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Experiment on the Feasibility of Cleaning Building Pipelines using Ultrasonic Cavitation

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Abstract: Residential heating systems in South Korea are largely based on the use of ondol pipelines. Heat is transferred to the floor by passing hot water through a metal or plastic pipe buried within the concrete of the floor. Consequently, it is difficult to clean the inside of these pipes after installation. Over time, foreign substances such as scale accumulate in the pipe when the ondol heating method is used for an extended period. Therefore, in the past, pipes were cleaned by removing foreign substances attached to the inside surfaces of the pipes using high-pressure water or by disassembling the pipes and removing foreign substances with chemical agents. Recently, a method for removing foreign substances through the cavitation effect of ultrasound has been proposed. This idea might lead to the development of new technologies for cleaning pipe interiors. Consequently, this study investigated the use of ultrasound to clean pipes embedded in concrete. In this study, devices that generated ultrasonic waves with various frequencies and directions were prepared. After preparing arbitrarily contaminated pipes, the appropriate frequency, output strength, and output direction for each foreign substance were determined through repeated experiments. The results of this experiment could provide important information for future methods of cleaning the interior of ondol piping systems.

Key Words: ultrasonic, cavitation, cleaning building pipelines

1. INTRODUCTION

In South Korea, residential heating is primarily based on the ondol pipeline system. The floor is heated by passing hot water through a metal or plastic heating pipe installed within the concrete of the floor. After an extended period of use, sludge, corrosion oxides, and microorganisms are deposited on the inner walls of such pipes [1], and issues such as corrosion or scaling arise when the heating efficiency deteriorates.

Public housing and many large buildings are equipped with water supply tanks. Although there are regulations requiring that they be cleaned periodically, there are no specific guidelines for cleaning the pipes [2]. Consequently, the pipes are used until their lifespans have expired [3]. The interior surfaces of these pipes are difficult to inspect or clean without removing them because they are buried in the concrete floor. Therefore, research and development are being performed to solve these problems, with attempted solutions that have included scale boosters, pipe replacement, epoxy lining, and other methods [4]. Scale boosters are physical water treatment methods that do not use magnets, electricity, or chemicals to remove and prevent rust, scale, and water stains within pipes. This method is completely harmless to the human body [3]. The epoxy lining process consists of a polishing (cleaning) step followed by a lining (painting) step. In the polishing process, the scale adhering to the interior surface of the pipe is ground using abrasives carried by a high-speed swirling airflow to prepare the surface for painting. As part of the lining process, epoxy resin paint is applied to the inner surface of the pipe using a high-speed airflow. In a study, compressed air was periodically injected into pipes using a shock wave cleaning device as a cleaning method, and bubbles were produced by pulsing the flow in order to produce turbulence. The explosive force from the destruction of these bubbles removed scale from the pipes [3]. Scale boosters are physical water treatment methods that do not rely on magnets, electricity, or chemicals. Using the galvanic effect of the potential difference between hetero-metals (brass and zinc) and the electrostatic effect of fluoroplastic, this method converts rust (Fe2O3) inside pipes into magnetite (Fe3O4), extending the lifespan of the pipes. By changing the shape of the water from needle-like to a spherical shape, this research was capable of preventing scale formation and removing the existing scale in a manner that was completely harmless to the body [5]. Recent research has focused on the use of ultrasonic waves to remove foreign substances by attaching an ultrasonic generation device to the exterior of a pipe to generate ultrasonic waves inside the pipe [6]. However, this method is not suitable for use in an environment where concrete is deposited around an Ondol pipe.

Recently, a method for removing foreign materials from inside a pipe using ultrasound has been developed. Additionally, ultrasonic cleaning has recently become popular for household use [7], although it has been widely used for industrial purposes for many years. In industrial cleaning, it is mainly used to remove fine dust and contaminants from liquid crystal displays (LCDs) and cathode-ray tubes (CRTs) [7]. Cavitation is the most important factor in ultrasound cleaning. The cavitation effect refers to the release of energy and heat to the surroundings when microbubbles are created by ultrasonic wave bursts. Variables such as the water temperature, water level, diaphragm, and vibrator position can influence cavitation [7].

We studied whether communication is possible in the pipe under the concrete [8], and in this study, experiments were conducted to clean contaminants in pipes with ultrasonic cavitation using a variety of ultrasonic cleaner types. During these experiments, the ultrasonic intensity, propagation direction, and cleaning efficiency of the cavitation were examined for use as baseline data to determine the optimum ultrasonic specifications for pipe cleaning equipment.

