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Feasibility Study on the Landfill Monitoring and Leakage Detection System

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SYNOPSIS: It is important to obtain real-time data from long-term monitoring of landfills and develop leachate leakage detection system for the integrated management of landfills. A novel real time monitoring system and early leakage detection system was suggested in this study. The suggested monitoring system is composed of two parts; (1) a set of moisture sensors which monitor the areas surrounding the landfill, and (2) a set of moisture and temperature sensors which monitor the landfill inside. For the assessment for landfills stabilization, real-time monitoring system was evaluated in dry and wet cell of pilot-site. In addition, the grid-net electrical conductivity measurement system was also suggested as early leakage detection system. In this study, the field applicability of suggested systems was evaluated through pilot-scale field tests. The results of pilot-scale field model tests indicate that the grid-net electrical conductivity measurement method can be applicable to the detection of landfill leachate at the initial stage of intrusion, and thus has a potential for monitoring leachate leakage at waste landfills.

Keywords: landfill, leakage detection, real-time monitoring, electrical conductivity

1. Introduction

The landfill leachate, mostly composed of harmful constituents can cause a contamination of soil and/or groundwater. Therefore, it is important to obtain data from long-term monitoring of landfills and develop early leachate leakage detection system on this basis for integrated management of landfills. In this study, a novel real time monitoring system was developed and evaluated for the field application. To verify its applicability in detecting the release of landfill leachate, the grid-net electrical conductivity measurement system was evaluated. Finally, a real-time monitoring was performed using a test cell in the field on the basis of the results obtained from the laboratory study. The grid-net detection system was also tested to verify its field applicability through controlled laboratory model tests.

2. Real-time monitoring system

2.1 Outline of the monitoring system

The real time monitoring system is composed of two parts; (1) a set of moisture sensors which monitor the areas surrounding the landfill, and (2) a set of moisture and temperature sensors which monitor the landfill inside. Figure 1 shows the schematic diagram of the monitoring system.

The moisture sensors are capacitance type sensors measuring the dielectric constant or permittivity of the material where they are buried. There are two types of dielectric moisture sensors. One measures the dielectric constant of a medium by finding the time taken for an electromagnetic pulse to traverse a transmission line buried in the medium. This type of sensor is called a Time Domain Reflectometry (TDR).

The other type of sensor (capacitance) measures the dielectric constant of a medium by finding the rate of voltage change on a sensor embedded in the medium. The soil moisture probes are of this type (Frequency Domain Reflectometry, FDR). The temperature sensor is thermocouple type sensor that measures the temperature difference of the material. Currently, field monitoring has been performed by measuring the moisture and temperature sensors in Y landfill in Korea.

