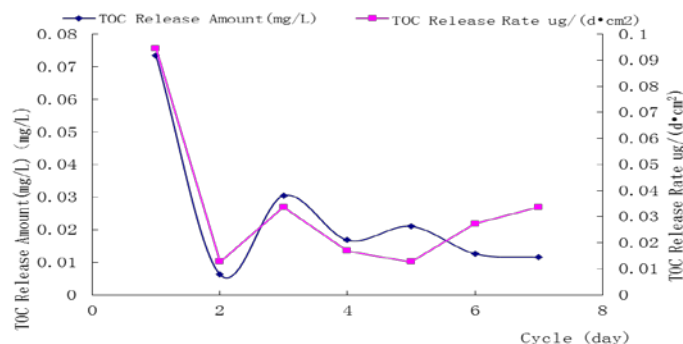


Figure 3.3 Change in TOC release amount and rate of PP-R pipe in the first soaking mode

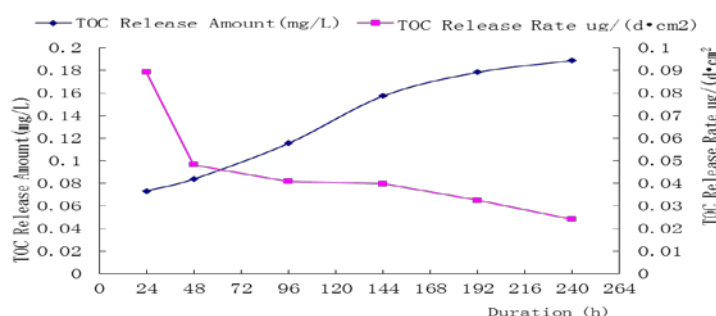


Figure 3.4 Change in TOC release amount and rate of PP-R pipe in the second soaking mode

From Figures 3.3 and 3.4, it is known that with the increase of the soaking time, the release rules of organics in the PP-R pipe were similar to that of the PE pipe. The TOC concentration and release rate both reached the maximum during the first soaking cycle, which were 0.074 mg/L and 0.095 ug/(d·cm²), respectively. From the second cycle to the seventh cycle, the ability of the PP-R pipe to release organics was weakened and stabilized, and the TOC concentration was maintained at 0.01 to 0.03 mg/L, and the TOC release rate was maintained at 0.01 to 0.04 ug/(d·cm²). In the initial stage of soaking of PP-R pipe, the rapid organics dissolution might also be due to the presence of additives or additives on the surface of the new pipe. In the second mode with long water retention time, the organics released from PP-R pipe into the water accumulated over time. After 10d soaking, the concentration of TOC in the soaking water of the PP-R pipe reached 0.19 mg/L. The release rate of TOC showed a significant decrease with time, indicating that the PP-R pipe's ability to release organics into water decreased with the increase of the service time. The above results indicate that the new PP-R pipe will release organics rapidly in the initial stage of service, causing water quality problems; in the dead water zone of the pipe network, the organics have a cumulative increase, which will accelerate the deterioration of water quality.

3.3. TOC release characteristics of PE pipe

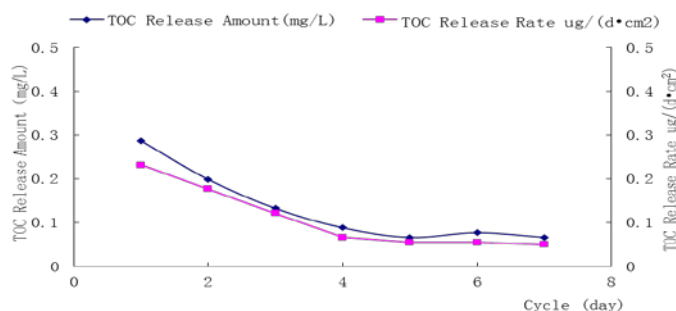


Figure 3.5 Change in TOC release amount and rate of PE pipe in the first soaking mode

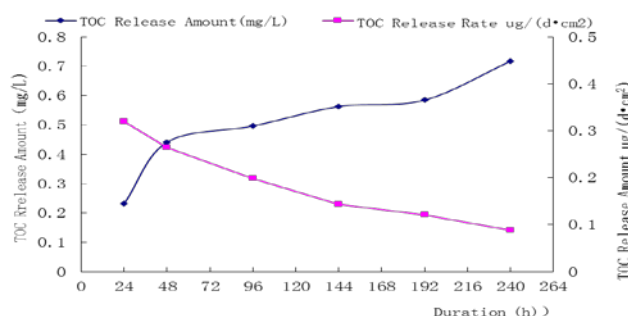


Figure 3.6 Change in TOC release amount and rate of PE pipe in the second soaking mode

From Figures 3.5 and 3.6, the release rules of TOC in PE pipe are different from that of PVC-U pipe. As shown in Figure 3.5, the TOC concentration and release rate were the highest during the first soak cycle, which were 0.27 mg/L and 0.22 $\mu\text{g}/(\text{d}\cdot\text{cm}^2)$, respectively. After the second soaking cycle, the concentration and rate of TOC released from the PE pipe were rapidly decreased and stabilized over time, with a TOC concentration of 0.03-0.05 mg/L and a TOC release rate of 0.05-0.11 $\mu\text{g}/(\text{d}\cdot\text{cm}^2)$. The TOC concentration and release rate showed a slowly decreasing and stabilizing trend with the increase of the soaking cycle. The above results indicate that new PE pipes will quickly release organics into the water during the initial stage of service, and with the pipe age increasing, their ability to release organics will decline. In Figure 3.6, with the increase of the water retention time of the pipe network, the concentration of organics in the water will continue to increase. After soaking from 24h to 48h, the TOC concentration increased rapidly from 0.22mg/L to 0.42mg/L. After soaking for 10 days, the TOC concentration increased to 0.71 mg/L, which was more than three times of the TOC concentration corresponding to 24h soaking. In addition, the release rate of TOC decreases exponentially with the increase of retention time, which indicates that the ability of PE pipe to release organics into water gradually decreases with time. The results of the two soaking modes show that the concentration and release rate of the organics from the PE pipe will decrease with the increase of the pipe service time; and the new pipe will quickly release organics at the initial stage of service, probably due to the existence of the organic additives and the like (residual in the production process) on the surface of the pipe [15]. In addition, the dead water zones in the pipe network are prone to deterioration of the water quality due to the long-term contact and reaction between the water and the pipe, and accumulation of organics.

4. Conclusion

In this study, PVC-U pipe had a low-level concentrations and release rates of the organics in both soaking experiments and released traces of organics continuously and slowly into the water, and the total amount of such organics was very low. The PP-R and PE soaking experiments show that the release rate of organics was fast at the initial stage of service. The sustained release rate decreased and tended to stabilize over time, but the total release exceeded that of the PVC-U pipe and PE pipe accumulated the most organics and the accumulation rate was the fastest of the three.

The experiments have shown that the release of organics from pipes is a slow and continuous process. Even if the pipe age increases, the release of organics from pipes will not stop. In addition, the concentrations of organics in the soaking water of the three types of pipes rose with the increase of the water retention time, indicating that the dead water zones in the pipe network will accumulate the organics released by the pipes, which is more likely to cause water quality problems.

Acknowledgments

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