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Influence of permeate from domestic reverse osmosis filters on lead pipes corrosion and plastic pipes leaching

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ABSTRACT

Reverse Osmosis (RO) filters are gaining popularity in domestic water supply system to meet the increasing demand for pure and improved drinking water. The focus of this research was on the corrosive effect of the permeate water on the leaching of lead metal pipes and the leaching of organic carbon from common plastic plumbing materials. Three commercially available RO filters with varying treatment stages—two, five and seven, were chosen for the tests. As the number of treatment stages increased, the pH, conductivity, hardness and alkalinity of the finished water were better balanced. The results show that the two-stage filter had the highest corrosion effect among the three filters with a lead corrosion rate of 0.382 mpy, followed by the five-stage filter with a corrosion rate of 0.064 mpy, and the seven-stage filter had the least corrosion rate of 0.007 mpy. From the migration test, it was found that the PEX and PVC pipes were more prone to organic carbon leaching as compared with the CPVC pipes. The two-stage filter showed the highest extraction of organic compounds, and the seven-stage filter showed the least. In all the samples, including the control, the initial TOC leaching during the first three-day period was higher than the subsequent leaching periods of three days.

1. Introduction

Reverse Osmosis (RO) technology is a pressure-driven process in which a semi-permeable membrane is used to pass water, filtering out dissolved constituents. RO is considered one of the best techniques for water purification and is extensively used in the water industry for desalination and water reuse [15]. RO is the fastest growing form of in-home water treatment in the U.S. [23]. When a moderately small volume of water (0–10 GPD) needs to be treated, RO is usually the most flexible and cost efficient treatment process available for residential use [13].

A RO system removes almost all minerals from the feed water and produces corrosive water with little buffering capacity [19,5]. Research has been done analyzing the product water of large-scale RO desalination plants and treatment systems and their corrosion and leaching effect on various metals and plastic pipes [7,11,29,8,31]. Liang et al. [19] reported that remineralization of seawater RO water with Ca^{2+} and alkalinity resulted in less corrosion of metal pipes, including ductile iron, cast iron and cement lined ductile iron. Very limited studies focused on the effect of product water from point-of-use (POU) household or under the sink RO filters on domestic pipe materials.

Although lead pipes are no longer used in drinking water distribution systems, some lead pipes can be found in old houses and even in some new metal alloy pipes and are highly prone to corrosion. A 2016 survey conducted by the American Water Works Association (AWWA) indicated a national estimate of 6.1 million lead containing service lines (either full or partial) currently present in Community Water Systems of the United States [10]. The most recent water crisis happened when the city of Flint, Michigan switched its water source in April 2014 and corrosion of the old lead pipe caused the people of the city to suffer from serious high levels of lead contamination (over 100 ppb) in their tap water [12].

With the increasing use of plastic pipes over traditional metal plumbing pipes, there is a need to test for leaching of organic components from these plastic pipes to ensure that the water quality is not compromised by recontamination or microbial regrowth. The plastic pipes are generally stable in water. However, the leaching of organic contaminants in the plastic matrix or in plastic surface binding solvents and the penetration of the pipe by organic solvents from the exterior environment has been reported [11]. It has also been reported that the organic content leached from plastic material led to higher bacterial growth in 100% RO permeate than tap water or blended water with higher initial TOC [31]. Although there is not much research conducted on the leaching effects of water from domestic RO filter on plastic pipes, leaching has been a concern among bottled drinking waters [29], and manufacturing by-products and chemicals migrating from plastic pipes

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to drinking water [8,31,18].

In this research, the corrosion effect of RO permeates on lead coupons was studied since lead has always been a grave concern in the safety of drinking water in the distribution system. In addition to metals, the leaching of various chemicals and organic matter into drinking water is a rising concern due to the increasing use of plastic plumbing pipes in the water distribution system. Thus, this research also intended to find the effect of product water from domestic RO filters on organic carbon leaching from plastic pipes.

2. Materials and methods

2.1. RO filtration systems

Three types of domestic RO systems were selected based on the number of treatment stages and market popularity, for the experiment. Their setups are briefly explained below.

The seven-stage filtration system consists of five components, i.e., a sediment filter, a carbon filter, a RO membrane, a carbon/remineralization filter and a storage tank. In a seven-staged process, water from a potable municipal or well water supply first passes through the sediment filter. Water then flows through the coconut shell carbon filter, and next through the RO membrane that removes about of 98% of sediment, chlorine, and other common chemicals and dissolved solids. Water from the RO system with dropped pH of about 6.2–6.8 then flows through the Carbon/Remineralization filter, which raises the water pH to around 7.0. Next the water flows through a check valve into the storage tank. When required, water flows from the storage tank through another check valve and enters Carbon/Remineralization filter and exits with apH around 8.0. [25]

The five-stage water purification process has a similar process, where the tap water first goes to the sediment removal filter, which removes dust and other particulate matter, to protect and extend the life of the RO membrane and system. Then water flows through the two carbon block filters, which remove excess chlorine, VOCs, unpleasant tastes, odors, and cloudiness. In the fourth stage, water flows through the high rejection TFC RO membrane where a wide variety of contaminants including arsenic, bacteria, lead, fluoride, chromium, radium, etc. are removed. The final stage is the coconut shell refining carbon filter that removes any possible residual taste from the storage tank.

