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Development of In-Situ Soil Gas Monitoring Well for Managing the Bioventing Performance

생물학적 통풍법 공정관리를 위한 원위치 토양가스 관측정 개발

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Abstract

Bioventing is commonly used for petroleum hydrocarbon (PHC) spills. This process provides better subsurface oxygenation, thus stimulating degradation by indigenous microorganisms. Therefore soil vapor monitoring points (VMPs) are extremely important in determining the potential effectiveness of bioventing and in long-term monitoring of bioventing progress. In this study in-situ soil gas monitoring well (GMW) was developed and presented the pilot test results which recover the contaminated site by bioventing method. The result of application was successful and it was expected that GMW developed could be applied to the evaluation procedure of bioventing effectiveness and long-term remediation potential.

Keywords : Contaminated soil, Remediation, TPH, Bioventing method, Soil gas monitoring

I. Introduction

Bioventing is a proven technology that stimulates the natural in situ biodegradation of petroleum hydrocarbons in soil by providing oxygen to native soil microorganisms. Bioventing has widespread potential application because soil organisms can degrade a variety of petroleum products, including JP-4 jet fuel, gasoline, diesel fuel and heating oils. In-situ treatment of fuel contaminants in soils greatly reduces the expense and destruction associated with traditional excavation and treatment (or disposal) methods. In contrast to soil vapor extraction (SVE), bioventing also utilizes low air-injection flow rates to provide only enough oxygen to sustain microbial activity and often eliminates expensive off-gas treatment required with conventional SVE systems. Bioventing can reduce remediation costs by as much as 50% on sites where vapor emissions must be treated. Factors that affect the

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cost include contaminant type and concentration, soil permeability, well spacing and number of wells, etc (AFCEE, 2000; Calabrese & Kostecki, 1992; U.S. EPA, 1995a, 1995b).

Bioventing technology is mechanically simple and requires minimum maintenance. Relatively few people are involved in the operation and maintenance of a bioventing system. Bioventing does not require expensive equipment and can be left unattended for long periods, making it a cost effective remediation solution. Cleanup takes approximately 1 to 5 years for Benzene, Toluene, Ethylbenzene, and Xylenes (BTEX) and 2 to 10 years for Total Petroleum Hydrocarbon (TPH) (Österreicher-cunha et al., 2004; North atlantic treaty organization, 2000; AFCEE, 1996a, 1996b).

In bioventing method, oxygen is most commonly supplied through direct air injection into contaminated vadose-zone soils via vertical or horizontal vent wells(see Fig. 1).

Vent well was generally composed such as Fig. 2 and extraction well often applied to the bioventing method for the purpose of the enhancing remedial efficiency.

Oxygen serves as a primary electron acceptor for soil microorganisms employed in the degradation of both refined and natural hydrocarbons. Following a hydrocarbon spill, soil microorganisms begin to use available soil gas oxygen. As the population of fuel-degrading microorganisms increases, the supply of soil gas oxygen is often depleted, creating an anaerobic volume of contaminated soil. Under anaerobic conditions, fuel biodegradation generally proceeds at significantly slower rates. In some cases, aerobic biodegradation will continue because the diffusion or advection of oxygen into soils from the atmosphere exceeds biological oxygen utilization rates. Under these circumstances the site is naturally aerated, and the hydrocarbons will be naturally attenuated over time. In addition to biodegradation of adsorbed fuel residuals, volatile organic compounds (VOCs) also are biodegraded as vapors move slowly through biologically active soils (Diele et al., 2002; Malina et al., 2002; U.S. EPA, 2001; Sun et al., 2000; Glascoe et al., 1999; Husemann & Truex, 1996; McClure & Sleep, 1996).