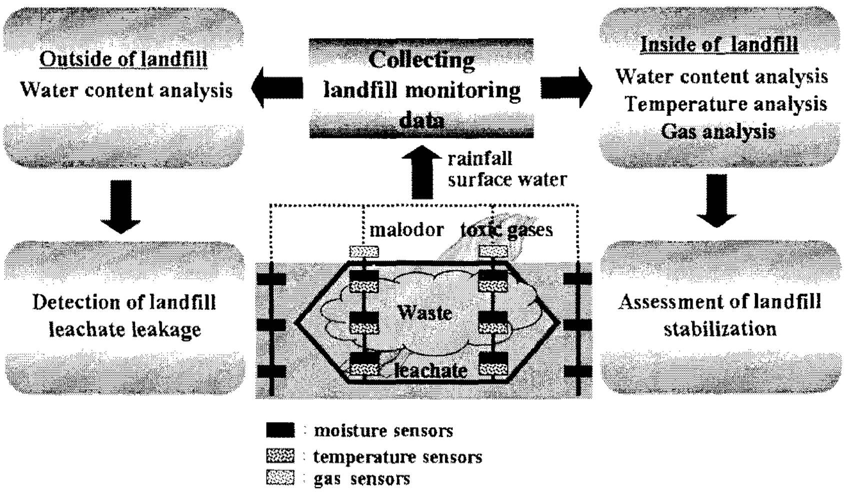


Fig. 1. Schematic diagram of the monitoring system

2.2 Ion effect on measurement of moisture sensor

Samples were prepared by mixing Jumunjin sand with deionized water or target contaminant solutions at gravimetric water content of 4%, 8%, and 12%. (The volumetric water content is 5.9%, 11.5% and 16.5%). Figure 2 shows the relationship between volumetric water content and moisture sensor output for each ion concentration. The base line shows measurement values by mixing Jumunjin sand with deionized water. The other lines show measurement values by mixing Jumunjin sand with ammonium and chloride solutions of various concentrations (100~1000 mg/L). From the test result, 400mg/L and higher concentrations of ammonium and chloride ion have gradually from base line. The higher the concentration of ions and water contents, more the moisture sensor output measurements we observed. These results can explain that the influence of ions on the dielectric constant measured by the moisture sensor are obvious and can be interpreted for the possibility of field applications.

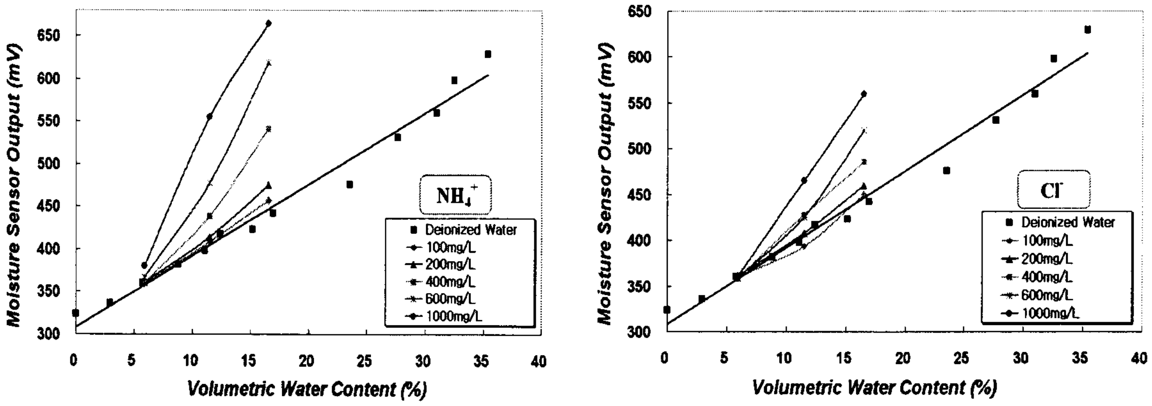


Fig. 2. Relationship between volumetric water content and moisture sensor output for each ion concentration

2.3 Pilot test

2.3.1 Field condition

For the assessment of landfill decomposition stabilization, pilot test was performed at the Y-landfill site located at Yeongwol, Gangwon province in Jan. 2007 (Fig. 3). The Y landfill has an area 9,000㎡ handling 66,000ton of municipal solid waste and it is scheduled to be close in Dec. 2012.

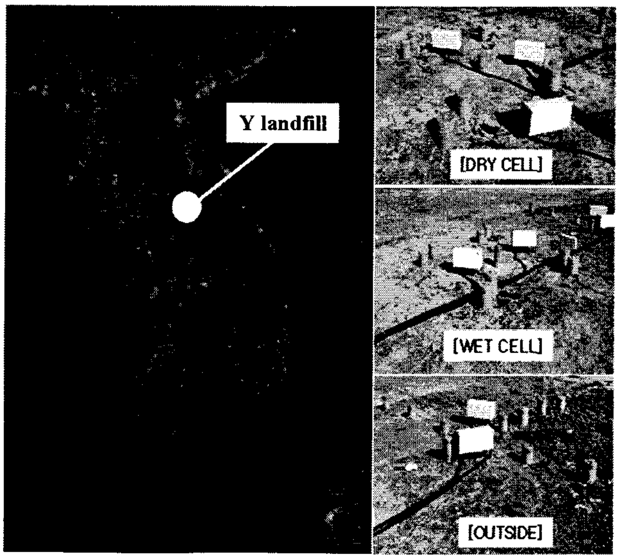
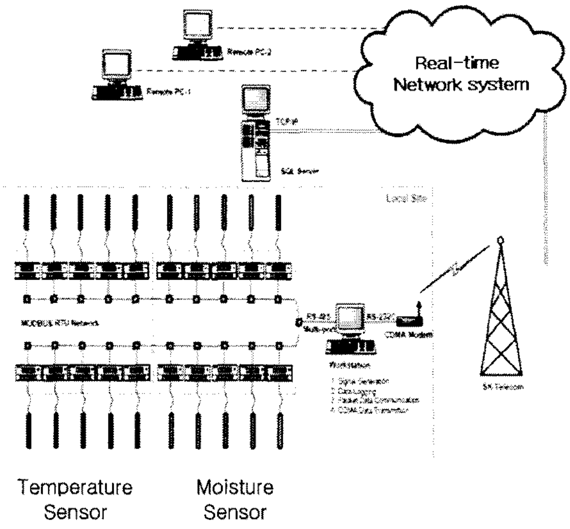


