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Optimization of Ultrasonic Soil Washing Processes for the Remediation of Heavy Metals Contaminated Soils

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1. Introduction

Various in-situ and ex-situ soil/groundwater remediation technolgies inclduing soil vapor extraction (SVE), solidification/stabilization, phytoremediation, pump and treat, bioremediation, soil washing, and chemical oxidation/reduction have been reported for petroleum hydrocarbons and hevay metals contaminated sites. It is well known that in-situ remediation technologies cost less and take more clean-up time to achieve the desired remediation goal while short operating time and high and homogeneous removal efficiency can be achieved in ex-situ remediation processes.

The soil washing process is considered as one of the easy applicable and very effective ex-situ technologies for heavy metal contaminated sites. Many researchers tested a variety of contaminated soils using several chemical extraction methods including high concentrated acids (ion exchange and dissolution), chelate agents (complexation), and low concentrated acids/salts. It was also reported that ultrasound technology can significantly enhance the removal of pollutants when combined with conventional soil washing processes.

When ultrasound is irradiated in aqueous phase, countless acoustic cavitation events occur and sonochemical effects including pyrolysis and radical reactions and sonophysical effects including shock wave, microjet, and microstreaming are induced. In heterogenous systems such as a slurry system (soil and liquid), it is known that sonophysical effects are more dominant due to the presence of fine particles. Some previous researchers tested various experimental conditions including input power, sonication time, pH, pollutant concentration, surfactant concentration, and particle size to investigate the effect of ultrasound in soil washing processes using small-scale probe-type and bath-type ultrasound equippments.

The purpose of this study is to investigate the effect of ultrasound in conventional soil washing processes with mechanical mixing and strong acid. The removal efficiencies of heavy metals in conventional and ultrasonic soil washing processes were compared under various conditions. Moreover design and operation parameters for large-scale ultrasonic soil washing were suggested using a relatively large-scale unit module.

2. Experimental methods

The contaminated soils were obtained from the old Y train station site in Seoul, contaminated with heavy metals and petroleum hydrocarbons as shown in **Fig. 1**. Large-scale remediation technologies have been investigated for several years.

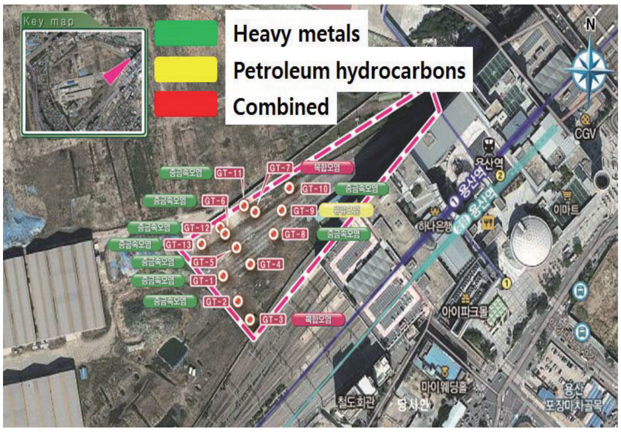

Fig. 1 The old Y train station site contaminated with heavy metals and petroleum hydrocarbons

Fig. 2 shows a schematic of the experimental setup. The square-shaped sonoreactor consisted of a stainless steel reactor (20×20×20 cm^3) and a transducer module equipped on the bottom. The transducer module included seven transducers. A stainless vessel (15×15×15 cm^3) for contaminated soils and washing liquid was placed in the sonoreactor. The applied frequency was 28 kHz and the input power was 250 W. The slurry (contaminated soils and washing liquid) in the vessel was violently mixed using a mechanical agitator. The mixing speed was 200 rpm and the washing time was 30 min.

After washing processes, the treated soils were dried for several hours and three to five dried samples were collected. The heating extraction was conducted for each soil sample (3 g) with 21 mL

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of HCl (100 %) and 7 mL of HNO_3 (100 %). The extracted liquid was filtrated and the concentrations of Cu, Pb, and Zn in the extracted liquid were analyzed using ICP-OES (Varian 720-ES).