2. MATERIALS AND METHODS

Three types of ultrasonic cleaners were used in this experiment: SH-S900D (Type A), TZ-1003 (Type B), and Wavelean W1 (Type C). As shown in Figure 1, Type A was an ultrasonic cleaner with ultrasonic waves emitted upward from the bottom of the tank, Type B emitted ultrasonic waves horizontally from a stick, and Type C was a stick-type ultrasonic cleaner with ultrasonic waves emitted from the tip.

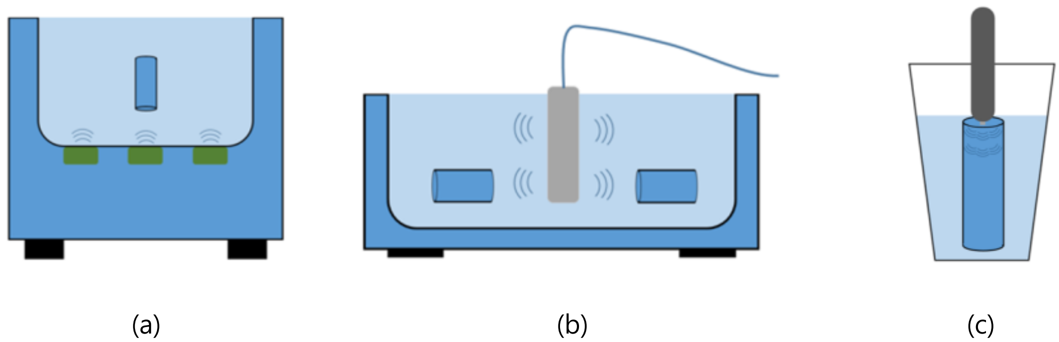


Figure 1. Type A (a), Type B (b), and Type C (c) operating principles

The contaminants inside the XL pipes used in the experiment were chosen based on their density, concentration, and viscosity. Contaminant 1 (mixed coffee), Contaminant 2 (chili pepper paste with vinegar), and Contaminant 3 (black ink) were applied and hardened inside the pipe. The contaminants were evenly applied to the interior of the pipe to thicken the contaminant layer. The interior of the XL pipe had a particularly thick layer of contamination at its center because of its circular shape. The XL pipes used in the experiment are shown in Figure 2.

Figure 2. XL pipes contaminated with Contaminant 1 (Left), Contaminant 2 (Center), and Contaminant 3 (Right)

The aforedescribed ultrasonic cleaners and contaminated XL pipes were used in the ultrasonic cleaning experiments. Every type of ultrasonic cleaner was tested for 5 min, and if the cleaning process was not completed after one session, additional ultrasonic cleaning sessions were performed. The cleaning process was continued until the inside of the pipe was thoroughly cleaned. When the cleaning could not be completed within one 5 min session, the time was increased to 10 min per session. If the pipe was not cleaned after three additional cleaning sessions, the experiment was terminated. After one cleaning session, photographs of the pipe interior were taken to determine the extent of cleaning. Image processing was performed to examine the extent of cleaning inside the pipe. Because of the shooting position and angle of the photographs, there was a slight error in image processing.

3. EXPERIMENT

A basic experiment was conducted to remove the scale from the ondol pipe. Three different types of ultrasonic cleaners were used to remove contaminants from the inside of the XL pipe to determine the effectiveness of cleaning in relation to the generation location and propagation direction of the ultrasonic waves. Three types of experiments were conducted for each type, that is, nine experiments were conducted as follows.

1) Type A - Contaminant 1, Contaminant 2, Contaminant 3

2) Type B - Contaminant 1, Contaminant 2, Contaminant 3

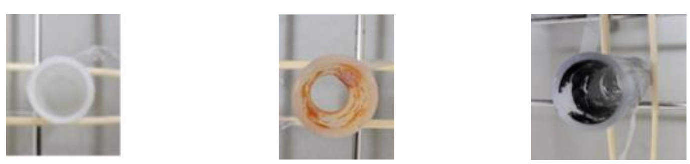
3) Type C - Contaminant 1, Contaminant 2, Contaminant 3

Each session of the experiment lasted for 5 min or 10 min if contaminants were present. The experiment was terminated when cleaning could not be accomplished after three sessions of 10 min each or when cleaning was complete.

