〈論　文〉

점토질 모래에서의 Ultrasonic을 이용한 투수성의 증진
Ultrasonic Enhancement of Flow in Clayey Sands

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Abstract☐ Remediation technology becomes an issue in enviromental engineering. The vibro-recovery technique is one of popular means to remove pollutants from contaminated soils and groundwater. Using Ultrasonic excitation in soil-fluid medium, it was found that removal efficiency in a mechanical effects was significant. In this paper, therefore, laboratory experiments were conducted on clayey sand soil columns using a probe-type ultrasonic prpcessor.

Ultrasonic treatment with simultaneous pumping enhances dislodgement of clay particles, and ultrasonic excitation reduced the proportions of finer particles and thus result in increased hydraulic conductivity significantly. Also, the results provided the changes in grain size distribution curve of the soil due to ultrasonic excitation The results indicated that the maximum size of particles mobilized by Ultrasonic is about 0.004㎜ and particles in the size range from 0.04㎜ to 1.0㎜ were subjected to fracturing.

The economic feasibility of Ultrasonic implementation is considered in power requirement of the generator and maintenance of the horn. At a specified amplitude of vibrations, the power requirment of the generator depends on overburden pressure of the horn, temperature and viscosity of fluid in the soil medium. For comparisons, the power requirement of a one inch and two inch diameter horn sonicators are compared with the power required for pumping water from different depths.

요　지 : 매립이 완료된 Landfills이나 오염된 지하수의 오염물질을 제거하여 다른 용도로 재사용하는 기술이 오늘날 중요한 문제로 대두되고 있다. 진동을 이용하여 제거효율을 높히는 방법은 요즙 흔히 사용되고 있는 방법중의 하나이다. Ultrasonic의 효과를 사용함으로써, 기계적인 제거효과가 대단하다는 것은 이미 몇몇 연구자들에 의해 확인된바 있다. 이 연구에서는 Probe-Type Ultrasonic Processor를 사용하여 Clayey-Sand Chamber를 가지고 실험을 해보았다. 실험중 계속적인 Pumping과 함께 Ultrasonic을 작동시킨 결과, Clayey입자들의 분리 및 제거에 큰 효과를 얻었으며, 그로 인하여 투수계수가 크게 증가하는 효과를 보았다. 또한, 실험 전과 후의 입자크기의 분포도가 크게 변했는데, 그 이유는 Ultrasonic의 진동효과 때문이다. 실험결과, 0.004㎜ 이하의 입자들은 Ultrasonic의 효과에 의해 Mobilize되었으며, 0.04-1.0㎜의 입자는 부서져서 작은 입자로 되었다.

이 기구를 사용하기 위한 유지비와 전력비등을 고려하여 이 기구의 실용성을 검토해 보았다. 필요한 Power를 위해 요구되는 전력의 양은 깊이에 의한 대상 site의 응력, 온도, 그리고 Fluid의 Viscosity에 의해 좌우되며, 그중 가장 큰 영향을 미치는 요소는 흙의 깊이이다. 여러가지의 다른 깊이에서의 경제적인 실용성을 1.0, 2.0in 직경의 Horn Sonicator를 사용했을 경우에 대하여 비교와 분석을 하였다.

INTRODUCTION

Low-permeability lenses in an otherwise homogeneous geologic setting pose significant problems in any groundwater remedition projects. By virtue of their large surface area, low-permeability sediments accumulate greater amounts of contaminants than like volumes of high permeability sediments. Thus, significant amount of contaminant reserves remain trapped in heterogenous settings and retard pumping effi-

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ciencies. The contaminant reserves will be gradually released to the high permeable zones over a long period of time under diffusion-controlled conditions. Also, in in-situbioremediation projects that require the injection and delivery of nutrients to the zone of intended action, access to contaminants in low-permeability zones are extremly usefull, and urgently needed, in the remediation industry.

