Variation of Inorganic Compounds in Home Bath Water

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Abstract

Bath water is heated to warm the body, and in Japan it is used to remove cleaning agents from the skin before entering the bathtub. Usually this water does not enter the body, but there have been cases where people have caught infectious diseases through inhalation of aerosols. In this study, we examined the change in hygiene and chemical composition of the bathtub water in various conditions as a model of circulating bath. To investigate the potential for bacterial growth in home bath water in Japan, changes in the concentrations of metal and non-metal inorganic compounds were studied as the number of days the water was re-used. With re-use of bath water within 1 week, the concentrations of most of the compounds increased, but the phosphorus decreased. Increasing concentrations could be attributed to sweat secreted from skin of the bather, compounds eluted from the water heater, as the bath water was re-heated, and addition of bath salts. Consumption of inorganic compounds by bacteria and precipitation of metal hydroxides could be thought to the decreasing concentrations. Common bacteria and coliform bacteria were also measured simultaneously, and only the coliform bacteria increased in the water on the second day the water was used for bathing. It seems bacteria probably grew in the pipes between the water heater and the bathtub.

Keywords: Inorganic compound; Bathing; Coliform bacteria

Introduction

Bath water is heated to warm the body, and in Japan it is used to remove cleaning agents from the skin before entering the bathtub. It is assumed that the water does not enter the body during bathing. However, in a shower, water can be unintentionally inhaled as an aerosol. Water could also enter the body through wounds in the skin. In public baths, used water may not be replaced with fresh water for several days, and this could result in spread of infectious diseases. Bacteria can grow in water heaters if they are not cleaned properly, and the addition of inorganic compounds to the bath water from the water source or the skin of bathers can be thought to promote bacterial growth. Many bacteria can grow in soil [1,2], and in a bathroom, bacteria in the bath water will circulate throughout the water heater where they could adhere and grow. Consequently, filtration of water before it enters the water heater is a requirement at large public baths in Japan [3]. However, many home bathrooms in Japan are equipped with small cyclical type boilers that re-heat bath water without filtration, and bacteria could multiply in these systems [4,5]. It is a Japanese custom to soak in a bathtub after cleaning the body outside of the bathtub, and the water is re-used for subsequent baths. If you wash the body in the home bathtub, dirt adheres to the pipe between the water heater and bathtub. So this pipe is difficult to wash, bring the risk of contaminating the dirt at the time of the next bathing. As a result, other than the part of the unit bath, it is not possible to wash the body in the bathtub.

This custom may increase the risk for contracting such illnesses compared with in other countries. Sekine et al. showed that bacteria such as Legionella, require inorganic compounds for growth [2,6]. She added trace elements to the agar medium, and checked the increase and decrease of bacteria. It is thought that this demand nature is naturally maintained also in the bathroom, the inorganic compounds may be required for growth of bacteria in bath water. This is considered to lead to prevention of infectious diseases. In order to prevent bacteria infection, daily water quality testing is important. In this study, as a model case of circulating bath, we examined the change in hygiene and chemical composition of the bathtub water in various conditions. Changes in the concentrations of inorganic compounds home bath water in Japan were investigated as the number of days the water was re-used for bathing. The relevance of these results to growth of bacteria was considered.

Methods

Instruments and reagents

The target analytes were inorganic elements (Li, B, Na, Mg, Si, P, K, Ca, Sc, Ti, V, Mn, Fe, Cu, Zn, Ge, Se, Rb, Sr, Mo, Ba, W, Tl, Pb, Th, U), inorganic anions (Cl−, NO3−, SO4−2), coliform bacteria, common bacteria, residual chlorine, chemical oxygen demand (COD) and pH. In these, the inorganic element was selected based on the report of Sekine.

The inorganic elements were analyzed at ppm levels by inductively coupled plasma emission spectrometry (ICP-AES, Optima 4300 DV; PerkinElmer, Waltham, MA), and at ppb levels by inductively coupled plasma mass spectrometry (ICP-MS, Elan 6100 DRC, PerkinElmer). The reference solution (XSTC-13; Spex Certiprep, Metuchen, NJ) was used for the inorganic element analyses by ICP-AES and ICP-MS. Anion chromatography was conducted using a A1 450 (Dionex, Sunnyvale, CA). A negative-ion mixed reference solution IV (Kanto Kagaku, Tokyo, Japan) was used as the standard for anion chromatography. Levels of coliform bacteria and common bacteria were measured using experimental paper (Sibata Scientific Technology Ltd., Soka, Japan) according to the manufacturer’s instructions. Packtests including N,N-diethyl-1,4-phenylenediamine and alkali permanganic acid (Kyoritsu Chemical-Check Lab, Tokyo, Japan) were used for measurement of