4. EXPERIMENTAL RESULTS

Using ultrasonic cleaners and contaminated XL pipes, the experiments were conducted for 5 min per session, and when cleaning was ineffective, the experiment was conducted for 10 min per session. Because the Type A ultrasonic cleaner emitted ultrasonic waves from the bottom up, the ultrasonic cleaning efficiency was increased by aligning the direction of the ultrasonic wave generation with the interior of the XL pipe and separating the system from the bottom using the tray.

Each experiment was conducted for 5 min, and the interior of the XL pipe was photographed and analyzed through image processing. An experiment was conducted for 10 min per session when cleaning was ineffective. The results of these experiments are shown in Figure 3.



(a) (b) (c)

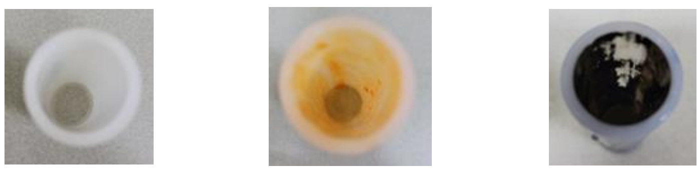
Figure 3. Pipe interiors after Type A ultrasonic cleaning

Following this, the contaminated XL pipes were cleaned using a Type B ultrasonic cleaner.

(a) (b) (c)

Figure 4. Pipe interiors after Type B ultrasonic cleaning

Then, a Type C cleaner was used on the contaminated XL pipes. In contrast to the other ultrasonic cleaners, the ultrasonic generator was positioned inside the pipe to perform cleaning. The cleaner body was waterproofed with masking tape.



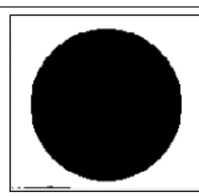
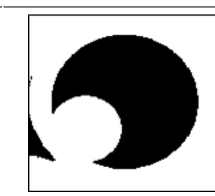
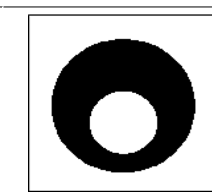
(a) (b) (c)

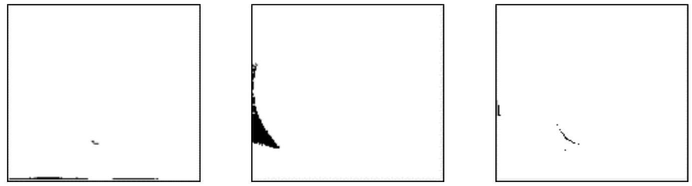
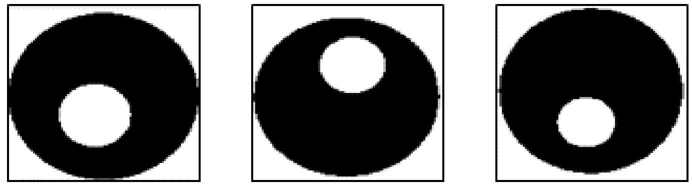
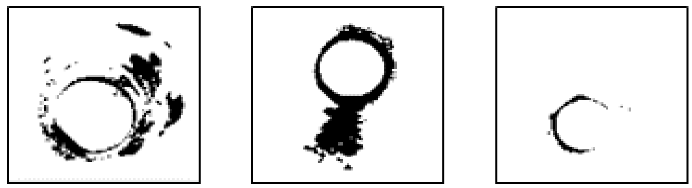
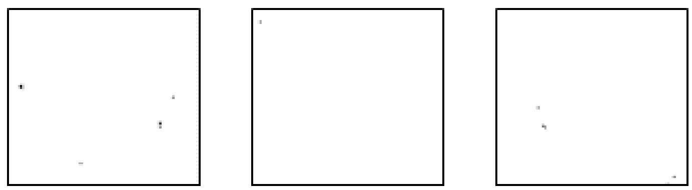
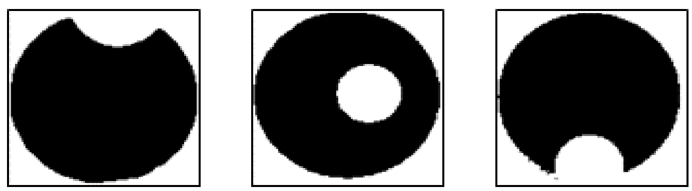
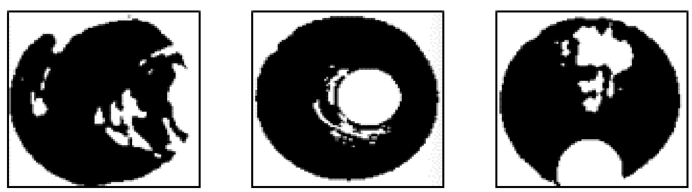
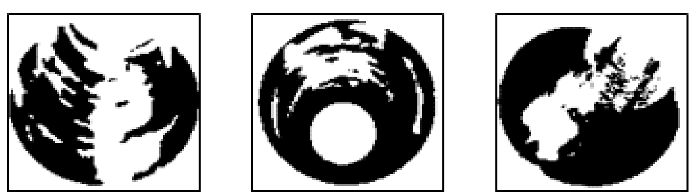
Figure 5. Pipe interiors after Type C ultrasonic cleaning