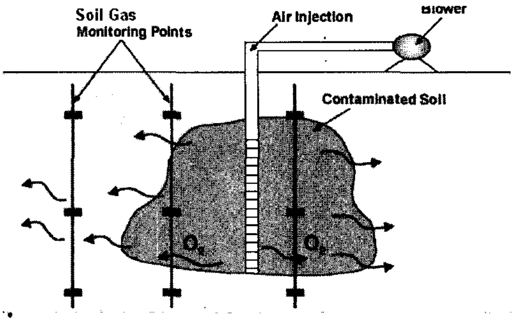
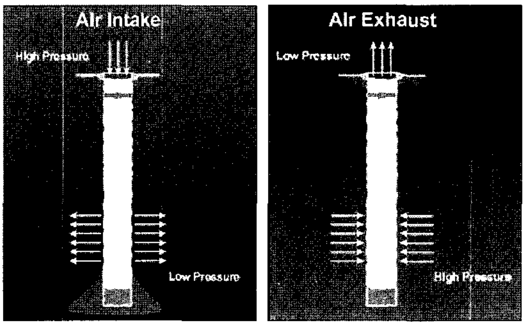


Fig. 1 Typcal bioventing system(U.S. EPA 1995a)



(a) Injection well (b) Extraction well

Fig. 2 Schematic diagram of injection and extraction well of bioventing method

Generally, monitoring is performed during the operational phase to evaluate whether the remediation equipment is functioning as designed and whether the remediation is progressing as predicted. In this case, the use of soil gas to determine bioventing performance and bioventing progress has several economic and technical advantages over more traditional drilling and soil sampling techniques. Thus the proper soil gas, not just off-gas, monitoring system must be developed and located strategically inside and outside of the contaminated soil volume to ensure the adequate aeration in subsurface contaminated zone (Hinchee et al., 1995).

In this study in-situ soil gas monitoring system was developed and proved by the results of field experiment which was carried out in actual remediation site.

Ⅱ. Development of Soil Gas Monitoring Well System

The chemical composition of soil gas can vary considerably from atmospheric composition as a result of biological and mineral reactions in the soil. Although numerous compounds and elements may be present in soil gas as a result of specific soil and bedrock geochemistry, three indicators are of particular interest in the bioventing context: oxygen, carbon dioxide, and hydrocarbon vapors. The soil gas concentrations of these indicators in relation to atmospheric air and uncontaminated background soils can provide valuable information on the ongoing natural biodegradation of hydrocarbon contaminants and the potential for bioventing to enhance the rate of natural biodegradation. There are many possible procedures for monitoring the progress of bioventing. These processes include point source monitoring, use of helium tracers, finger printing and continuous monitoring using sensor technology (Hinchee et al., 1995).

In this study, It was assumed that the use of subsurface oxygen, carbon dioxide and temperature sensors in addition to soil sampling is the most adequate monitoring scheme to track the progress of the remediation of the soil. A monitoring process using various sensors offers the possibility of continuous, uninterrupted monitoring of the average respiration rate and the activity of microbiota metabolic in the air flow path.

The sensor consists of an electrochemical cell which monitors the oxygen, carbon dioxide content of the media continuously. Sensors were installed at various depths, between from the surface to 5 or 6 m depths. The sensors were packed with sand and isolated. This installation method was chosen over simply hanging the sensors in existing wells because it generally

