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Effects of Temperature on Corrosion and Bacterial Growth in Water Distribution Pipes

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This study evaluated the impact of pipe materials and water temperature on bacterial water quality and corrosion rate. Four kinds of domestic manufactured pipes (carbon steel, galvanized, copper and stainless steel) were used in this experiment. This investigation was carried out at two different temperatures of 30 and 40 °C for 1 year exposure with tap water supplied to Seoul, Korea. Pipe materials and temperature conditions influenced bacterial activity for the attached and suspended microorganism. Biofilm activity was ranked in the order of stainless steel, carbon steel, galvanized and copper pipe. Stainless steel pipe was shown to have the highest bacterial population measured in Seoul tap water by evaluating the heterotrophic plate count (HPC). The corrosion rate of galvanized pipe at 40 °C was 3.3 times higher than that at 30 °C.

Key Words: Pipe materials, Biofilms, Temperature, Heterotrophic plate count, Drinking water, Distribution system.

INTRODUCTION

In Korea, the source of tap water is usually surface water and it is estimated to be corrosive, low alkalinity water and is easily exposed to microbiological pollution[1,2]. The management of water quality in the water distribution system as well as that at water treatment utilities is being emphasized more and more and it is an important challenge in the water industry.

The corrosion problem in the water distribution system provokes a number of impediments for public hygiene and maintenance water facilities for the appropriate management of the water distribution system and the social and academic concern about and interest in the management of pipe plumbing have gradually increased. Problems such as red water, turbid water and deposition and taste and odor appeared due to pipe corrosion[3,4]. In addition, there are health related problems due to heavy metals leaching from pipe materials such as copper and lead and economic loss brought by leakage by pipe material damage and facilities replacement by life reduction[5,6].

Bacterial stability is a significant criterion of drinking water quality. Regrowth of microorganisms during water distribution, which are inactivated by disinfectants, can cause trouble for water utilities[7]. The terms of breakthrough and regrowth in the water supply system were defined by Characklis[8]. Breakthrough as defined bacteria goes to pass without inactivation in the disinfection process and regrowth is made up of the multiplication of bacteria as an attached and suspended type in the water distribution system.

Bacterial growth may lead to negative effects of bacterial water quality, amplification of pipe corrosion and the occurrence of taste and odour in the drinking water[9-12]. Yoon and Lee[13] reported that microbial regrowth is found at the end area points in the distribution system due to the decay of chlorine residuals and a higher level of HPC was detected at longer distances from water treatment plants. Inflowing microorganisms to the water distribution system attach and grow on water distribution facilities, such as reservoir tanks and pipes and develop biofilms. LeChevallier *et al.*[14] reported that biofilms also might be related to microbially influenced corrosion (MIC). The formation of biofilm is influenced by various factors, such as nutrients for growth of microorganisms, temperature, residual chlorine, sorts of pipe materials and water flow velocity.

The influence of temperature on bacterial growth in the water distribution system has been investigated by a number of authors. Lund and Ormerod[15] showed that the formation of biofilms is directly correlated to variations in water temperature. Ollos[16] reported that there are interactions between temperature, biodegradable organic matter (BOM) and shear stress on concentrations of biofilms. Ndionge *et al.*[17] observed that temperature has a limited effect on the steady-state biofilm as the HPC level achieved before chlorine addition. The level of HPC in hot water exceeds that in cold water[18]. Water temperature affects bacterial growth and behaviour as well as chemical reactions in drinking water. Water supplied to residence for hot water is processed in water treatment plants, then heated and the tap water is preserved in water tanks, roof reservoirs and pipe lines and other water supply facilities. Chemical and microbiological variations due to changes in temperature conditions can happen.

This study was performed to evaluate how water temperature, the characteristics of bacterial colonization and growth, and pipe corrosion correlate and determine the impact of various pipe materials on microbiogical chemical water quality. This study was planned to provide useful information for selecting suitable pipe materials to minimize micro-bial and chemical pollution in drinking water.

EXPERIMENTAL

This research was performed to evaluate the variation of corrosion and microbial behaviour on different pipe materials at 30 and 40 °C. Tap water supplied to Konkuk University, Seoul, South Korea was used as the feed water to test pipe materials. The tap water was drained before applying for 2-3 min and used after the process as a sample. The samples' characteristics are presented in Table-1.