Fig. 3. Location of Y landfill and monitoring system installation

The pilot plant in Y landfill was divided into 2 types including dry and wet cell. The main difference between dry and wet cell is in having final cover installation. This final cover is to prevent the moisture intrusion such as rainfall, snow, or water supply infiltration into the cells. Inside the dry and wet cell, 4 moisture and temperature sensors were installed at G.L(-)1.5m and (-)2.5m. In the middle of each dry and wet cell, multipurpose measurement hole for gathering leachate and measuring landfill gas was installed. In addition, 3 temperature sensors were installed inside of landfill.

2.3.2 Real-time monitoring network system

Real-time Monitoring Network System (RMNS) for field monitoring and leakage detection from a disposal facility is of importance for the management of landfills. In this study, a network system has been designed for transferring field data with TCP/IP from a long distance. It allows real-time measurement of moisture contents, temperature for landfill stabilization in landfills. Figure 4 shows the schematic diagram of network system and the real-time monitoring operated with online webpage.



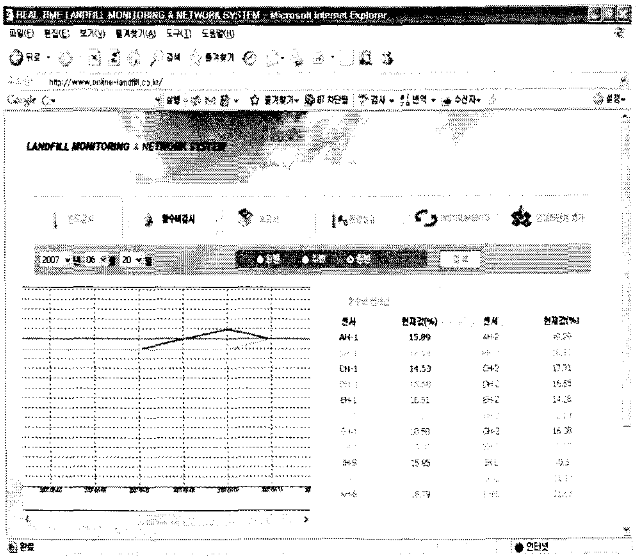


Fig. 4. Schematic diagram of network system and the real-time monitoring operated with online webpage

2.3.3 Moisture sensors monitoring results

Moisture content is considered as the most important parameter in refuse decomposition and landfill gas production. It provides the aqueous environment necessary for gas production and also serves as a medium for transporting nutrients and bacteria throughout the landfill. The overall moisture content of refuse as received at a landfill ranges typically from a low of 15 to 20 % to a high of 30 to 40 % on a wet weight basis. Typical average moisture content is 25 % (Emcon, 1975).

Figure 5 shows the field monitoring results of moisture sensors at pilot plant in Y landfill which was recorded from Jan. 1, 2007 to July 5, 2007. For the field monitoring water content, the graph was prepared by the average values of the 15 days field moisture sensors measurement data at each depth. In field measurement monitoring data, initial moisture content was measured in between 13.2 to 15.0 % in dry and wet cell. Respectively, as time passes the moisture contents of the wet cell was measured higher than that of the dry cell. As receiving rainfall infiltration the maximum value of measured water content of the wet cell was 18.5%. As expected, lower depth values are higher than the deeper depth. In order to assess the landfill stabilization more accurately, field monitoring data should be collected continuously for a long period of time.