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residual chlorine and COD, respectively. The pH was measured with a pH meter (F-22; Horiba, Kyoto, Japan). High purity nitric acid (TamaPure AA-100, Tama Chemicals, Kawasaki, Japan) was used in the experiments. A membrane filter (MILLEX HA, Millipore, Billerica MA; pore size 0.45 μm) was used for filtration of the samples. Purified water (>18 MΩ cm, Elix 3/Element A10, Millipore) was used for reagent preparation. All other reagents were of special grade and available commercially.

**Sampling and pretreatment**

Samples of home bath water were obtained from one residence in Chiba, Japan, from June to July 2008. The gas heater (FR-250, Hitachi Housetec, Ibaraki, Japan) at this residence was equipped with a hot-water supply, a system for re-heating the water, and controls for the volume and temperature of water entering the bath.

Bath water samples were collected before bathing every day for 1 week in each of the condition. For each day of the week, the same water was used for bathing and not exchanged for fresh water until the next week. The bathtub (Kiramic RPU-0042, Otaki Gas, Chiba, Japan) was cleaned on the first day of each week, and then water (42°C, 200 L) was added. A sample of this water was collected after the bath before bathing, and a sample of tap water was collected from the bath faucet. Measurements for common bacteria, coliform bacteria, and residual chlorine were conducted. Another sample of the bath water was taken after the water had been re-heated for bathing on subsequent days, and the same measurements as above were conducted. In particular, continuous rising and falling of the component concentration is thought to indicate that the same phenomenon is continuous.

**Results and Discussion**

**Inorganic components**

The concentrations of Na, K, Ca, Cu, Zn, Rb, Ba, Cl⁻ and SO₄²⁻ increased over each week (Figure 1). By contrast, the concentration of P decreased (Figure 2), and the concentrations of Mn and Ti showed both increases and decreases (Figure 3). The concentrations of Li, B, Mg, Si, Sc, V, Fe, Ge, Sr, Mo, W, Th and NO₃⁻ did not change. ICP-MS measurements were performed for Se, Tl, Pb and U. However, the measured values were close to the limit of detection, and the results cannot be considered as reliable. The bathtub, water heater, bather, and bath salts, were all considered as potential sources of the inorganic elements. The concentrations of Cu and Ba increased in all experimental conditions (I–VIII), and the bathtub and the water heater were likely

For pre-bathing, test water of the first day in each condition was considered to reflect the between-day variation of tap water components, and little affected passing through the water heater. Component variations of test water from the second day, are affected by re-heated, bathing and standing. In particular, continuous rising and falling of the component concentration is thought to indicate that the same phenomenon is continuous.

![Figure 1: Changes in the concentrations (increasing concentrations) of inorganic compounds within the 7 days.](image)

![Figure 2: Changes in the concentrations (decreasing concentrations) of inorganic compounds within the 7 days.](image)
sources for these elements. To support this, the water heater was known to contain Cu. The concentrations of K, Ca, Zn, Rb, and Cl– increased under all conditions, except for IV. Therefore, these elements are likely secreted by the bather. Sweat is known to contain Na, K, Ca and Cl– [7,8], and a small amount of Zn [9]. Rb is thought to behave like Na and K because it is an alkaline metal. When bath salts were added to the bath, the concentrations of Na, Ti, Cl– and SO$_4^{2–}$ increased dramatically. The ingredients label of the bath salts confirmed that it contained Na and SO$_4^{2–}$, and Ti is also a known ingredient of bath salts. The Ti concentration decreased in some conditions and the P concentration decreased in all the conditions. Bacteria in the water could have consumed these elements. The changes in the concentration of P could be attributed to the source water as with the COD. In condition IV, where bathing did not occur, the decrease in the P concentration was slow. This is because bacteria that would have entered the bath water from the bather were not present to consume P. By contrast, Ti can be consumed rapidly by only a few bacteria, and may have a catalytic function. Furthermore, the possibility that Mn was oxidized to oxynions was investigated. Sekine et al. reported that Mn and Se are co-factors of Legionella growth [2,6]. In the present study, the Mn concentration did not decrease, and the bather did not develop Legionnaires’ disease. To support this, the concentration of Fe, which is required for Legionella growth [10,11], did not change.

