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Analysis of Energy Consumption in Ultrasonic Soil Washing Processes for the Diesel-Contaminated Soil

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1. Introduction

Ultrasound irradiation in aqueous phase leads to cavitation events including the formation, oscillation/growth and violent collapse of bubbles in micro-scale. Extreme conditions inside bubble enable to generate sonochemical effect and sonophysical effect. Generally sonochemical effects are used for the removal of organic pollutants in homogeneous aqueous phase while sonophysical effects are employed for the surface cleaning and micro-mixing such as emulsification in heterogeneous system [1-5].

In soil-washing process, desorption of the organic or inorganic pollutants from the contaminated soil is the key step. Conventionally, water or water with surfactants is added as solvent and then mechanical mixing for washing is applied. Basically this typical washing process can remove pollutants only from the soil particle surface. However residual pollutants strongly adsorbed on the surface or pollutants entrenched inside pore require more mixing intensity, mixing time, or washing solvent. Sonophysical effects induced by ultrasound irradiation can enhance the mass transfer from the solid phase to liquid phase by violent action including micro-jet, micro-streaming, and shock wave, therefore the removal efficiency can be increased significantly by ultrasound [6, 7].

The purpose of this study was to esimate removal efficiency for mechanical soil washing, ultrasonic soil washing, and ultrasonic and mechanical soil washing process and to optimize the energy consumption in ultrasonic and mechanical soil washing processes.

2. Experimental Methods

Fig. 1 shows a schematic of the experimental set-up. The pentagon-shape sonoreactor consisted of a stainless steel reactor and five ultrasonic transducer modules (Mirae Ultrasonic Tech.) which was placed on each side wall. Each transducer module contained three lead zirconate titanate (PZT) transducers (Tamura) which could produce four frequencies of 35, 72, 110, and 170 kHz. The ultrasound of one of four frequencies was irradiated from five side walls and concentrated at the center of the reactor. A 400 mL pyrex vessel containing target materials was placed at the upper position of the sonoreactor. The reactor was filled with 5 L of tap water and the water temperature was maintained at 25 ± 2 using recirculation cooling system.

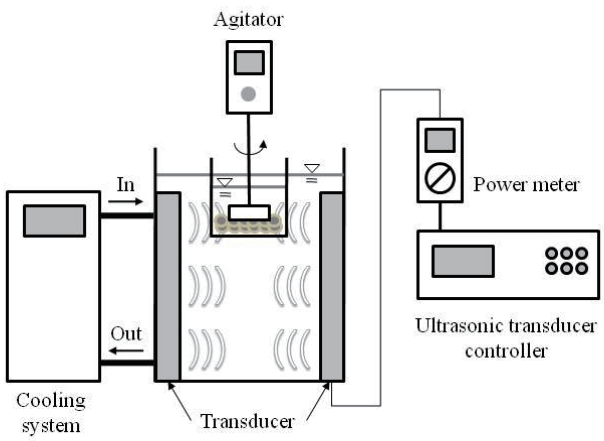

Fig. 1 Schematic of sonoreactor for soil washing processes.

The electric input power for the whole sonoreactor was measured by a multi-meter (M-4660M, METEX). The water temperature in the vessel was measured for calorimetry during ultrasound irradiation using a thermometer (DTM-318, Tecpel) and effective ultrasonic power in the vessel was obtained using following equation:

$$Ultrasonic\ Power = (dT/dt)\, c_p\, M \qquad (1)$$

where dT/dt was rate of temperature increase in the solution, c_p was heat capacity of solution (water), M was mass of solution

Joomunsin sand commercially available in Korea was sieved to the particle size of 0.24~2 mm. The sieved soil was contaminated with diesel and then aged over 15 days in the dark vessel at room temperature. The initial concentration of diesel in the soil was 20,000 mg/kg.