TABLE-1
CHARACTERISTICS OF FEED WATER QUALITY

Parameters	Tap water
HPC (CFU/mL)	< 100
Free chlorine (mg as Cl_2/L)	0.2-0.5
pH	6.9-7.5
Alkalinity (mg as $CaCO_3$/L)	30-40
DOC (mg/L)	1.2-1.8
Turbidity (NTU)	< 0.5

In this experiment, the types of carbon steel, galvanized, copper and stainless steel pipe selected for pipe materials are used in the plumbing system in Korea. The pipe was cut to a length of 30 cm and filled with tap water. Then, it was packed by rubber stoppers and sealed with parafilm on the outside to minimize the influence of corrosion by the atmosphere (Fig. 1). The temperature was controlled at 30 and 40 °C in equipment with constant temperature. The samples were changed every 3.5 d. After the reaction time was reached, samples were taken for analysis of the pH, alkalinity, disolved organic carbon (DOC) and free chlorine.

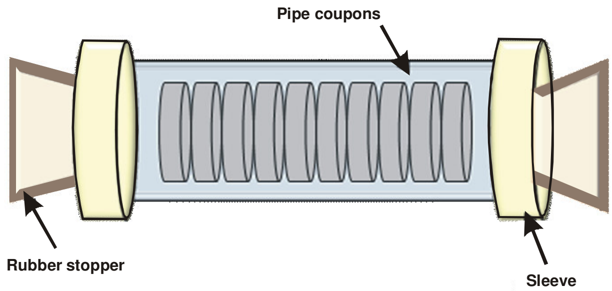


Fig. 1. Schematic diagram of experimental unit

The characteristics of pipe materials are presented in Table-2. The coupons for attached microorganisms were manufactured by the same pipe materials. The pipe was amputated to 1 cm with a stainless steel cutter and polished outside the coupon and washed with a sonificator. Coupons were located in a column.

TABLE-2
CHARACTERISTICS OF PIPE MATERIALS USED

Pipe materials	External diameter (mm)	Thickness (mm)
Copper	22.22	1.65
Carbon steel	21.70	2.65
Galvanized iron	21.70	2.80
Stainless steel	21.70	2.80

Analysis methods

Measurement of heterotrophic plate count (HPC): HPC was analyzed with R2A medium and the samples were inoculated with a micropipette on media that were autoclaved for 15 min at 121 °C and smeared on the prepared media by 3 cm glass spreader. The media were incubated at 20 °C. The colonies were enumerated after selecting the Petri-dishes that contained colonies within the scope of 30 and 300 colony forming units (CFU) after 7 d.

Attached microorganisms on pipes: Distillated water was sterilized in the autoclave and distributed to 5 mL of pre-distillated test tubes. Biofilms were removed from the surface on pipe coupons by swabs (Fisher Scientific) when the reaction time set had arrived. Biofilms smeared by swabs, were put into sterilized water in the test tubes and mingled by vortex mixer (KMC-1300). The parts of the swab hand-touched were broken and eliminated. The samples prepared by these methods were inoculated on R2A media. Another portion in the same sample was taken and analyzed for adenosine triphosphate (ATP) by AMSA lite III.

Corrosion rate: The corrosion rate was measured by the methods of weight loss between the initial weight and the weight at the reaction time with prepared coupons for individual experiment conditions. The initial coupon weight and surface area were measured and the coupons were separated at the individual reaction time from the sleeve. Corrosion product was eliminated by sterilized swab and cleaned by sonification for 0.5 h at 20 °C. They were washed three times with distillated water, then dried and the weight measured. The corrosion rate was expressed as mdd [(mg/dm^2)/d)].

Analysis of water quality: DOC was measured by TOC analyzer (TOC 5000, Shimadzu) after filtering by a 0.45 μm pore size PVDF (poly vinylidene fluoride) filter. Turbidity was analyzed by a turbidity meter (Hach 2100) and expressed as NTU. The surface of the pipes was observed by scanning electron microscope, Leika Stereo Scan 440) with 3,000 magnification. Metals such as copper, zinc and iron were measured by ICP (inductively coupled plasma spectroscopy, Labtam 8440).

RESULTS AND DISCUSSION

Corrosion rate on pipe materials: The corrosion rate on different pipe materials was evaluated in Fig. 2 for the temperature condition of 30 and 40 °C. A number of studies on pipe corrosion and biofilm formation for the supplied water distribution have been performed at the room temperature. However, the supplied temperature is known to be usually over 40 °C for warm tap water for bathing, showering and doing laundry at home.

