Ultrasonic enhancement for remediation of diesel-fuel contaminated soils

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개요 : 본 연구는 유류로 오염된 지반을 개선하는데 초음파를 사용한다는 점에 초점을 둔다. 초음파의 원리는 고체의 재료가 음파의 좋은 전도체라는 사실에 근거를 두고 있다. 초음파에 의한 정화는 초음파의 적용에 의해 재료의 표면이 변화되고 그것에 의해 오염물질이 제거된다는 것을 의미한다. 본 연구에서는 초음파의 지속, 간극률, 초음파력, 입자의 크기와 유속율 같은 초음파 취급에 영향을 끼치는 요소들을 고려하여, 초음파를 쓴 것과 쓰지 않은 오염된 흙을 다룬 결과를 비교 분석하였다.

주요어 : 초음파, 유류, 오염된 지반

1. Introduction

A considerably amount of diesel fuel may spills in the ground due to possible leakage of diesel fuel from underground storage tanks, gas station, or military facilities. The contaminated soils should be remediated because it may penetrate to ground water and soils through subsurface water flow.

Nowadays, ultrasonic extraction is merging as an alternative to develop more rapid extraction technique. Ultrasonic mechanism in geotechnical field is widely used for extraction of chemical compounds from contaminated soil and ground water. The ultrasonic principle is based on the fact that solid materials are good conductors of sound waves. Ultrasonic treatment involves changing the surface of soil particles in contaminated soils by the application of ultrasonic principle, thereby removing contaminants. It is primarily the removal of contaminants from surface of soil particles through the ultrasonic treatment of ultrasonically which is induced cavitation. Cavitation accelerates both chemical and physical reactions, which is why it is a preferred extraction technique.

Although the use of ultrasonic waves to remediate contaminated soils has received considerable attention in recent years, most of the investigations found that ultrasonic principle was able to enhance the remediation of contaminated soils. Feng and Aldrich [3,4] investigated that the influencing factors on contaminant extraction using ultrasonic such as ultrasonic power intensity, duration, and particle size. Kim Young-Uk et al. [5] had test result that indicated ultrasonic can enhance contamination removal considerably and the degree of enhancement depends on ultrasonic power, water flow rate, and soil density. Y. U. Kim and M. C. Wang [6] concluded that the rate of removal efficiency increased considerably with increasing sonication power up to the level where cavitation occurred and also the effectiveness of sonication-enhanced soil flushing can be expressed as a function of $(D_{10})^2 * i$, in which D_{10} is the effective grain size, and i is the hydraulic gradient.

This study focused on using ultrasonic waves to enhance diesel fuel extraction in soil flushing method. In this study, the result of the treatment of contaminated soils without and with ultrasonic waves is being compared and the influence factors on ultrasonic treatment such as duration of ultrasonic, ultrasonic power, particle size, void ratio and water flow rate are considered.

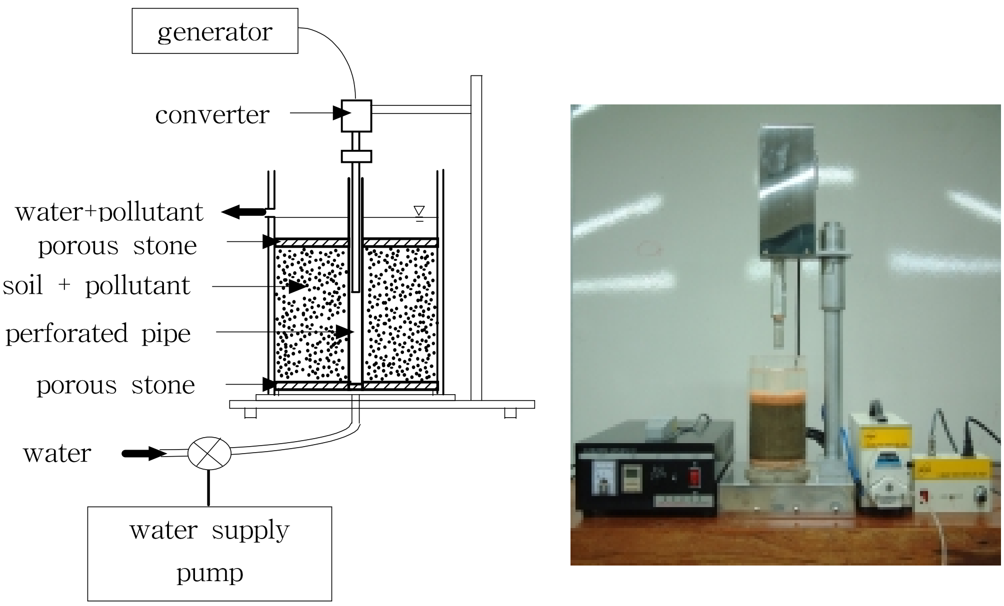
2. Experimental Scopes

2.1. Experimental setup

The series of laboratory experiments were conducted using the testing apparatus shown in Fig. 1. It is composed of two parts, ultrasonic processor and plexiglas cylindrical chamber.