The two-stage system consists of a RO membrane and a carbon and sediment combination filter to reduce chlorine and other unwanted contaminants, to assure good membrane life. The combo filter is the first stage in the RO process, in which the sediment portion effectively removes particles and sediments like sand. The carbon portion of the filter effectively reduces VOCs from the feed water supply. The RO membrane component in the system reduces TDS like salts or calcium. A properly operating membrane usually provides a TDS reduction of at least 90%.

All filters were fed with tap water from the City of Milwaukee and the flow rate was set at 0.08 L/min with “Masterflex® Easy Load II” pumps (Model 77201-60). The pH and conductivity of the samples were measured using VWR Symphony® B30PCI benchtop meter. The total hardness was measured using SM 2340C. hardness EDTA titrimetric method. The total alkalinity was analyzed using SM 2320 B. titration method [2].

2.2. Lead corrosion test and sampling protocols

Immersion corrosion experiments were performed to evaluate the effect of filter permeates on lead metal corrosion. A set of six permeate samples was collected from each filtration system. The corrosion effects were estimated through the coupon weight loss method based on ASTM standards [3,4].

Lead coupons were prepared from lead metal sheets with a density of 11.3 g/mL (Fisher Scientific). The metal sheets were cut into 2 in $\times$1 in $\times$0.03 in coupons, with a small hole of about $\frac{3}{16}$ in diameter punctured at one end. The coupons were vigorously wiped and then polished with paper towel as a more uniform result is expected when a considerable layer of metal is removed from the specimens to eliminate variations in condition of the original metallic surface. All coupons were then stored in a desiccator until they were ready to be immersed in the water samples. The dried lead coupons were then weighed on an analytical balance. Each lead coupon was then placed in 500 mL plastic bottle reactors filled with permeate samples. A nylon string, sanitized using acid bath, was placed through the hole on each coupon. The string was then attached to the cap of the reactor bottle and immersed in the water sample so that the metal coupon was suspended freely inside the bottle. Based on ASTM G1 standard ASTM [3], the nylon string was chosen so that it does not interfere with the metal and water sample, and no galvanic interactions would occur. Then the reactor bottles were properly sealed and covered with aluminum foil, to protect the samples from any foreign contaminants or evaporation. Nine of the sample reactors were gently stirred continuously and the remaining nine samples were left stagnant, to simulate both the flow through and stagnant conditions. The experiment was conducted at room temperature of about 21.4 °C, and was carried out for 40 days to achieve sufficient weight loss according to ASTM G31 standard [4].

After 40 days, the coupons were carefully taken out of the reactors and dried by hanging the coupons in empty bottles. Then they were stored in vacuum desiccators. The physical appearance of the coupons were observed and recorded. They were then carefully cleaned using mechanical cleaning method to remove the corrosion products. Abrasive paper towel was used to gently scrub off the corrosion products from the surface of the coupons without removing the sound metal. After the cleaning process, the weight of the coupons was recorded.

Aliquot from each of the samples was filtered through a 0.45 μm filter to determine soluble lead concentrations by Inductively Coupled Plasma-Mass Spectroscopy (ICP-MS) according to EPA method 200.8. The average corrosion rate was then calculated by the following equation [4]:

Corrosion rate = $(K \times W)/(A \times T \times D)$where,

K = a constant (3.45×10^6, for corrosion rate in mpy)

T = time of exposure in hours to the nearest 0.01 h,

A = area in cm^2 to the nearest 0.01 cm^2,

W = mass loss in g, to nearest 1 mg, and

D = density of metal in g/cm^3.

For this experiment, time ‘T’ of exposure was 960 h, surface area of coupon ‘A’ was 12.90 cm^2, and density of the lead metal used was 11.3 g/cm^3.

2.3. Plastic leaching and TOC test protocol

Three types of plastic pipes, 1/2” PVC (JM Eagle Sch. 40), 1/2” CPVC (Charlotte FlowGuard Gold) and 1/2” PEX (SharkBite), were selected for evaluation of organic matter leaching. All pipes were certified with NSF 14 and 61 standards for use in potable water systems. Each pipe was cut into a total length of three feet. The dimensions of the pipes, surface area-to-volume (S/V) ratios and the volume of water samples used are shown in Table 1. The cut samples were then rinsed thoroughly with DI water after removing all tapes and labels. The water samples were collected from the RO filters, and stored in clean glass bottles at 4 °C.

A total of twelve pipes, including three different pipes for each filter and tap water samples, are used for the plastic leaching study. Each pipe was filled with the water sample and the open ends of the pipes were covered with sealant tapes. The leaching test was conducted for three consecutive 72-h periods, under stagnant conditions. After each leaching period, the leachate water was collected for TOC analysis. Then the pipes were refilled with fresh RO water and tap water samples.