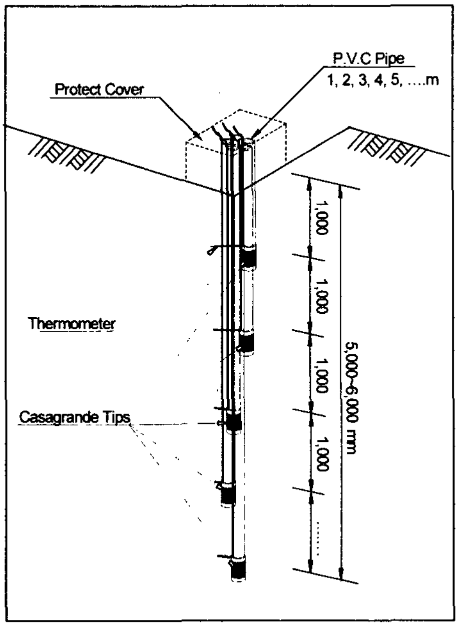


Fig. 2 Diagrammatic representation of soil gas monitoring well system

Table 1 Specification of measurement equipment & sensors

Item	Specification	Remarks
Oxygen meter (XO-326ALA)	Gases detected: Oxygen Detection principle: Galvanic cell Range: 0 ~ 40% VOL	Alarm at below 18%
IAQ monitor (TSI IAQ-Calc™ Model 8762)	CO_2: 0 to 5000 ppm Temperature: 32 to 140°F Relative humidity: 5 to 95% RH % Outside air: 0 to 100%	CO: 0~500 ppm
Thermo meter (KM320)	Sensor type: Thermocouple type K Measurement range: -50℃ ~ +1,300℃ Resolution: 1℃ Connector type: Sub-miniature	Operating temperature range: 0℃ ~ +50℃
Thermo couple (SK32M)	Probe type: patch probe Sensor type: K(-200℃ ~ +1,372℃) Temp range: -50℃ ~ +250℃ Response time: 0.5 s	Lead length: 1.0 m Lead material: PTFE (Polytetrafluoroethylene)

provides more accurate results (Hincheeet al., 1995). It is necessary to take an initial reading of oxygen levels as soon as the installation is complete. In addition, a control sample from a nearby unaffected area should be taken to establish the normal chemistry of the soil (North West Soil Research, 1979). Fig. 2 was shown the soil gas monitoring well developed in this study and the specification of analyzers and sensor which was used to compose the soil gas monitoring system were as Table 1.

Oxygen analyzer(XO-326ALA) was to measure a oxygen concentration in the subsurface and it can be measured oxygen concentrations in liquids or gases. The diaphragm galvanic cell type sensor in this equipment produces a high electrical output and displays great stability of sensitivity to oxygen over long periods of use.

The IAQ monitor(TSI IAQ-Calc™ Model 8762) simultaneously measures and data logs several parameters using a single probe with multiple sensors. The parameters include CO_2, CO, humidity, and calculates dew point, wet bulb temperature, absolute humidity, humidity ratio and % outside air. The data logger allows users to log 14,000 samples with a time and date stamp. Variable time intervals for data collection can be selected.

Thermo-meter(KM320) and thermo-couples (SK32M) were used to measure the temperature variation in the subsurface. KM320 can be measured flow and return temperature and radiator output temperature, and KM320 uses various types of thermocouple. PTFE (Polytetrafluoroethylene) is a high performance polymer material which on its own or filled with various fillers, such as Glass fibre, Graphite, Carbon, Bronze, Stainless steel, Ceramic, Ekanol, Mineral fibres etc. The well known non-stick quality of PTFE, its excellent resistance to most chemicals and corrosive conditions. Fillers can be added to PTFE in varying proportions and combinations. Thus PTFE can be tailored to suit the specific requirements and conditions of the proposed application.

Ⅲ. Site Description

The site which was considered in this study was in Busan, Korea. The Busan is located on the southeastern region of Korea. The site has been utilized as the headquarter of train transportation since 1910's and various heavy works have been carried out to repaire or coat the trains in the site and huge wastes disposed into the ground. Therefore the soil and groundwater were mainly contaminated by petroleum hydrocarbon and heavy metals and the maximum concentration of petroleum hydrocarbon which was reported as TPH (total petroleum hydrocarbon) item up to 50,000 mg · kg^{-1}. After the thorough site investigation, the bioventing was selected to the remediation method for the areas that were contaminated by petroleum hydrocarbon.

According to the design drawing, injection wells of 73 and extraction wells of 61were installed into the subsurface and soil gas monitoring wells of 3 were also installed such as Fig. 3.

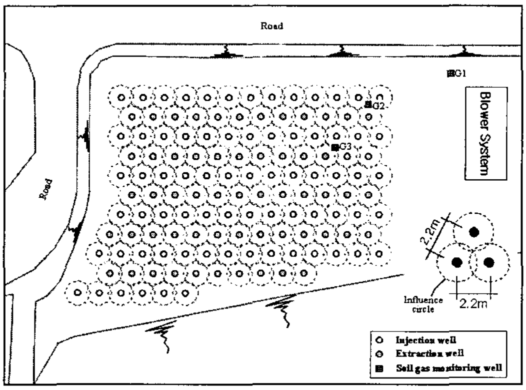
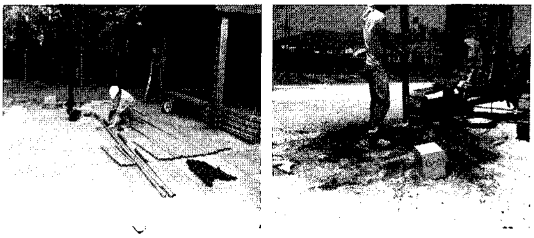
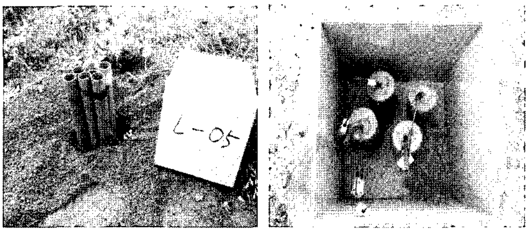