In this paper, results are pressented from laboratory experiments involving hydraulic modification of clayey sands due to Ultrasonic excitation. Ultrasonic engineering found its applications in almost every segment of moden industry[5,6]. Studies of Ultrasonic applications in soil science are few and are yet in conceptual stages. Busacca et al. [3], lin their laboratory studies, showed the efficiency of Ultrasonic generators in dispersing minerals from laboratory sand samples. Through similar studies, Beard and Stulen [1] concluded the viability of ultrasonic generator as down-hole devices to treat skin damage. Muroduch et al. [7], in a cursory attempt to determine the effect of ultrasonic excitation on the mixture of clay and sand, conducted falling head permeability tests on sandy clay samples in ultrasonic cleaning chambers. They observed that the hydraulic conductivity of samples increased abruptly from 3.8×E-4cm/sec to 1.8×E-3cm/sec upon 30 seconds of ultrasonic excitation. Recent test by Cole et al.[4] indicate that ultrasonic washing of soils containing semi-volatile organics (anthracene, pentachlorophenol, and dioctylphthalate) can achieve satisfactory contaminant removal(99%). These tests were all conducted on soil samples in Ultrasonic chambers and as such provided no indication of potential in-situ applications of ultrasonic. The purpose of this report is to show laboratory test results which indicate the feasibility of enhancing flow in clayey sands using a horn-type sonicator. The practical implications of these results, and technical and economic feasibility of in-situ applications of ultrasonics are discussed.

THEORY

Remediation technology is the best issue concerning the recovery of polluted areas of the land. Several technics that have been used by most related companies are all drainage methods and the vibro-recovery system. Generation of ultrasonic waves has several mechanical, chemical, and biological effects on the medium. Its mechanical effect, popularly known as cavitation, is of particular relevance in the present context. Cavitation is the rapid and repeated formation, and resulting implosion, of microbubbles in a liquid, resulting in the propagation of microscopic shock waves. At high enough intensity, these alternating pressure and vacuum waves cause microbubbles to grow. This is however, a transient situation, in which the compression wave only last for one forty-thousandth(1/40,000) of a second for the ultrasonic probes. Since the liquid temperature is below the boiling point, there is insufficient energy to sustain the vapor phase and it condenses back to the liquid phase, leaving behind a void. The surrounding molecules as a shock wave. The number of cavitation bubbles collapsing per second can will be in the millions; hence their cumulative effect can be significant. In a soil-fluid medium, these cavitational bubbles generate high differential fluid-particle velocities. The velocity perturbations occur on a microscopic scale and are capable of dislodging micron-size clay particles in the system by overcoming the factors binding clay to particles.

EXPERIMENTAL METHODOLOGY

Laboratory experiments are conducted using a sonicator(probe-type ultrasonic) shown in Fig. 1. A power supply converts conventional 50 or 60Hz alternating current to 20KHz electrical energy. This high-frequency electrical energy is fed to a convertor consist of two or more titaniate crystals which transmit the excitations to the titanium alloy horn. The tip of the horn, one inch in diameter, generates sound waves creating the process of cavitation. A maximum tip amplitude of about 60 microns is achieved with this horn with a corresponding power requirement of 800 watts.

The experimental set-up is shown in Fig. 2. Mixtures of commercial sand and natural New Brunswich clay were prepared in 6 inch diameter plexiglass columns at desired density. Premixed soil were compacted at 24cm hight by standard static compaction method(ASTM D698). The soil columns were allowed to be saturated by water. After the saturation, the tip born of ultrasonic is inserted through the soil column. Grain size distributions of representative samples were obtained by conducting sieve and hydrometer analysis in accordance with ASTM D422. Figures 4 and 5 show the typical grainsize distributions of the clay-sand mixture used in the experiments. The soil column was saturated by pumping water from bottom of the sample. Ultrasonic probe was then inserted with minimal excitation(to faciliate the insertion). Saturated hydraulic conductivities of soil were measured using falling head test prior to ultrasonic treatment. Under the heads used in the process of permeation, no dislodgement of clay particles was observed. The treatment is then conducted incrementally with hydraulic conductivity measured at the end of