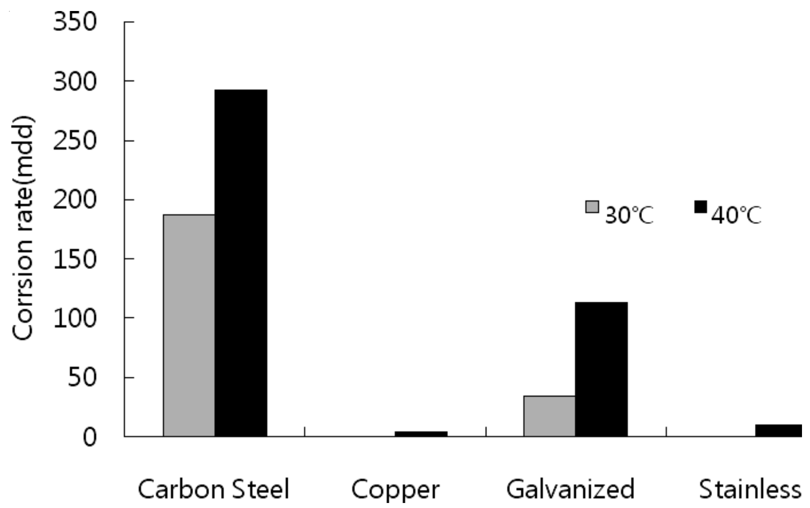


Fig. 2. Corrosion rate for different pipe materials in the temperature of 30 and 40°C

A higher order of corrosion velocity was shown for carbon steel, galvanized steel, stainless steel and copper pipe. This tendency was same as that at 20 °C by the previous report[19]. The corrosion rate for carbon steel coupon was 2.6, 68 and 29 times higher than those of galvanized, copper and stainless steel coupons at the condition of 40 °C.

The corrosion rate is higher at 40 °C than that at 30 °C. The corrosion reaction for the stainless steel and copper pipes did not evidently proceed with the temperature of 30 °C. But, it was shown to increase corrosion levels at 40 °C. The corrosion rate of copper was reported to increase with temperature, which was related to water velocity and the influence of temperature was low under the 1 m/s of water velocity[5]. The corrosion rate at 40°C was shown to be 1.6 and 3.3 times higher than that at 30°C for carbon steel pipe and galvanized pipe.

The rate of corrosion for galvanized steel was not seriously affected by the water velocity[20] while the corrosion rate of galvanized pipe was more sensitive for temperature condition in this experiment. Zinc release and occurrence of tuberculation were observed[5] to be high under pH 7. The reported corrosion velocity of the iron layer accelerated after the zinc layer was corroded in the galvanized pipe, the pipe life was expected to be 10 to 20 years.

The variation of zinc released at the water temperature 30 and 40 °C in the galvanized pipe is presented in Fig. 3. The highest level of zinc released was after the 56th days of the experiment, which was 17.8 and 8.4 mg/L for 30 and 40 °C. This high level of zinc released was reported at the initial operation time, which was shown to release zinc of 9 mg/L till 15 months of operation[5]. The level of zinc in the galvanized pipe did not seem to be related to the temperature condition in this experiment. The level of iron released in the galvanized pipe was not high (Fig. 4). The iron concentration was shown to be less than 1 mg/L in galvanized pipe during 322 d of exposure time. Turbid water was discharged initially in the galvanized pipe and turbidity after 273 d was lower than that of the initial operation time. Previous research in the condition of 20 °C showed that the problem of turbidity in galvanized pipes was resolved after 200 d. Turbidity was reported[19] to be 0.74 NTU at 322 d for the condition of 20 °C. However, turbidity was still more than 1 NTU after 322 d for the condition of 40 °C. Therefore, the use of galvanized pipe as a material for a hot water supplying system might not suitable when evaluating the maintenance issue for water quality and pipe life.