Fig. 3 Locations of injection, extraction and monitoring wells

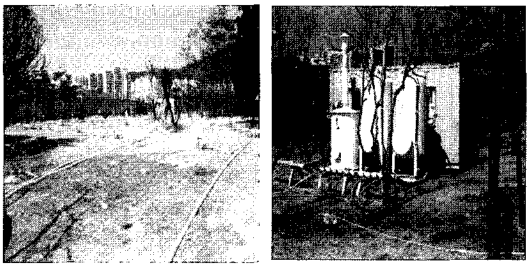


(a) Assemblage (b) Drilling

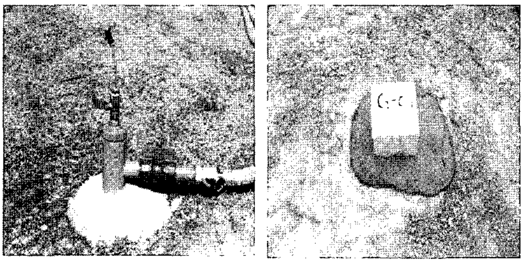


(c) Sensors buried (d) After installation

Fig. 4 Installation procedures of soil gas monitoring well



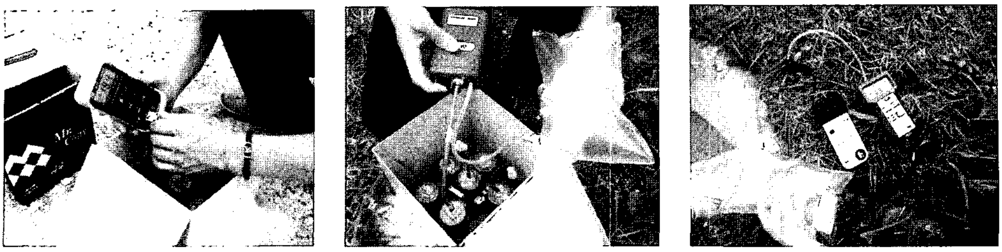
(a) Site view (b) Blower system



(c) Injection or extraction well (d) GMWs

Fig. 5 Site view after the installation of facilities for bioventing

Fig. 4 showed the installation procedure of soil gas monitoring wells which was developed in this study. Soil gas monitoring wells of 3 were in-



(a) Tmperature (b) Suction of gases (c) Measurement of concentration

Fig. 6 Measurement procedure of temperature and gases concentration

stalled down to the depth of 5 m and it included one control monitoring well which was installed for the purpose of comparison in the uncontaminated area. Site views after the completion of variety facilities installation are shown in Fig. 5.

Fig. 6 was shown the measurement procedures of oxygen, carbon dioxide, and temperature. Temperature was directly measured using thermo meter. However, Oxygen and carbon dioxide were first sucked into the tedlar bag using vacuum pump and measured the concentration of oxygen and carbon dioxide which were contained in tedlar bag using oxygen meter and IAQ monitor. Tedlar bags are a convenient and accurate means of gas and vapor samples in air. This is particularly true in areas where the concentration is above the detection limits of common analytical instruments. Many chemical hazards can be effectively collected by tedlar bags (Calabrese and Kostecki, 1992). Soil samples were collected 2 times during the observation period nearby the soil gas monitoring wells beside the investigation of soil gases.