The ultrasonic processor was composed of a generator and a ultrasonic horn with a corresponding power requirement up to 700watt and a frequency of 20kHz. The generator converts main voltage to high frequency of 20kHz. The tip of ultrasonic horn, one inch in diameter, generates sound waves which induces the cavitation.

The Plexiglas cylinder has 15cm in diameter with 20cm in height. The bottom of cylinder was provided an inlet for flowing water from the water reservoir to the soil sample which was placed in the cylinder. The test soils are mixture of sandy soils and diesel fuel with 10% concentration by soil volume. Those test soil had a diameter of 15cm and a height of 10cm.



(a) Detail of test chamber set-up (b) Ultrasonic processor set-up

Fig. 1. Schematic of ultrasonic testing apparatus

2.2. Materials

The physical properties of test soil is shown in the Table 1. The dry sandy soil was given the initial water content of 12% prior to mixing with the diesel fuel. The diesel fuel used in the experiments as contaminants was commercial goods obtained from a gas station. Distilled water was used in all the experiments.

Table 1. Physical properties of test soils and contaminants

Parameter	Test soil
Specific gravity (Gs)	2.64
Uniformity coefficient (C_u)	2.68
Effective grain size (D_{10}), mm	0.25
Void ratio (e)	0.86
Unified soil classification	SP
Density of diesel fuel, g/mL	0.8074±0.00028

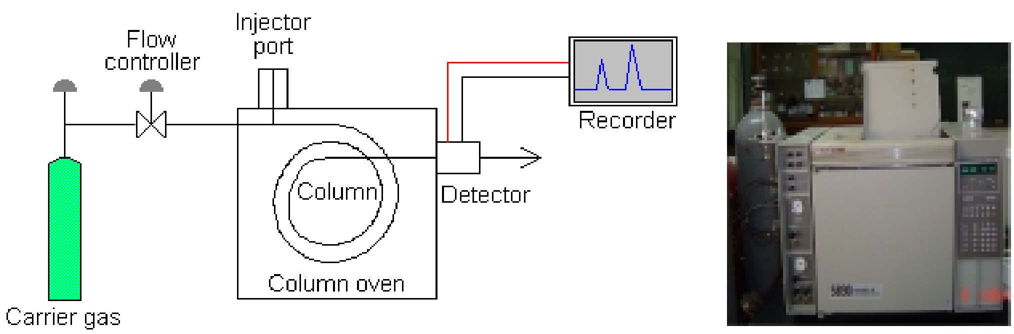
2.3. Test Procedures

The experiments were conducted without ultrasonic waves and with ultrasonic waves in parameter as in the Table 2.

The premixed soil was placed into the Plexiglas cylinder. The soil columns were allowed to be saturated by water and the water level was maintained at the top of the test soil. After the saturation, the tip of ultrasonic horn was inserted to the test soil and it was subjected to ultrasonic waves at 20kHz frequency. While the treatment processes, the distilled water was allowed to flow through the test soil. The effluent was collected and the volume of diesel fuel removal were then measured.

Table 2. Parameter of experiments

Parameter	Test soil
Density of test soils, kN/m^3	14.15
Frequency of ultrasonic wave, kHz	20
Power of ultrasonic, W	462 ; 528 ; 616
Particle size of test soil	#40-20 ; #60-40 ; #100-60
Water flow rate, cm/sec	4.5 ; 14.5 ; 23.6
Time duration of soil treatment, min	3 ; 6 ; 10 ; 12 ; 15



(a) (b)

Fig. 2. Testing process of gas chromatography (a) and gas chromatography testing apparatus (b)

The measurement of diesel fuel removal were using two kinds of measuring methods. First, for the effluent of soil treatment without ultrasonic, it was allowed to stand overnight for gravitational segregation of water and diesel fuel, afterward the volume of the separated diesel fuel was measured. Second, the amount of extracted diesel fuel with ultrasonic was determined by gas chromatography (GC) as shown in Fig. 2 and the percentage of diesel fuel removal was calculated.

Before the GC test, effluent was prepared first. The effluent was stirred about 30 sec using magnetic stirring to make the homogeneous solution. Sample of effluent was taken during the stirring. Afterward, 4 mL of Hexane was added to 2 mL of sample, and those mixture was then shake using shaking machine for 2 min.

Measurement of the diesel fuel in the effluent was performed by GC (HP 5890 series II). In this test, 6mL of mixture of effluent with hexane were concentrated to 1μL sub-sample was injected in the injection port to the column HP 5 MS (Crosslink 5% Ph ME Siloxane), on a 30m column (0.25mm in diameter, 0.25μm film thickness). The oven was programmed from 50°C(5 min) and increased at 20°C/min to 280°C (4 min) then maintained at 295°C. The carrier gas, Helium (1mL/min) and Nitrogen (30mL/min), are used at a column.