5. IMAGE PROCESSING RESULTS

The inside of the pipe was photographed using the camera of Samsung's Galaxy Note20 Ultra. Image processing was performed using MATLAB of MathWorks. After image processing the photos taken during the experiment, the removal rate of contaminants inside the pipe was measured. Even if the inside of the pipe was photographed with the same composition, the contaminant removal rate was different depending on the inside of the pipe being photographed. So, in order to reduce the error, the average value of the photos taken from various angles was obtained. Table 1 presents the results of calculating the cleaning range after the image processing of the photographs taken after cleaning.

Table 1. Image processing results

Contaminant	Time elapses	Type A	Type B	Type C
1	0			

	5 min	
2	0	
	5 min	
	15 min	
3	0	
	5 min	
	15 min	

As for the contaminant removal rate, if the contaminants inside the pipe are on the whole, the standard was set as 0%, and the percentage was calculated by calculating the removed part. Through image processing of the picture before ultrasonic cleaning, the area with contaminants inside the pipe was image-processed so that the black color and the outside of the pipe were white. When the contaminants inside the pipe are removed, the part that was black in the image processing before ultrasonic cleaning changes to white. So, for the calculation of the contaminant removal rate, the black part before ultrasonic cleaning was taken as 100%, and the white part after washing was calculated to obtain the percentage. The image processing results were calculated according to the following equation and are shown in Figures 7, 8, and 9.

$$\frac{\text{(Number of bits in the contaminated part} - \text{The number of bits in the contaminated part after cleaning)}}{\text{Number of bits in the whole image}} \times 100 \quad (1)$$

Contaminant 1 was thoroughly cleaned with all three types of ultrasonic cleaners in one pass. For Contaminant 2, Type C was the most effective, Type B and Type A showed similar cleaning efficiencies, and most of the contaminants were removed after several sessions. For Contaminant 3, the cleaning efficiencies from best to worst were Type A, Type B, and Type C. However, despite repeated attempts to clean the contaminants, they could only be partially cleaned.