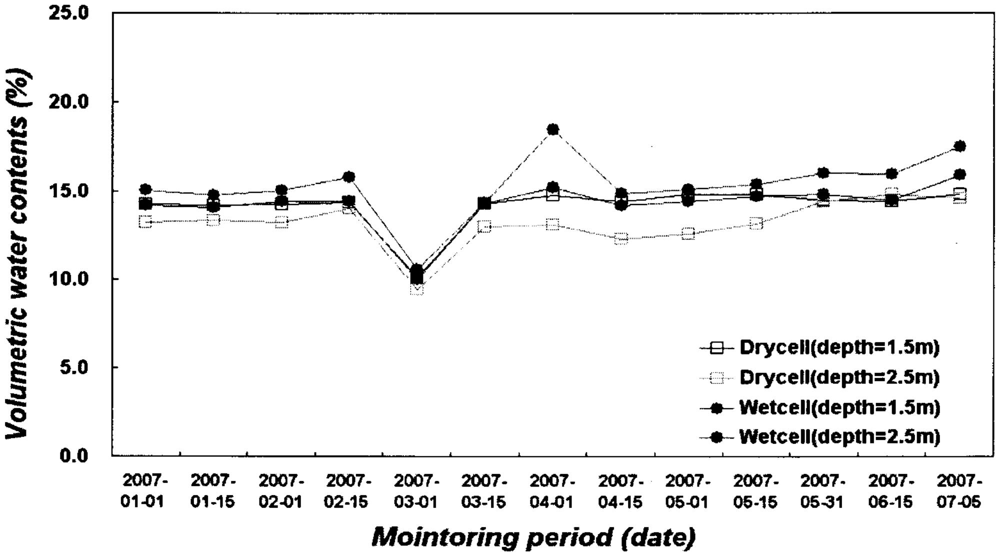


Fig. 5. The field monitoring results of moisture sensors

2.3.4 Temperature sensors monitoring results

Temperature conditions within a landfill influence the type of bacteria that are predominant and the level of gas production. As mentioned previously, the optimum temperature range for mesophilic bacteria is 30℃ to 35℃, whereas the optimum for thermophilic bacteria is 45℃ to 65℃. Thermophiles generally produce higher gas production rate; however, most landfill exist in the mesophilic range. Landfill temperatures often reach a maximum within 45 days after placement of wastes as a result of the aerobic microbial activity (Edward, 1995).

Figure 6 shows the field monitoring data of the temperature sensors present in the pilot plant in Y landfill for the same period. To obtain the temperature field monitoring, graph was prepared by the average values obtained from the 15 days of the field measurement data at each depth. In field measurement monitoring data, an initial temperature of 19.4 to 30.9℃ was measured in dry and wet cell. The temperature of the wet cell was measured higher than that of the dry cell. The field monitoring data of temperature sensors has different date for biodegradation in favor condition and will be collected continuously for a long period. Thought out the measurement, field data has been successfully collected by RMNS for further assessment of landfill stabilization.