3. Results and discussion

The major factors that may influence the effect of ultrasonic enhancement on diesel fuel removal were investigated through a series of laboratory testing.

The effect of the time duration of treatment is shown in Fig. 3, Fig. 4, and Fig. 5. The percentage of contaminant removal is plotted against time duration of treatment for both without and with ultrasonic at 462W power for all of range of particle sizes. These graphics show increasing the duration time of treatment for both without and with ultrasonic and for all sizes are followed by increasing the contaminant removal. In the initial stage of process, the increasing contaminant removal is high because the diesel fuel was bonded around the surface of particles, thus the bonded can be extracted easier. During the ultrasonic treatment, the hydrocarbons are desorbed from the particle surfaces and contaminant-water emulsions are generated. Also, that figures show the effect of void ratio of soil in removal of diesel fuel from soil. The contaminant in a soil with a higher void ratio can be removed more easily than a soil with a lower void ratio. As shown in Fig. 6, apply the ultrasonic waves can enhance the removal of contaminant more efficient in the larger particle size of soil.

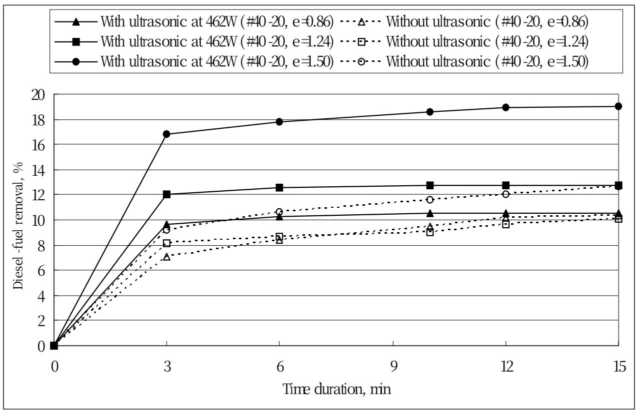


Fig. 3. Time duration vs diesel-fuel removal for range particle size of #40-20

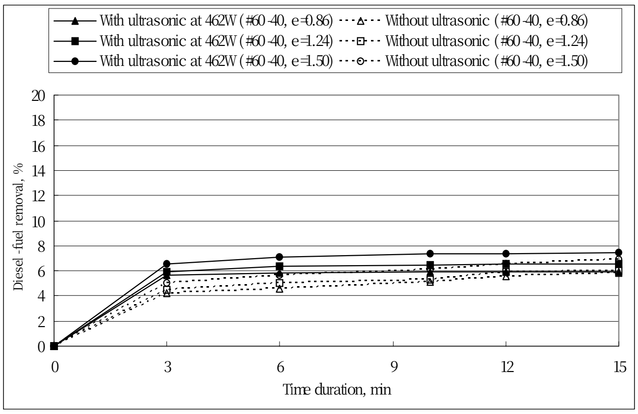


Fig. 4. Time duration vs diesel-fuel removal for range particle size of #60-40

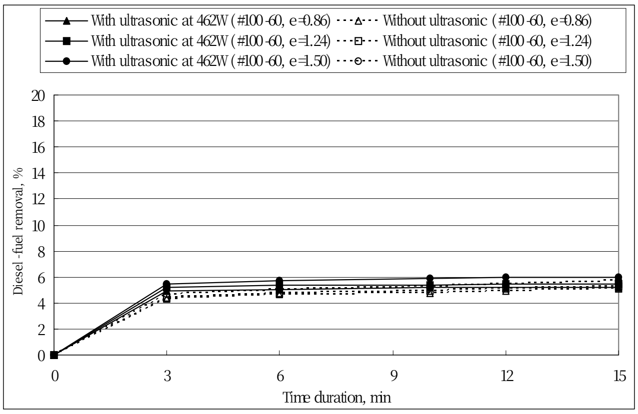


Fig. 5. Time duration vs diesel-fuel removal for range particle size of #100-60

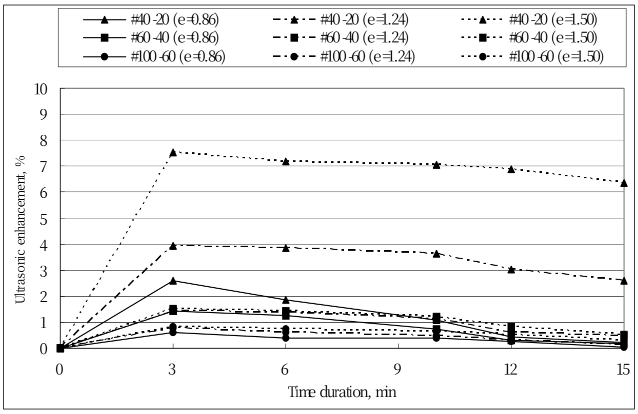


Fig. 6. Time duration vs ultrasonic enhancement for all of particle size

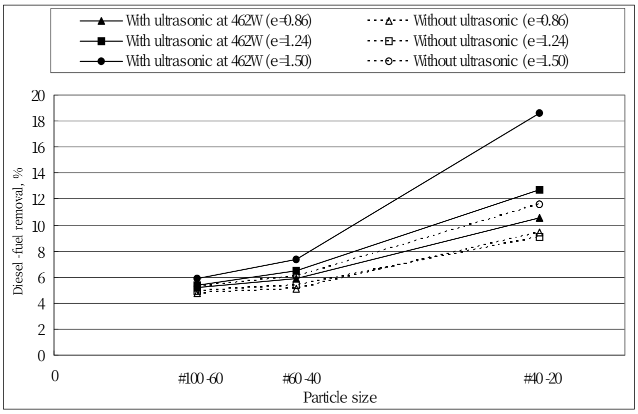


Fig. 7. Particle size vs diesel fuel removal

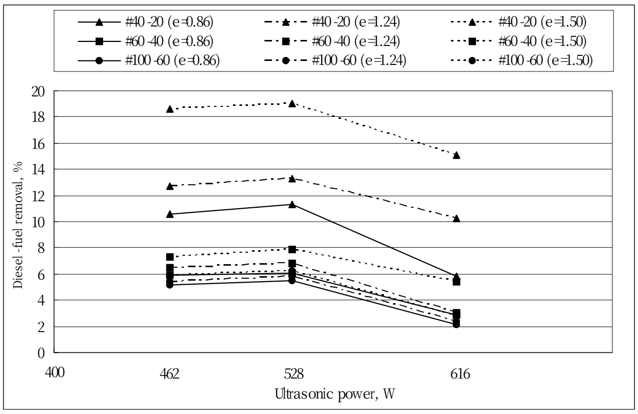


Fig. 8. Ultrasonic power vs diesel-fuel removal

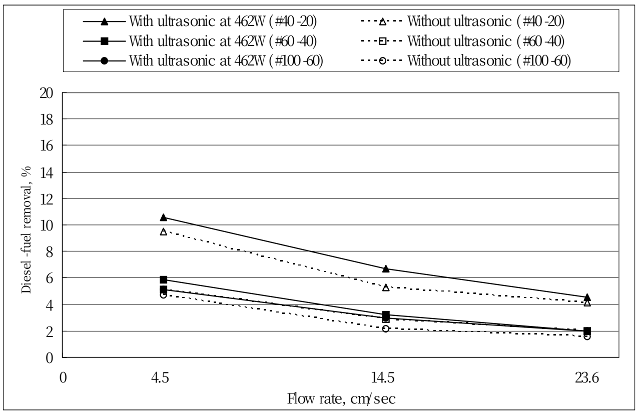


Fig. 9. Water flow rate vs diesel fuel removal