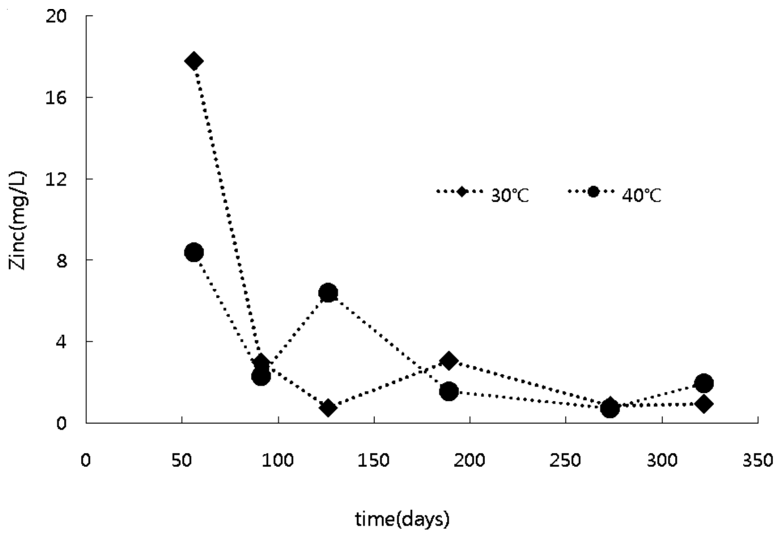


Fig. 3. Variation of zinc released in galvanized pipe

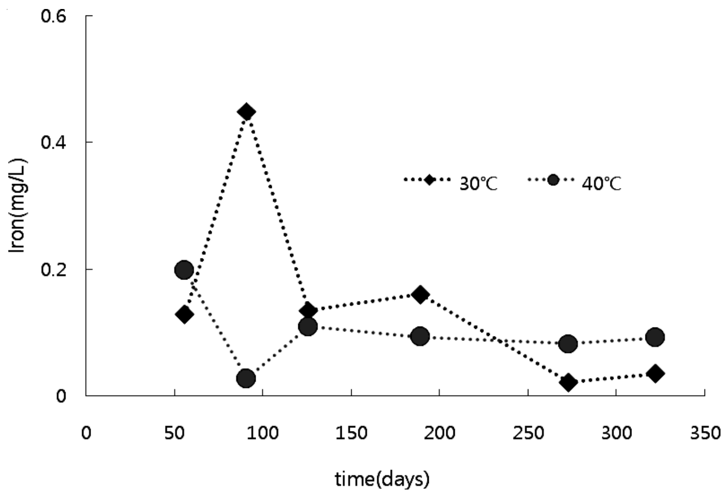


Fig. 4. Variation of iron released in galvanized pipe

The level of iron in effluents is presented in Fig. 5 at 30 and 40 °C in the carbon steel pipe. A high level of iron was released initially till 126 d and the level of iron was released under the extent of 5 mg/L after 189 d at 40 °C. The level of iron at the 30 ºC was higher than that of 40 °C. But the difference was not high between 30 and 40 °C after 189 d. Kim *et al.*[19] reported the detection of turbidity in the carbon steel pipe was related to the level of iron.

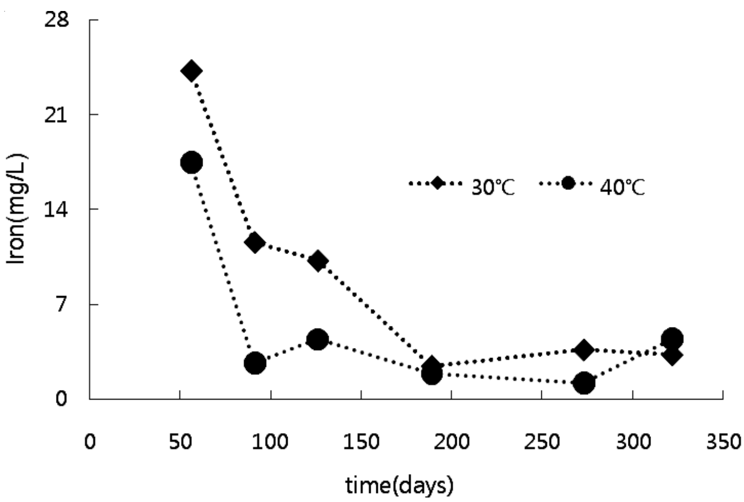


Fig. 5. Variation of iron released in carbon steel pipe

Variations in copper were compared for 30 and 40 °C in the copper pipe is shown in Fig. 6. The level of copper for 30 °C was decreased till 190 d and it increased as time passed after the minimum release value was shown at 190 d. The concentration of copper was 2.3 and 2.1 mg/L for 30 and 40 °C at 322 d. The level of copper released from the temperature condition of 30 °C was a little higher than that of 40 °C.