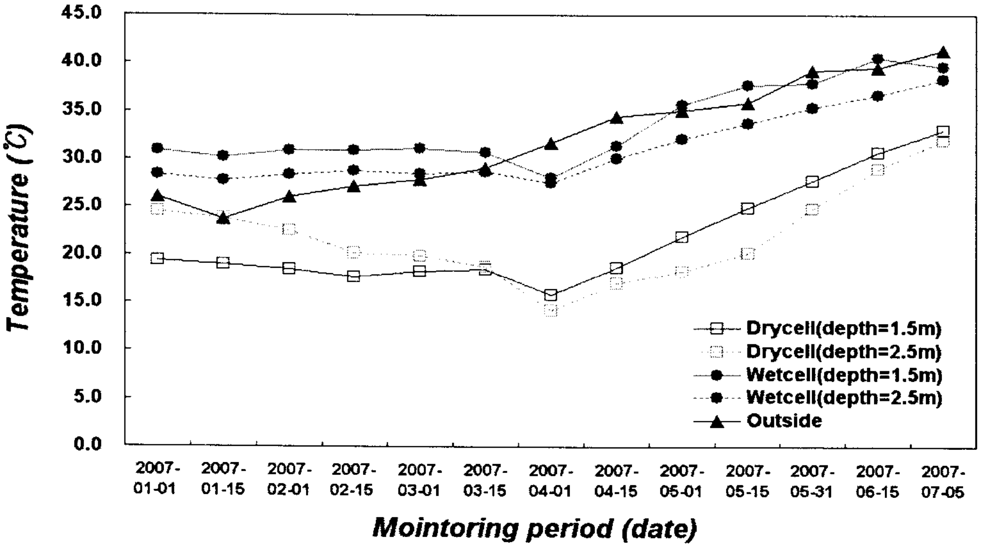


Fig. 6. The field monitoring results of temperature sensors

3. Leakage detection system adapting electrical conductivity measurement

3.1 Conventional leakage detection system

A leak detection system will locate leak points without laboratory analysis. Although the perfect vadose zone monitoring system has not yet been designed, several different types of sensors provide possibilities. These include electrical methods of measuring the voltage or current density chemical methods of analyzing soil vapor or reacting directly to leachate or using tracer chemicals to detect leaks. To date, a leak detection system based on using the electrical method is the most widely researched out of the many other leak detection systems. The established electrical method relies upon the insulating properties of the geomembrane liners (Parra 1988; Parra and Owen 1988; Colucci and Lavagnolo 1995; Frangos 1997). This method requires installing electrodes inside and outside the landfill. If the geomembrane liner is physically punctured, leaks into the underlying subsurface form conducting paths along which localized currents can flow through the liner. However, this method is applicable to landfills where an insulating geomembrane liner is installed. In order to apply a detection system without concern for the type of containment system, direct measurement of the intruded contaminants would be preferable.

3.2 Description of grid-net detection system

Contaminants influence the bulk conductivity of soil because they change the electrical properties of the soil and groundwater. Every soil type possesses a natural conductivity value within certain limits; deviations of conductivity may indicate possible subsurface contamination by leachate intrusion(Yoon et al., 2002). Such changes in electrical properties might be applicable for a detection system for leachate leakage. A detection system using electrical conductivity measurement is advantageous since measurement of conductivity is fast and little data processing is required in order to obtain accurate and repeatable results.

The schematic diagram of grid-net electrical conductivity measurement system is shown in Figure 7. The grid-net electric circuit is based on installing two perpendicular sets of horizontal electric wires in specific intervals with sensors located at their intersections. The sensors are directly installed in the subsurface to measure electrical conductivity. Measurement is performed by connecting the (+), (-) terminal of the source meter to two grid wires that lead to one of the two electrodes of a specific sensor, which completes a closed circuit. The electrical conductivity at a sensor of a closed circuit is obtained by measuring electrical potential under the application of a constant current using a source meter. Measurements at all sensors are achieved by connecting the wires to the source meter in series.

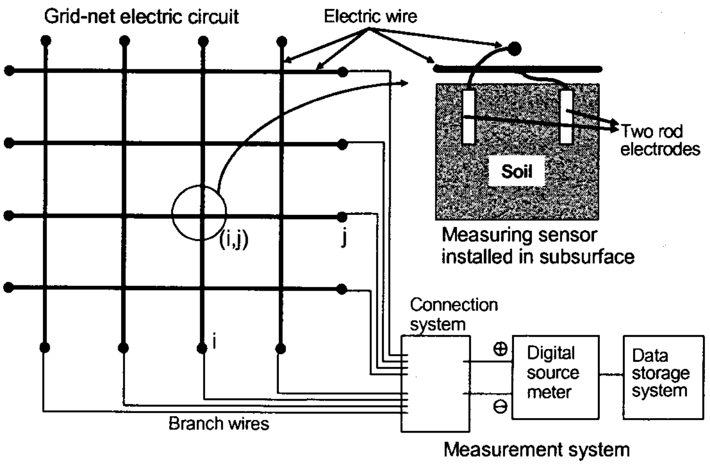


Fig. 7. Schematic diagram of the grid-net measurement system

3.3 Applicability of grid-net leakage detection system

3.3.1 Experimental Description

The prepared site for the pilot-scale model test was 11m×11m site in Seoul National University, Korea. Two perpendicular sets of ten horizontal electric wires at 1m intervals were installed at site to form a grid-net. Then one hundred two-electrode sensors were installed in the subsurface at each wire. After the installation of the grid-net electric circuit with sensors, the test site preparation was completed by connecting the branch wires of the grid-net circuit to a measuring instrument system. The digital source meter(Keithley 2400, USA) was used to induce the constant current of 0.1mA and measure the electrical potential.