The effect of the soil particle size is shown in Fig. 7. Contaminated soil treatment in time duration of 10 minute, for both of without and with ultrasonics at 462W, the contaminant removal decreased with a decrease in particle size. As reason, the finer particles had larger surface areas per unit mass and thus more adsorption sites were available for bonding of the contaminants. The sand samples were treated with different ultrasonic power, as shown in Fig. 8. The ultrasonic treatments for particle size of #60-20 in the time duration of 10 minute showed an increase in contaminant removal with an increase in ultrasonic power and followed by a gradual decrease after a certain point. The drop in diesel fuel removal beyond 528W can be caused by the cavitation effect. When cavitation occurs, the swarm of minute air bubbles may impede upward diesel fuel flowing thus diesel fuel removal is dropped.

The effect of water flow rate in soil treatment is shown in Fig. 9. The faster the water flow rate will decrease contaminant removal. The slower water flow has longer time to interact with contaminated soil, so that the slower water flow is more efficient to remove contaminant than the faster one.

4. Conclusions

The results obtained indicated that with an application of ultrasonic waves during flushing, the diesel fuel extraction could become more effective method for remediation of contaminated soils than without ultrasonic waves. The removal efficiency depends on a number of factors such as particle size, void ratio, ultrasonic power and water flow rate.

The efficiency of diesel fuel removal was significantly affected by particle size rather than other factors. For the same void ratio of soil column (e=1.50), the largest particle size of soil has the ultrasonics enhancement rate around 7% and for the smallest particle size of soil is around 0.8%.

For further study, the other influencing factors of ultrasonic treatment on the contaminated soil could be investigated to develop the evaluation of ultrasonic effect on diesel fuel removal.

5. Acknowledgements

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