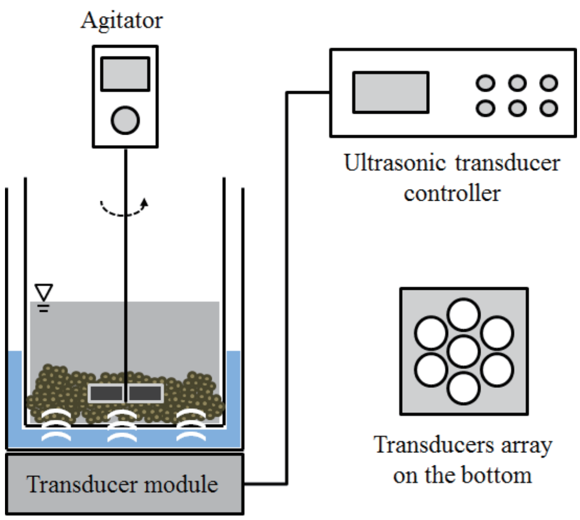

Fig. 2 A schematic of the ultrasonic soil washing process and the array of transducers in the transducer module

3. Results and discussion

Mechanical and mechanical/ultrasonic washing processes were investigated when the soil:liquid ratio was 1:2 (**Fig. 3(a)**) and the ratio was 1:3 (**Fig. 3(b)**). The amount of soil was 300 g and the washing liquid was a 1M HCl solution. It was found that ultrasound could significantly enhance the removal efficiencies of heavy metals due to the sonophysical effects. The mechanical washing enabled the adsorbed pollutants on the surface of soil particles to easily separate while the pollutants trenched in the soil pores, which were not easily desorbed by the mechanical mixing, could be effectively removed by sonophysical actions.

For the soil:liquid ratio of 1:3 the removal efficiencies increased for both mechanical and mechanical/ultrasonic processes compared to the ratio of 1:2. It was because more polluted particles could be affected by washing liquid and acoustic cavitation when more washing liquid was applied. Moreover the attenuation of ultrasound for the higher soil:liquid ratio might less occur due to the density change of the slurry. Less attenuated ultrasound can induce more violent cavitation events and more pollutants removal from soil particles.

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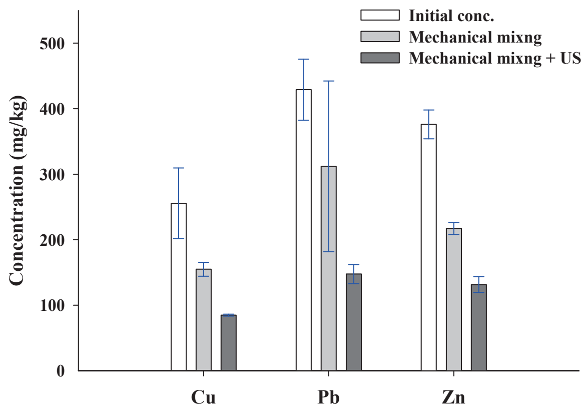
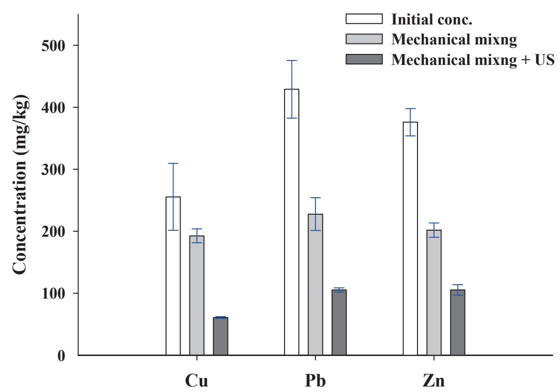


(a) Soil 300 g and HCl 1M solution 600 mL



(b) Soil 300 g and HCl 1M solution 900 mL

Fig. 3 The variations of heavy metal removal for mechanical and mechanical/ultrasonics soil washing processes