Oh et al.(2003) have shown that the electrical conductivity measurement in a grid-net measurement system gave somewhat high values of electrical conductivity. In addition, when the electrical conductivity at a specific point was much higher than that of others, dummy increases in measured conductivity were developed at sensors connected to wires containing the specific point of high electrical conductivity. They have demonstrated that the dummy increases in electrical conductivity area result of electric circuit effects from the grid-net measurement system and can be effectively excluded by a process of calibration using the P-SPICE(Professional Simulation Program with Integrated Circuit Emphasis) simulation. Therefore, to obtain the actual electrical conductivity distribution excluding electric circuit effect, P-SPICE simulation was performed.

3.3.2 Effect of landfill leachate on electrical conductivity of soil

The conductivity of solutions is primarily affected by the ionic concentration, thus the proportion of landfill leachate. Figure 8 shows that the electrical conductivity of soil is also linearly dependent on the ionic concentration of the pore fluid. Dissolved cations and anions of leachate contaminated pore fluid are mobile and unbound particles that serve as charge carriers which result in an overall rise in the electrical conductivity of soil. Such relationship is clearly more apparent at greater volumetric water contents where the electric conduction through the pore fluid becomes predominant over that of the entire soil matrix. High determination coefficient values confirm that the electrical conductivity of soil is mainly controlled by the proportion of landfill leachate in pore fluid.

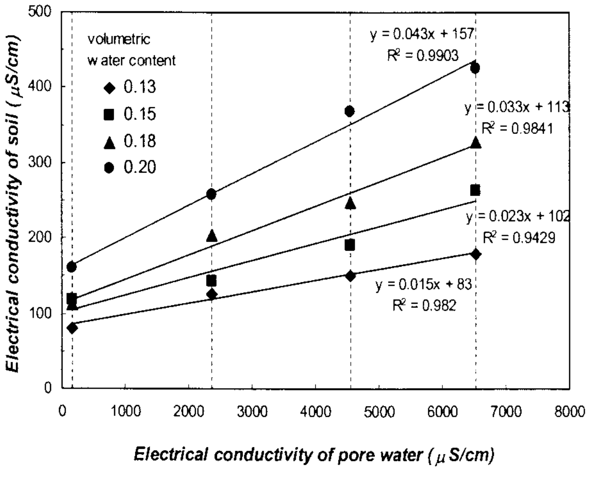


Fig. 8. Effect of landfill leachate on electrical conductivity of soil

3.3.3 Evaluation of accuracy in detecting landfill leachate

Figure 9 shows the distribution of electrical conductivity in the subsurface without any landfill leachate intrusion. In Figure 9, electrical conductivity values of the subsurface before leachate injection lie within a small range of 24.8~43.0 S/cm.

To evaluate the accuracy in detecting landfill leachate intrusion into the subsurface with the aid of a grid-net electrical conductivity measurement system, three cases of tests were performed. Case I simulates a single point release and Case II a dual point release of landfill leachate into the subsurface, respectively. Case III was performed to verify whether the differences in electrical conductivity between leachate and tap water intrusion could be distinguished.

Figure 10 and 11 show the distributions of electrical conductivity in the tested site after 1 hour after leachate release occurred. The total volume of released landfill leachate into the subsurface for 1 hour was 0.8L in case I and 1.0L in case II. Spikes in the distributions of electrical conductivity are corresponding to the locations of landfill leachate releases. While the area without any release of leachate showed constant electrical conductivity, the area with leachate release showed 10 times higher electrical conductivity. Actually, the electrical conductivities at leachate release locations increased by 487.8 S/cm for case I(Fig. 10), 632.1 S/cm and 547.6 S/cm for case II(Fig. 11), while electrical conductivities of other locations without any intrusion of leachate remain within the ranges of 22.0~44.1 S/cm and 19.7~40.2 S/cm, respectively. This result indicates that intrusion of landfill leachate is accurately identified at its initial stage by the grid-net conductivity measurement system regardless of the number of leaching points.