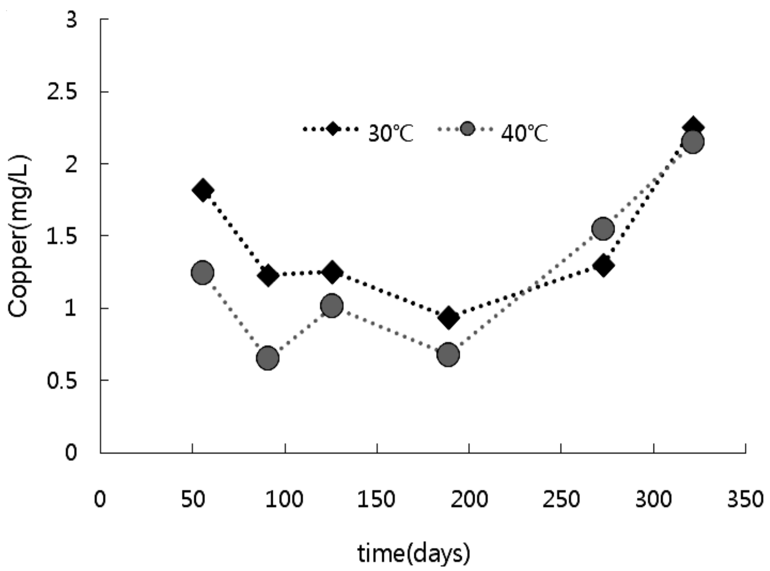


Fig. 6. Variation of copper released in copper pipe

Growth variation of microorganism: The growth variation of the HPC was monitored in effluents from carbon steel pipes with temperature of 30 and 40 °C (Fig. 7). The level of the HPC increased as time passed and reached the steady state after 190 d. The level for log growth of the HPC during 7 d of contact time was 1.0 and 2.7 for 30 and 40 °C. The ratio of the HPC level for 7 d at and 322 d was 20 and 53 % for 30 and 40 °C. The increase of the HPC was high for the condition of 40 °C during the initial 1 week contact. However, the growth difference of the HPC between 30 and 40 °C decreased as the contact time passed (Fig. 7). There is no big difference for the temperature condition between 30 and 40 °C at 322 d.

The levels of the HPC in effluents from galvanized pipe were shown to be similar values for the condition of 30 and 40 °C (Fig. 8). At 322 d, the level of the log HPC for 30 and 40 °C was 4.3 and 4.9. The value of suspended HPC in the carbon steel pipe registered a higher level than that of the galvanized pipe.

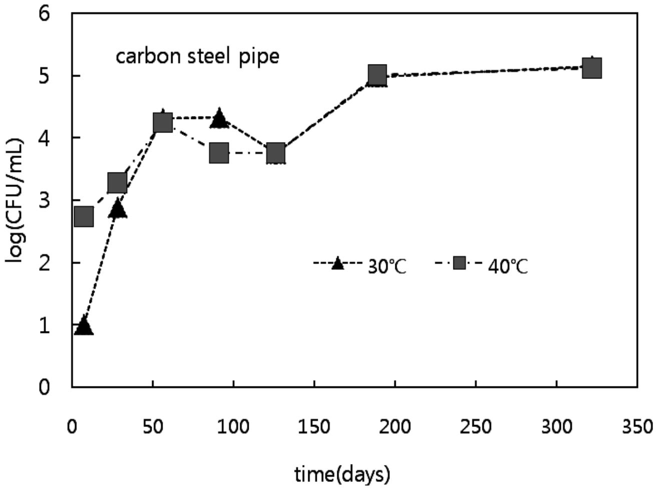


Fig. 7. Variation of HPC populations in effluent in the carbon steel pipe at the temperature conditions of 30 and 40 °C

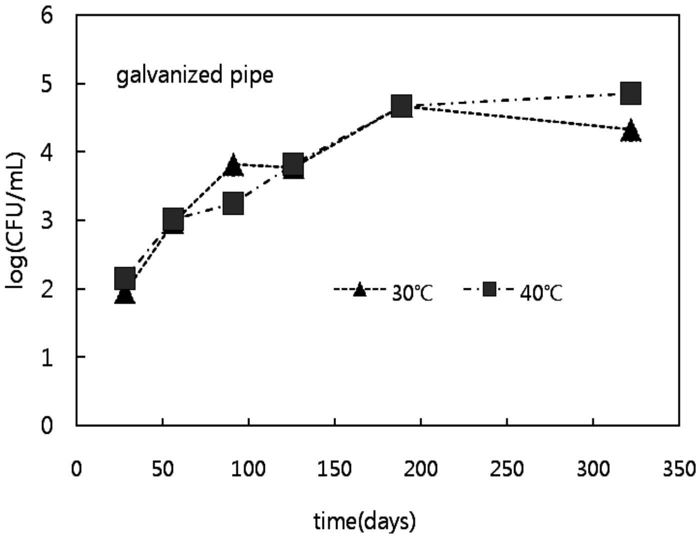


Fig. 8. Variation of HPC populations in effluent in galvanized pipe at the temperature condition of 30 and 40 ºC

The suspended HPC variation in the copper pipe is given in Fig. 9. The initial increased level of the HPC during 1 week was high for the condition of 40 °C. The multiplication of the HPC was already reached about 61 % at 7 d of that at 322 d for the temperature condition of 40 °C. After fast multiplication achieved during the initial contact time, the growth of the HPC was shown to be stagnant between 56 and 126 d. Lehtola *et al.*[12] reported that level of microorganisms decreased till 200 d by toxicity of copper at the initial operation time but increased after 200 d. In this experiment, the variation in HPC did not show a dramatic decrease for an increase of the copper level.