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For all experimental sets the soil-water ratio was 1:3 (a 10 g of soil was used) and mechanical mixing using agitator with Teflon blade was applied at the speed of 50 and 100 rpm. The electric power consumed by agitator was measured using the multi-meter. After 1 min washing process the residual diesel concentration in terms of total petroleum hydrocarbons (TPH) was measured according to the Korean standard method for soil pollution. The slurry sample in the vessel was dehydrated using anhydrous sodium sulfate and then residual diesel was extracted from the soil using dichloromethane under ultrasonic irradiation for 10 min. The extraction solution was filtered by disposable syringe filter and injected into a gas chromatography (Agilent Technologies 6890N) equipped with a flame ionization detector and a DB-TPH column (30m × 0.32mm × 0.25 mm).

3. Results and Discussion

Fig. 2 shows removal efficiency of diesel from contaminated soil for ultrasonic soil washing and ultrasonic/mechanical soil washing under various conditions. Low removal efficiencies were obtained in ultrasonic soil washing while relatively high removal efficiencies were observed in ultrasonic and mechanical soil washing. High removal efficiency in ultrasonic and mechanical soil washing was resulted from physical effects such as micro-jet and micro-streaming induced by ultrasonic cavitation. These sonophysical effects could enhance mass transfer of diesel from soil to aqueous phase and enable to remove the pollutant inside the pore which hardly desorbed by mechanical mixing.

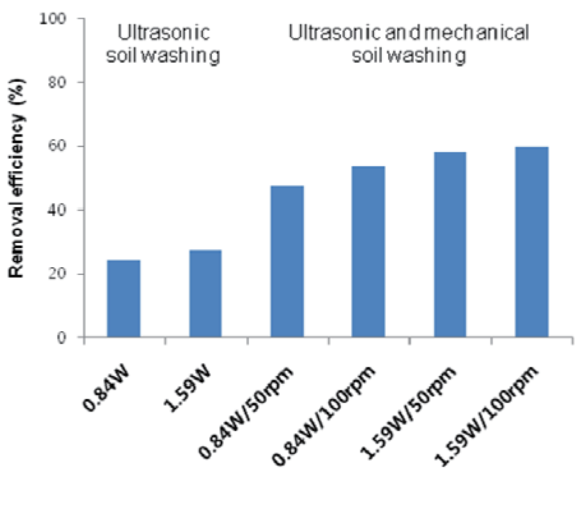

Fig. 2 Removal efficiency under ultrasonic and ultrasonic/mechanical soil washing conditions.

Fig. 3 shows the removal efficiency for electric energy consumption under various conditions. The mixing speed was 50 and 100 rpm and electric energy consumptions for 50 and 100 rpm were 2.00 and 2.70 W, respectively. In ultrasonic and mechanical soil washing increase of energy for mechanical mixing resulted in about 6 % increase of removal efficiency at ultrasonic energy of 0.84 W while at ultrasonic energy of 1.59 W increase of mechanical mixing did not make any significant increase.

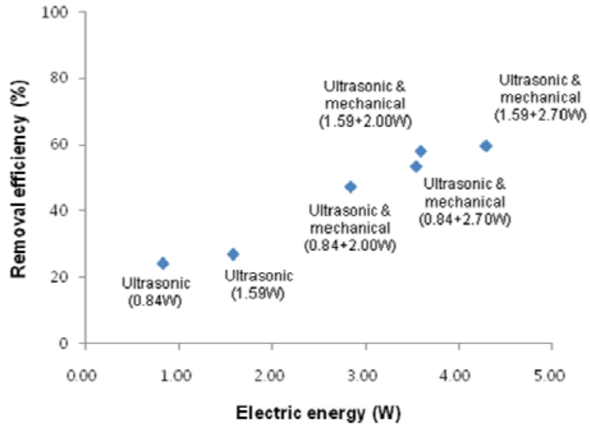

Fig. 3 Removal efficiency for electric energy consumption under ultrasonic and ultrasonic/mechanical soil washing processes.

Acknowledgment

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