Figure 12 shows the results of case III. The total volume of solution used in the case III experiment was the same 2L for leachate and tap water. The local electrical conductivity in the area with the intrusion of tap water was two-fold higher than the area without any intrusion as 106.0 S/cm. The increase of electrical conductivity in the area with the intrusion of tap water was caused by the increase of volumetric water content. Although the increase of electrical conductivity was observed in the area with the intrusion of tap water, it was possible to identify the leachate intrusion because the electrical conductivity in the leachate-released area showed much higher electrical conductivity values of 538.1~612.9 S/cm. It indicates that the intrusion of contaminants with high electrical conductivity, such as landfill leachate, could be detected by electrical conductivity using a grid-net measurement system, even though slight increases of electrical conductivity may occur by the intrusion of uncontaminated clean water. Model test results show that the grid-net electrical conductivity measurement system is effective for locating leachate intrusion into the subsurface.

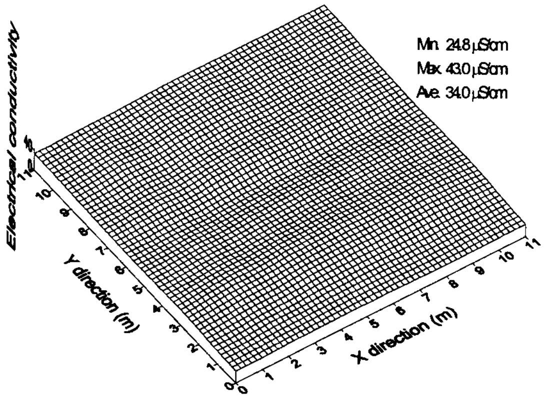


Fig. 9. The initial electrical conductivity in tested site without any landfill leachate leakage

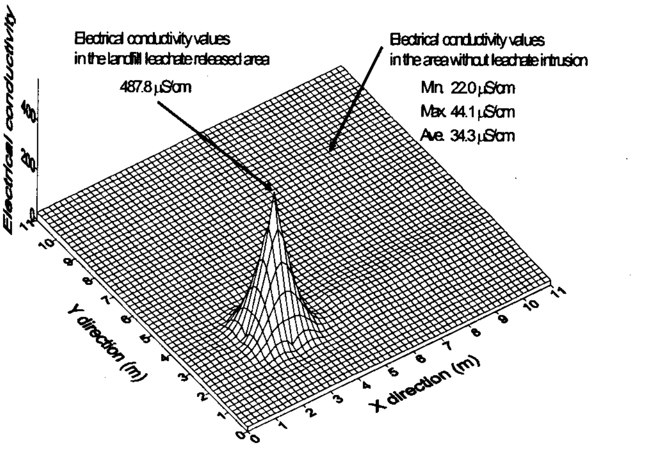


Fig. 10. The electrical conductivity in tested site 1 hour after the landfill leachate leakage occurred (Case I)

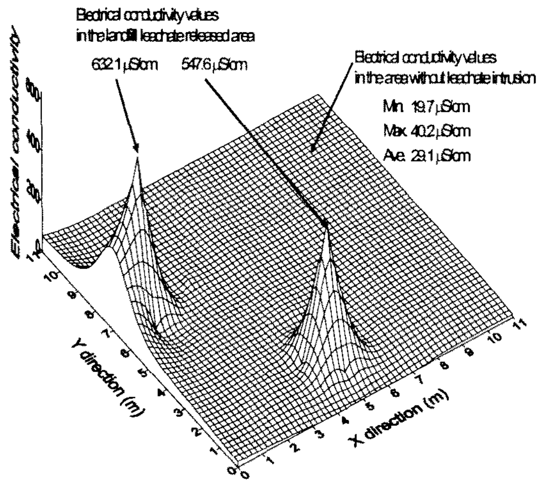


Fig. 11. The electrical conductivity in tested site 1 hour after the landfill leachate leakage occurred (Case II)

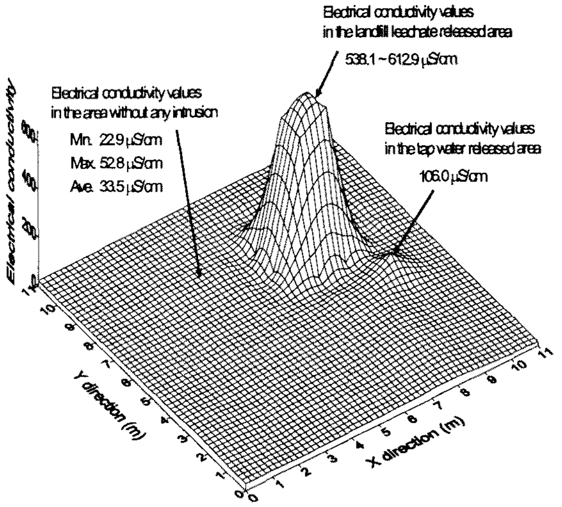


Fig. 12. The electrical conductivity in tested site 2 hours after the landfill leachate and tap water leakage occurred (Case III)