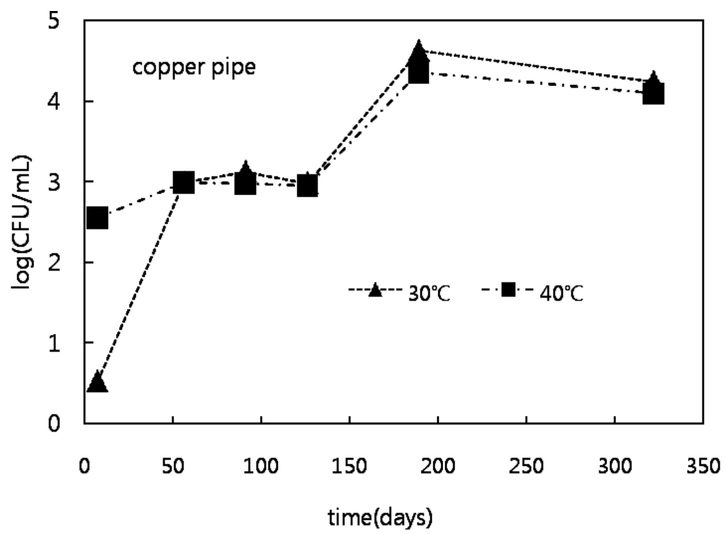


Fig. 9. Variation of HPC populations in effluent in copper pipe at the temperature of 30 and 40 ºC

The highest level of the HPC was shown in the stainless steel pipe for the condition 40 °C in selected pipes (Fig. 10). The multiplication of the HPC proceeded rapidly for the stainless steel pipe in the initial first week for both temperature conditions. The ratio of the HPC at 7 d to that at 322 d was shown to 0.98. It showed a stagnated phase till 56 d after a fast initial increase of the HPC. Then after, the level decreased narrowly over the time and then increased again. Crevices on the surface of stainless steel were observed (Fig. 11) with the expose of the dose condition of chlorine 3 mg/L after 322 d of the study period with tap water and it was expected to contribute for offering a location for a high multiplication level of microorganisms in stainless steel pipe. Applying for stainless steel increase these days in Korea because use of stainless steel pipe appreciated for showing low corrosion rate compared with carbon steel and galvanized steel pipe. However, the selection of stainless steel for pipes might not beneficial for microbial management for drinking water distribution by this result.

The limiting nutrient in drinking water was supposed to be organic carbon[21]. Chandy and Anglis[22] reported that the limitation factor was organic carbon in a distribution system in Sydney, Australia. In this experiment, the relationship between biodegradable organic matter (BOM) and the level

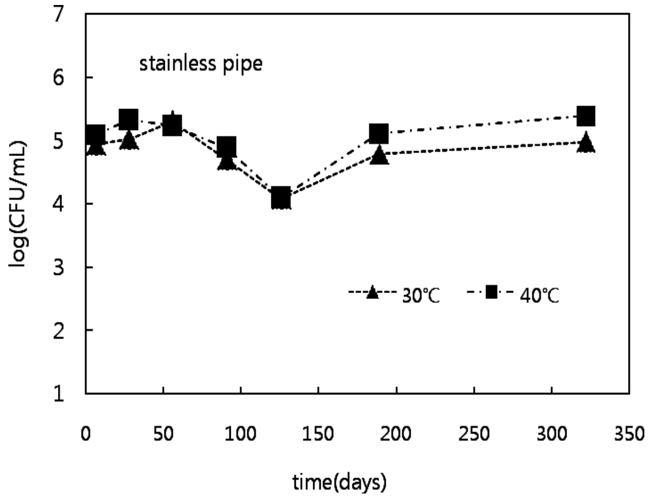


Fig. 10. Variation of HPC populations in effluent in stainless pipe at the temperature of 30 and 40 ºC