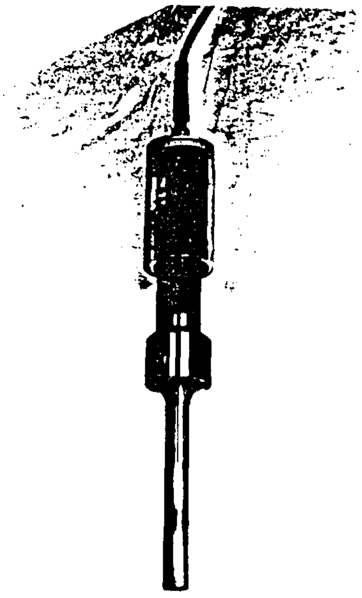

Fig. 1 Ultrasonic Processor

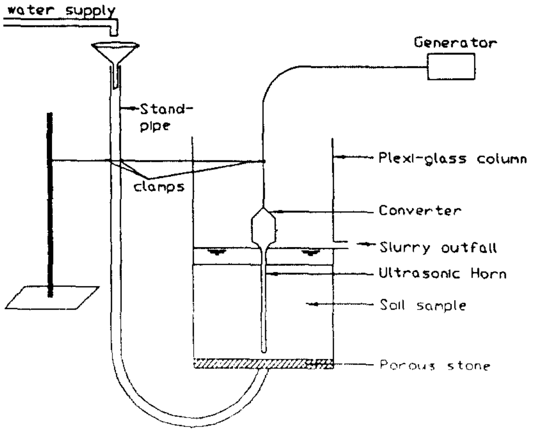

Fig. 2 Experimental Set-up

every time increment. In test series 3 and 4, continuous flow throgh the soil column under a hydraulic head of 20cm was maintained during ultrasonic excitation. This is to check the beneficial effects of augmenting cavitation with hydraulic gradients. At the ent of each test, representative soil samples at three levels of the column away from the probe were taken for grain size distribution and hydrometer analyses. Hydrometer analyses were also conducted on the effluent slurries obtained during treatment.

RESULTS AND DISCUSSION

Figure 3 shows the hydraulic conductivities at the end of every treatment increment for the tests. A summary of test results is shown in Table 1. An increase in hydraulic conductivity was observed in all the tests with the maximum reaching after about 8 to 10 minutes of excitation. The relative increase in hydraulic conductivity differences between test 1 and 2, and 3 and 4 show that ultrasonic treatment with simultaneous pumping enhances dislodgement of clay particles. Increasing amplitude of the ultrasonic vibrations resulted in sharp increases in the initial hydraulic conductivities but has no influence in the final stages of experiments. As can be expected, enhancement of hydraulic conductivity is inversely proportional to the density of the soil. It is important to note that the hydraulic conductivity measurements in Fig. 3 possibly include probe–soil interface leakages; however, visually it was noticed that the probe remained in tact througtout the duration of the experiments. The hydraulic conductivity measurements are also justifiable considering that the intent of the experiments is a relative comparison and not an absolute prediction.

The changes in grain size distribution curves of the soil due to the ultrasonic excitation are presented in Figures 4 and 5 for third and fourth