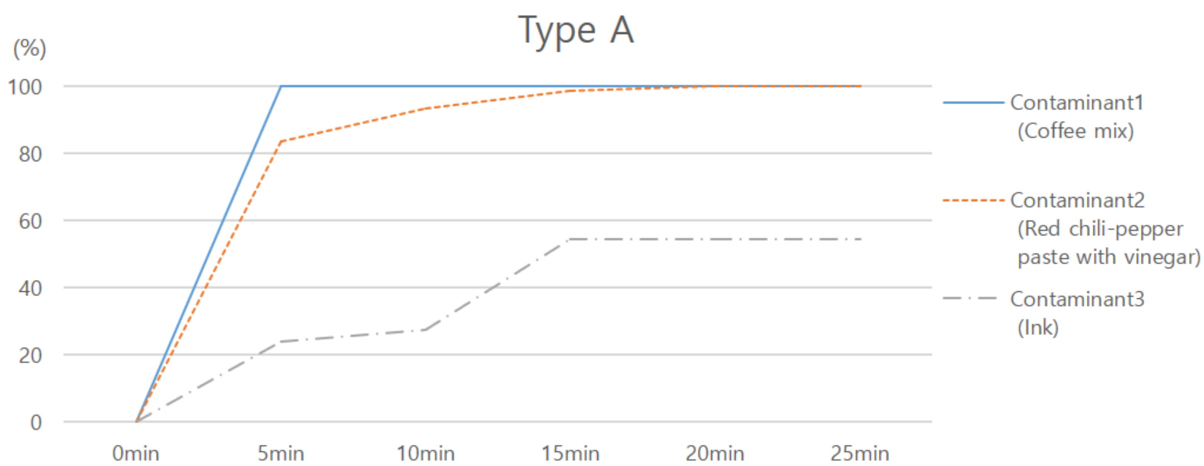


Figure 7. Results of Type A cleaning

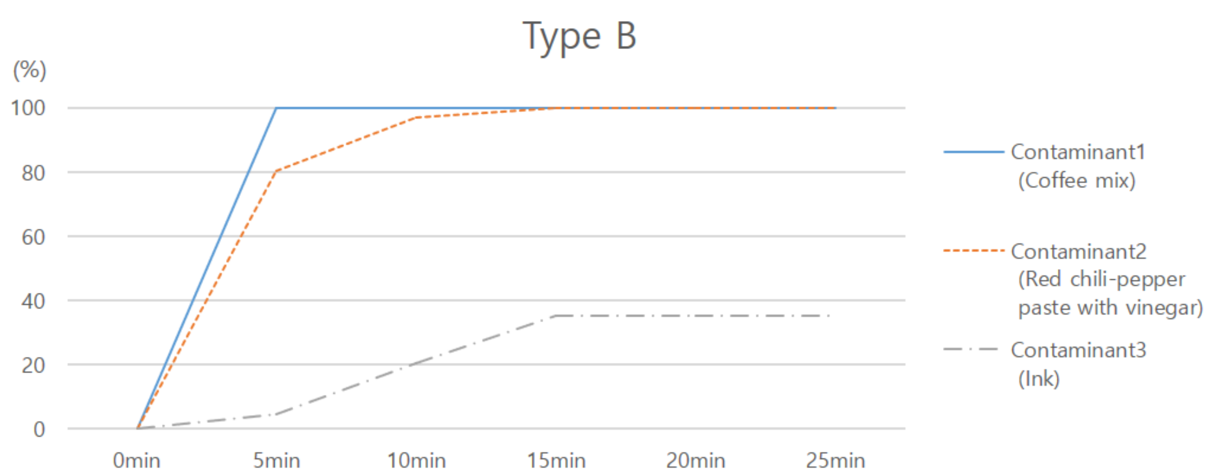


Figure 8. Results of Type B cleaning

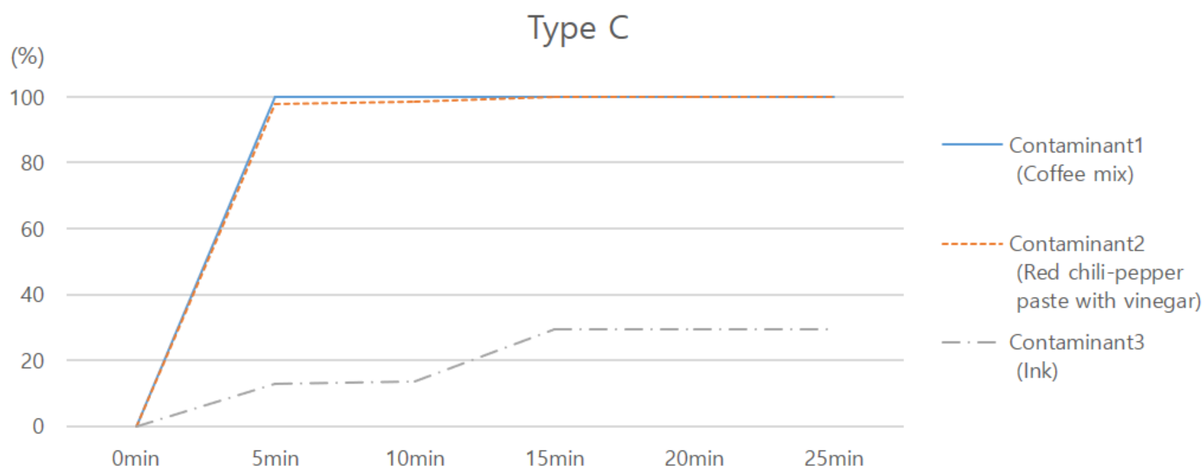


Figure 9. Results of Type C cleaning

6. DISCUSSION AND FUTURE WORKS

Experiments were conducted in this study to obtain basic information for the development of a device for cleaning the interior of an XL pipe. In these experiments, the cavitation effect of ultrasonic waves was utilized to examine whether it was possible to clean the inside of the pipes. Cleaning experiments were conducted using ultrasonic cleaners and contaminated XL pipes. The results of these experiments demonstrated that ultrasonic cavitation could also be used to clean pipes. Additionally, it was considered possible to clean and descale pipes using a wireless smart ball, which is being developed. Whereas many studies have been conducted on conventional pipe cleaning, very few studies have been conducted on the image processing-based inspection of a pipe's interior. In future research, image processing will be used to examine the interior of pipes after cleaning.

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