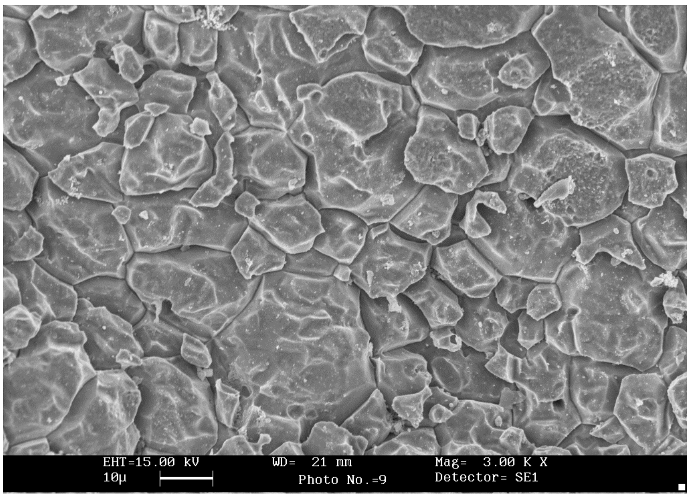
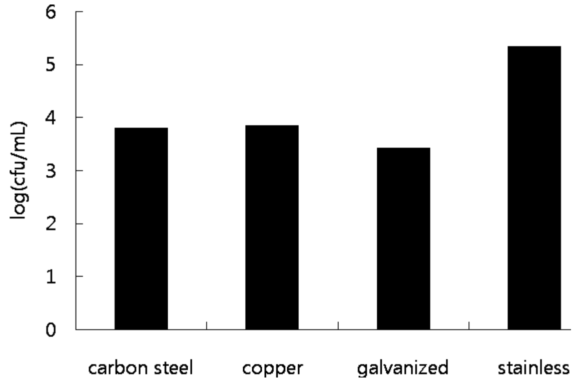
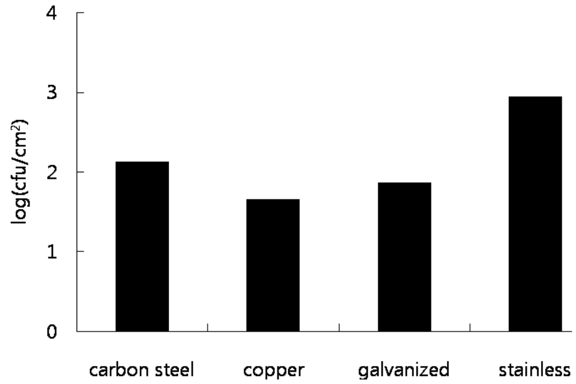


Fig. 11. SEM observations of stainless pipe coupons with 3 mg/L chlorination after 322 d exposure

of HPC was evaluated for pipe materials. Thus, only 3 mg/L glucose was injected without any other supplements. The suspended at 322 d and attached HPC at 273 d with glucose supplemented is presented in Fig. 12. During this experiment, stainless steel and carbon steel pipes showed high levels of suspended HPC. The higher multiplication order of attached HPC was shown in stainless, carbon steel, galvanized and copper pipes.



(a) Suspended HPC from effluents of each pipe



(b) Attached HPC on pipe materials

Fig. 12. HPC multiplication for each pipe in glucose only supplemented water

The values of ATP in effluents from each pipes were presented at the time of 322 d in Fig. 13. The values of ATP at 40 °C are higher than that at 30 °C in effluents from each pipe. Kim *et al.*[19] found that biodegradable organic carbon (BDOC) increased in autoclaving tap water compared to control water. The higher order of the ATP level appeared in stainless steel pipe, carbon steel pipe, galvanized pipe and copper pipe at 30 °C. The highest value of the HPC was shown in the stainless steel pipe at 30 and 40 °C. Copper pipe showed the highest ATP level and the carbon steel pipe showed the lowest ATP level at 40 °C.

Copper pipe showed the highest ATP difference between 30 and 40 °C and stainless steel pipe showed the lowest ATP differences between both temperatures in effluents. Delahaye[23] reported that ATP values were consistent with the HPC by measuring with R2A medium for a microbiological evaluation study for a Paris distribution system. But, two items were not evidently related for the temperature condition of 40 °C with tap water distributed in Seoul, South Korea.

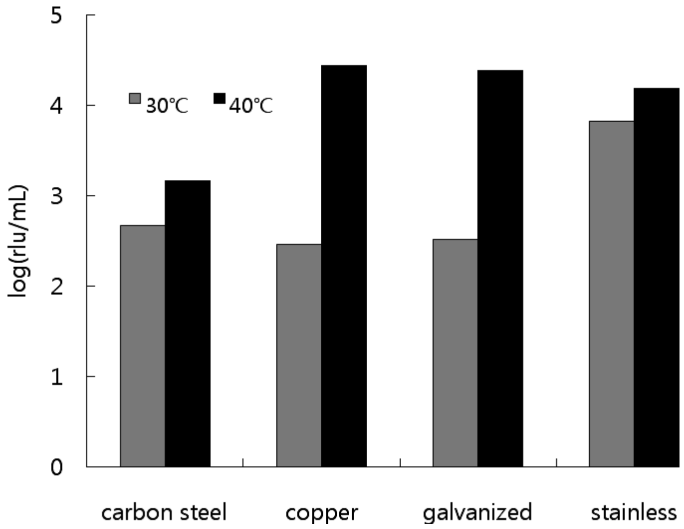


Fig. 13. ATP value from each pipe effluent

The level attached HPCs from biofilm and ATP are presented at 273 d in Fig. 14. The attached HPC level and ATP of stainless steel were higher than other sorts of pipes.