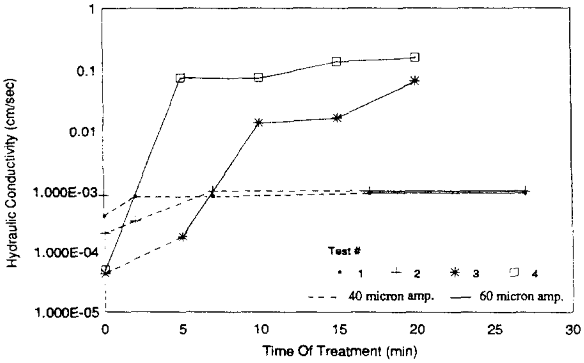

Fig. 3 Variation of hydraulic conducfivity with of ultrasonic treatment

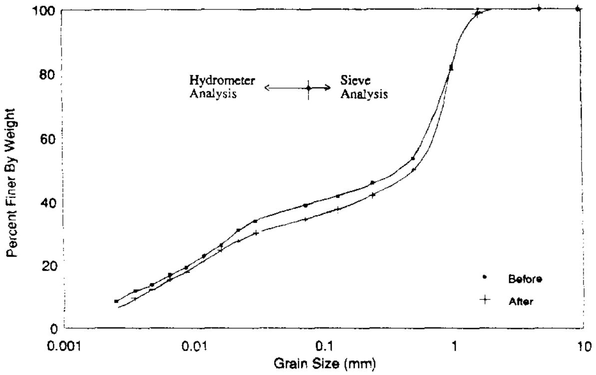

Fig. 4 Grain size distribution of soils in test series 3 before and agter ultrasonic treatment

TABLE 1. SUMMARY OF HYDRAULIC CONDUCTIVITY TEST RESULTS

Test Series No	Dry Density of Soil(pcf)	Time of Treatment (min.)	Hydraulic Conductivity(cm/sec) Before	After
1	121.48	27	3.87×10^{-4}	9.3×10^{-4}
2	111.25	27	2.0×10^{-4}	1.0×10^{-3}
3	104.47	20	4.29×10^{-5}	6.73×10^{-2}
4	102.95	20	4.98×10^{-5}	1.60×10^{-1}

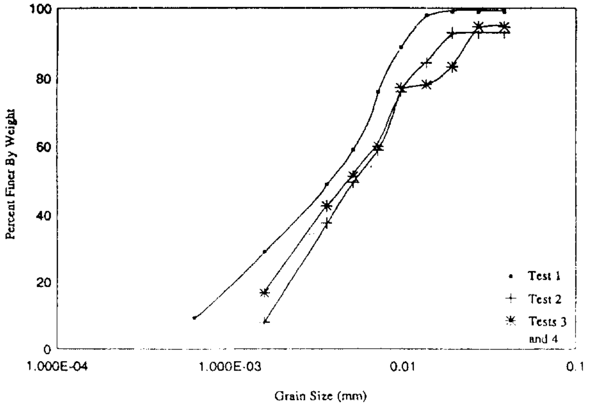

Fig. 5 Grain size distribution of soils in test series 4 before and agter ultrasonic treatment