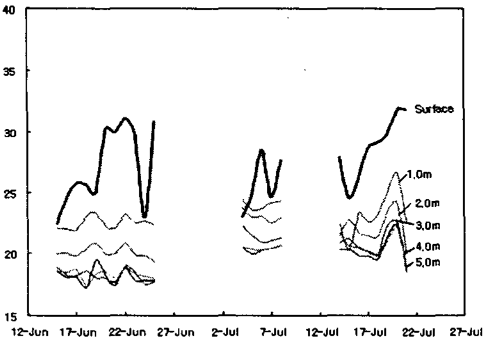
Ⅳ. Results and Discussion

Fig. 7~Fig. 9 were shown the results of the variation of soil temperature and gas concentration with the time at soil gas monitoring wells which were developed in this study (Because of the rainy season, the measure could not carry out from 26 July to 3 June and from 9 June to 13 June).

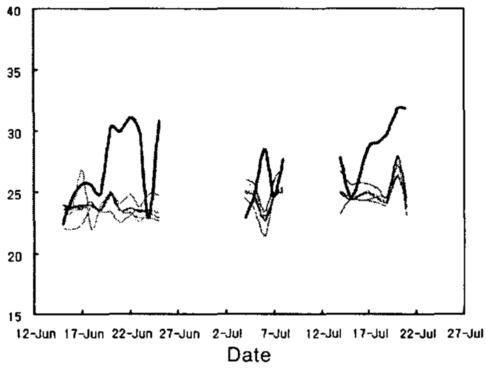
Fig. 7 showed the results of subsurface temperature observation. Subsurface temperature was observed down to the 5.0 m depth in the interval of 1.0 m. At the G1 well which was the (uncontaminated) control well, the temperature was decreased with the depth and it was believed that this pattern was shown the general temperature characteristic in the subsurface.

However, the temperature profile of the G2 and G3 wells contaminated with petroleum hydrocarbon was not same pattern as G1 well rather more higher than G1 well and it was expected that the activity of soil microorganisms in these wells was vigorous. Among the wells, the temperature of G2 well was highest and G1 well was lowest.

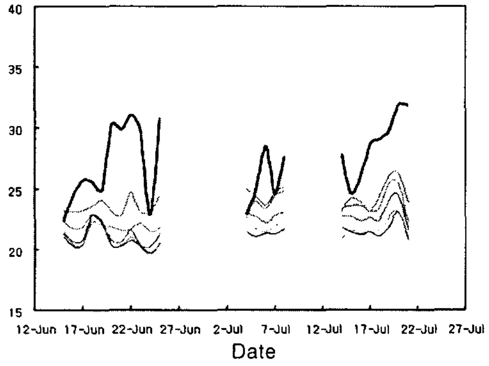
Fig. 8 showed the results of subsurface oxygen concentration observation. Subsurface oxygen concentration was observed down to the 5.0 m depth in the interval of 1.0 m. During the observation period, the subsurface oxygen concentration was maintained at the level of 20% which is necessary to the effective biode-