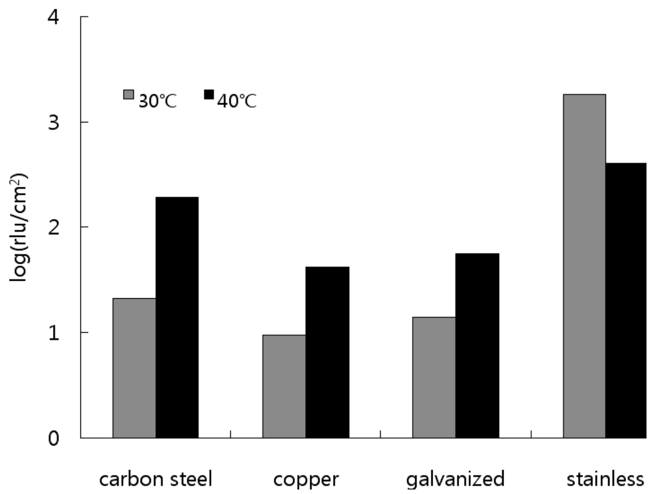
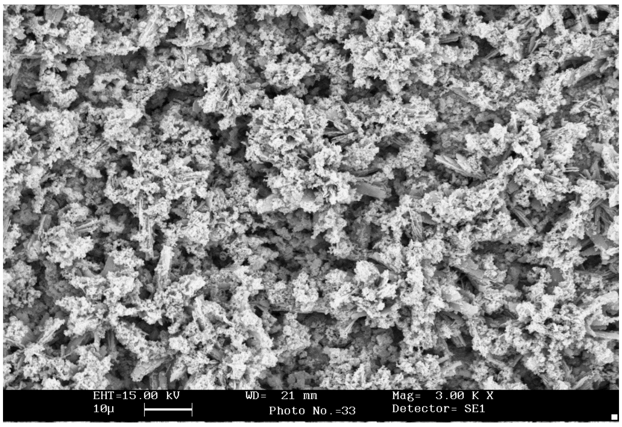
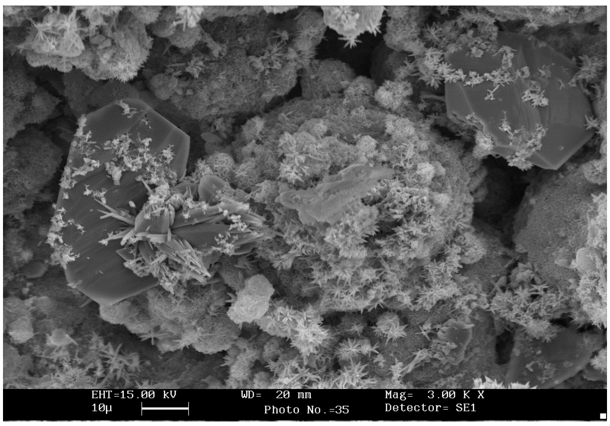


Fig. 14. ATP concentration on pipe from biofilm

van der Kooij *et al.*[24] found the level of attached microorganism was detected to a similar extent for copper and stainless steel pipes. The level of attached microorganism was reported to low for copper pipe compared to plastic pipe[12]. In this experiment, the ATP level of the attached microorganisms in the copper pipe registered a lower value than those of selected other pipes. The thick scale was found on the surface of the carbon steel and galvanized pipe after exposure to the temperature condition of 40 °C according to SEM observation (Fig. 15). These types of deposits on pipes might contri-bute to the consumption of residual chlorine in water and offer nutrients for growing microorganisms.



(a) Carbon steel pipe



(b) Galvanized pipe

Fig. 15. SEM observations of carbon steel and galvanized pipe coupons after 322 d exposure

Conclusion

This research was performed to investigate the effects of temperature and pipe materials on the corrosion rate and level of the HPC in water plumbing system. The following conclusions were drawn from this study.

Pipe material influenced bacterial growth. Bacterial growth potential was ranked in the order of stainless, carbon steel, galvanized and copper at the temperature condition of 30 ºC. Temperature appeared to have an important effect on bacterial activity and corrosion rate in pipe systems.

Stainless steel pipe showed the highest multiplication of HPC on biofilm and in effluents with temperatures of 30 and 40 °C. When sufficient BOM was added, the growth rate of the HPC in the stainless steel pipe was higher than those of the other pipe materials. The presence circumstances in which the use of stainless pipe has increased recently in Korea is due to the merits of a low corrosion rate. Therefore, high microorganism multiplication on stainless steel pipe and its health effect have to be evaluated in detail.

The corrosion rate was increased for all selected pipe materials when the temperature condition increased from 30 to 40 °C. The corrosion rate increased 3.3 times more than that of 30 °C with temperature of 40 °C for galvanize pipe. The corrosion rate for carbon steel was the highest for the selected pipe materials with the temperature condition of 30 and 40 °C.

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