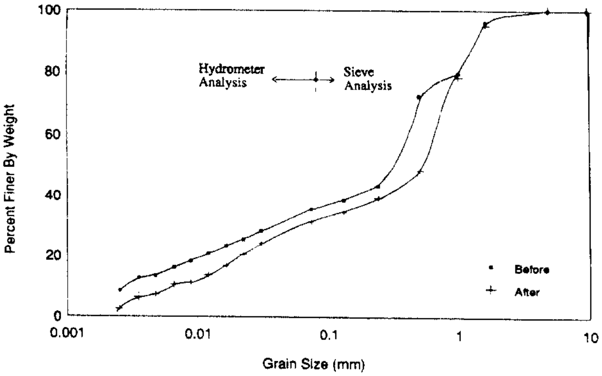

Fig. 6 Particle size distribution of effluent slurry

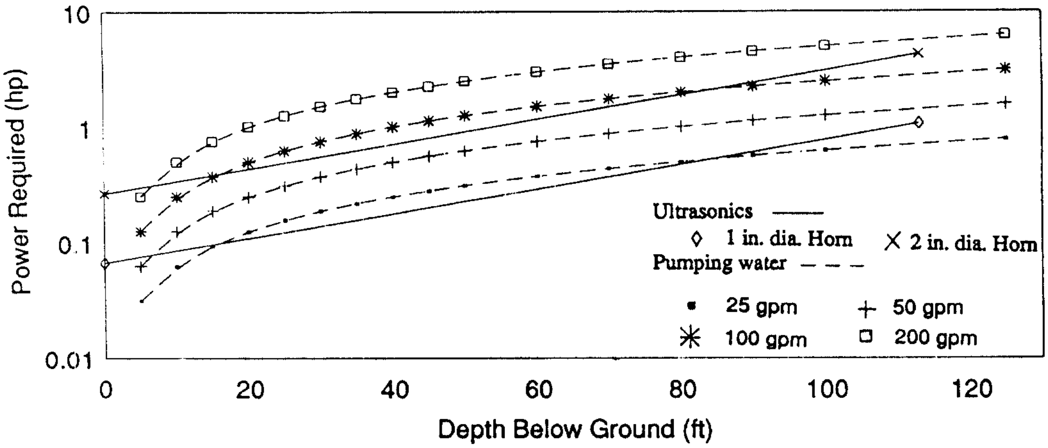

Fig. 7 Comparison of powers required at Various depths of treatment
i)by ultrasonics and ii)to pump water at various rates

test series. These figures show that ultrasonic excitaton reduced the proportions of finer particles and thus provide an explanation for higher hydraulic conductivities. The grain size distribution curves also show that, after the ultrasonic treatment, a decrease in fine particle propotions did not result in a corresponding increase in coarser fractions. This is attributed to the abrasion and/or fracturing of sand-sized grains due to ultrasonic which has been observed by previous investigators including Busacca et al. [3]. Results from hydrometer analyses of the effluent slurry are shown in Fig. 6. These show similar particle size distributions for all the tests and indicate that the maximum size of the particles mobilized by ultrasonic is about 0.004㎜. A comparison of figures 4, 5, and 6 indicates that particles in the size range 0.04㎜ to 1.0㎜ were subjected to fracturing.

PRACTICAL IMPLICATIONS AND CONCLUSIONS

The results indicates that a horn-type ultrasonic processor can adequately enhance the hydraulic conductivity of low-permeable sediments by dislodging and/or fracturing clay and other colloidal-range particles. Several issues need to be considered in evaluating the technical feasibility of in-situ implementation. Foremost of all, the radius of influence of the cavitation process at any given depth needs to be evaluated. This would require attenuation characteristics. As suggested in the present laboratory studies, the dislodgement of clay particles can be enhanced by augmenting the cavitation process with hydraulic gradients. One possible approach is to create injection system at the tip of the horn and a withdrawal system through a well screen at the top of the horn. Simultaneous pumping and withdrawal together with ultrasonic excitation will create a flow path around the probe for an effective treatment.

The ecomomic feasibility of ultrasonic implementation depends on the power requirement of the generator and maintenance of the horn. Berliner [2] provided an excellent clarification about the popular misconception that "more power is better". This misconception may lead one to conclude that ultrasonic excitation is a costly proposition. Power is the energy required to drove the ultrasonic horn at a specific resonant frequency of the device. Intensity, on the other hand, is a measure of the energy available per unit volume of sample and is directly related to amplitude. It is the intensity of the cavitation that contributes to the beneficial effects of the ultrasonic. At a specified amplitude of vibrations, the power requirement of the generator depends on overburden pressure of the horn, temperature, and viscosity of fluid in the soil medium. Therefore, power requirement of the unit is in direct proportion of depth of treatment. For comparative purposes, the power requirements of a 1 inch and 2 inch diameter horn sonictors compared in Figure 7 with the power requirements for pumping at various rates were obtained from Crane [4]. The ultrasonic power requirements were obtained in the laboratory, subjecting the horn to various overburden stresses. The computations in Figure 7 assume the unit weight of soil to be 20KN/m. Considering that only a few minutes of treatment are needed for significant enhancement of hydraulic conductivity, the energy requirement of ultrasonic excitation are only a fraction of energy requirement for pumping.

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