**COD, residual chlorine and pH**

In the water sample taken before bathing, the COD was not 0 mg/dL. This was attributed to the tap water source, which was swamp water. Increases in the COD during the experiments (Figure 4) could be cause by sweat and dirt from the bather. Consumption of organic matter by bacteria was thought to cause the decreases observed in the COD. Additionally, the pipes and water storage area could have affected the COD. Compared with the other experimental conditions, V and VIII had higher COD values. These results could be attributable to soap and the chlorine disinfectant in the water. The residual chlorine

![Figure 3: Changes in the concentrations (no consistent trend) of inorganic compounds within the 7 days. The same bath water was used in each of the eight experiments (I–VIII). The experimental conditions are shown in Table 1. Ti was varied in the same trend as Mn.](image)

![Figure 4: Changes in the COD (a), pH (b) and residual chlorine (c) within the 7 days. The same bath water was used in each of the eight experiments (I–VIII). The experimental conditions are shown in Table 1.](image)
concentration was highest on the first day of each week, and then decreased gradually as there was no further addition of chlorine disinfectant during the week. This decrease was probably caused by volatilization of the chlorine with heating of the water. However, even with these decreases, a free chlorine concentration of 0.1 mg/L was obtained on the seventh day. Because other results showed that bacterial growth occurred, these chlorine measurements were not useful for determining if disinfection of the water occurred [12,13]. Measurement of residual chlorine is recommended at public baths and hot springs in Japan. In the present study, the Pakctest was used for the measurement. However, this kit can react to substances other than chlorine [14]. Therefore, the chlorine concentration should be measured by other methods [15]. Over the week, the pH decreased gradually under all experimental conditions. The decrease under the conditions in experiment V was particularly remarkable, and this could be attributed to sweat remaining on the skin of the bather [16].

Common bacteria and coliform bacteria

Bacteria were detected in the water sample from the faucet. In each of the eight weeklong experiments, the number of bacteria decreased initially and then increased again (Figure 5). All bacterial levels were less than 100 cells/mL, which is the upper limit for domestic water supply in Japan [17]. Coliform bacteria were not detected in the water samples on the first day, but they were detected on the second day, which was the first day the water was heated for re-use after bathing. The levels of coliform bacteria then decreased and increased at different points after the second day. Increases in the viable cell counts show that bacteria were present on the body of the bather or in the bathroom. Changes in the coliform levels were probably affected by circulation of the bath water through the water heater, piping, and bathtub. Because cleaning the bathtub before each experiment was sufficient to remove any bacterial growth, there were very few places that bacteria could adhere and grow within the bathtub. Therefore, bacteria must have grown inside the water heater or pipes between the bathtub and heater [18]. Some bacteria are protected from detergent by formation of a biomembrane, and cannot be easily removed [1,12]. Mold growth can occur at the faucet and enter the bath water when the bath is filled [19]. Bacteria were detected in the bath water immediately after the water heater was cleaned, which indicates that the bactericidal effect of chlorine in the bath water was not maintained for a long time.

Conclusion

As a result of taking a bath for relaxation and health promotion, it is putting the cart before the horse if it suffered from infection. The direct detection procedure of the legionella bacteria which is the typical infection over bath water takes time very much, and needs a special culture condition. Therefore, it is not suitable for a routine test. There are some commercial kits for measurement of standard bacteria or residual chlorine, and anyone can perform it simple. If these are strongly related from infection, it can prevent and monitor indirectly. To clarify the potential for bacterial growth in home bath water, we investigated changes in the concentrations of metal and non-metal inorganic compounds as the water was re-used. Then the concentrations of most of the compounds increased. However, the concentration of P decreased, and the concentrations of Ti and Mn showed both increases and decreases. These are considered to have been consumed by growth of a microbe.

In future, an investigation of the inorganic compounds present in bath water in a public bath would be useful. Measurement of residual chlorine by other methods should also be investigated. These results could be used to clarify if bath water is a suitable environment for the growth of pathogenic bacteria, and if bathing enhances or decreases bacterial growth. In cases where bacteria could enter the water from soil, such as in a hot spring, chlorination can be used to prevent bacterial growth. However, addition of chlorine could lower the quality of the water for bathing by affecting its color and/or smell. In situations where it is difficult to perform chlorination, other methods for stopping bacterial growth should be investigated.

References