3.4 General Attributes of Grid-net Detection System

The grid-net detection system fulfills the demands for low-cost system that can be emplaced and operated with minimal supervision, since the system are easy to construct and made of relatively inexpensive materials. The grid-net system provides the complete 2-D monitoring for the entire area beneath landfill. In addition, electrodes made of non-corrosive and high-grade stainless steel alloy are less likely to fail before the design life of the facility.

However, the grid-net detection system has a few inherent limitations on field applications as follows. Firstly, the system might not be applicable to existing landfills since the grid-net circuit and electrodes must be placed in a sub-layer beneath the containment unit during the initial construction. In the existing landfill site, potable electrical method could be an alternative to detect the contaminant release. Secondly, it might be difficult to identify and determine the type, species, and the quantity of released contaminant. This is not essential problem since the primary concern of applying the leakage detection system is to simply know that a release of contaminant is occurring at initial stage. In addition, the contaminant types and species are already known in the most cases of applying the leakage detection system.

3.5 Comments for Field Application

At this stage, authors recommend the following comments for field application of the system.

(1) Soil type: Soil with high specific-surface area (e.g., bentonite) shows high electrical conductivity, which could obstruct the differentiation that may arise from conductive contaminant (e.g., landfill leachate) release into the soil. When the target layer for the detection contains such a soil, installation of sand layer

with the detection system can be a possible alternative.

(2) Electrical conductivity of contaminants: The electrical conductivity of the target contaminants should differ significantly from that of the residual pore water. Therefore, to estimate the feasibility of the system for certain contaminated sites, the contaminants found in those areas should be initially confirmed to show sufficient electrical conductivity difference between the contaminants and the pore water in these sites.

(3) Seasonal variation: The monitoring system should work for a long-period during the operation of the containment facilities independent of seasonal variation. It has been noted that the electrical conductivity of soil is varied with temperature. The relationships between temperature and the electrical conductivity of soils reported in literature (Keller and Frischkenecht 1966; Abu-Hassanein et al. 1996) may be used to calibrate the measured electrical conductivity at various temperatures to electrical conductivity at a fixed temperature. However, to confirm the long-term performance of the monitoring system, field tests should be continued for over a year.

(4) Database establishment: The applicability of the system could increase with more field measurement data under various conditions.

4. Conclusion and further study

This study was focused on the feasibility of the landfill monitoring and early leakage detection system and the following preliminary conclusions can be suggested.

(1) A novel real time monitoring system was developed and evaluated for field application. The system is composed of two parts; (1) a set of moisture sensors which monitor the areas surrounding the landfill, and (2) a set of moisture and temperature sensors which monitor the landfill inside. From the laboratory test results for chloride, the difference between ion measurements and deionized water measurements was found to be negligible. The moisture sensor output of ammonium increased significantly upon specific concentration. Therefore, moisture sensor with measuring the dielectric constant was well affected by ions. For the assessment for landfills stabilization, real-time monitoring system was evaluated in dry and wet cell of pilot-site. The moisture content and temperature of wet cell were measured higher than those of dry cell. For the assessment of landfill stabilization, long-term field monitoring data of moisture and temperature will be collected, and needs to be compared and analyzed.

(2) The grid-net electrical conductivity measurement system for locating landfill leachate leakage was suggested. Leakage locations can be detected accurately by locating points with a significant increase in the distribution of electrical conductivity over an entire test area using the grid-net detection system based on electrical conductivity measurement. The results of pilot-scale field model tests indicate that the grid-net electrical conductivity measurement method can be applicable to the detection of landfill leachate at the initial stage of intrusion, and thus has a potential for monitoring leachate leakage at waste landfills. However, accumulation of data under various field conditions is required for successful operation.

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