(a) G1



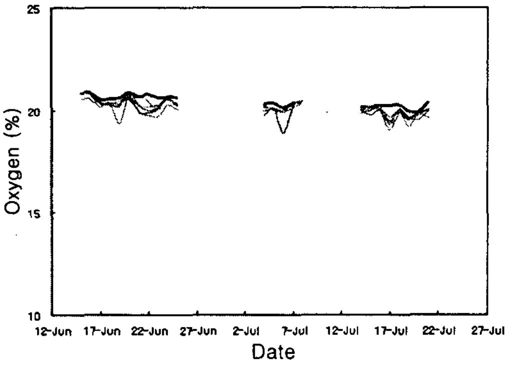
(b) G2



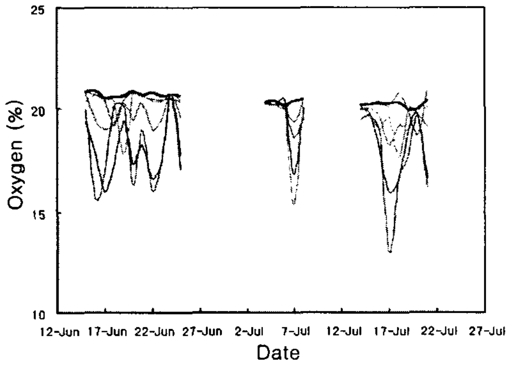
(c) G3

Fig. 7 Variation of subsurface temperature during observation period

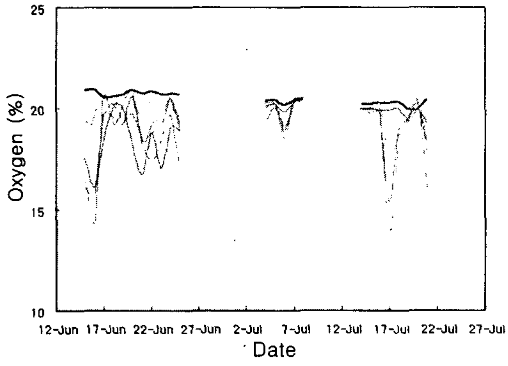
gradation in the bioventing method. Although it was often depleted to the level of 16~15%, it was recovered in a short time and so it was interpreted that the blower system showed the reliable performance.



(a) G1



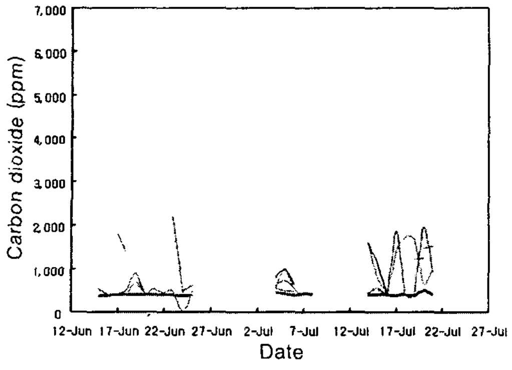
(b) G2



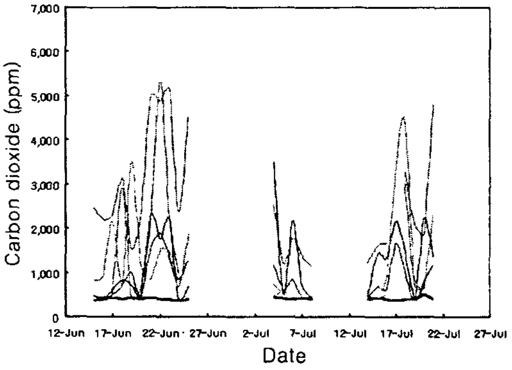
(c) G3

Fig. 8 Variation of subsurface oxygen concentration during observation period

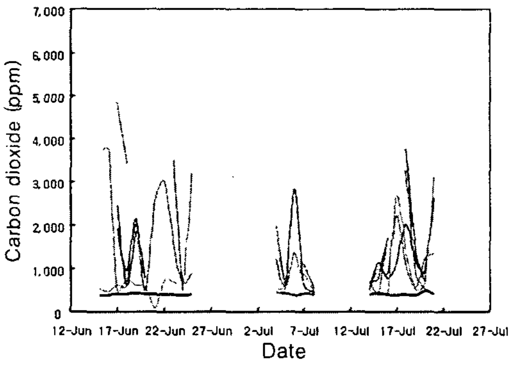
In G1 well, there was no obvious variation of oxygen concentration with the depth. But the oxygen concentration of G2 and G3 well were



(a) G1



(b) G2



(c) G3

Fig. 9 Variation of subsurface carbon dioxide concentration during observation period

varied drastically during the observation period and it was expected that the biodegradation process by soil microorganisms was effectively proceeded in these wells. Among the wells, the oxygen depletion of G2 well was more higher than G3 well and this phenomenon was the evidence of vigorous biodegradation by soil microorganisms in the G2 well.

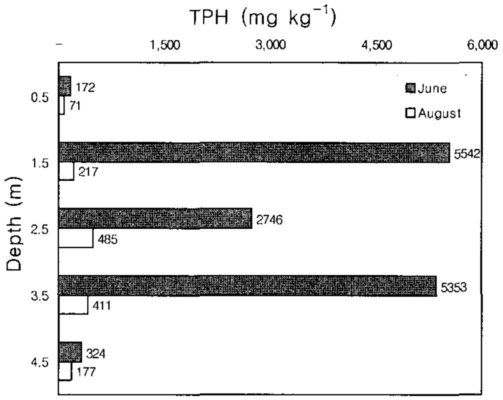
Fig. 9 showed the results of subsurface carbon dioxide concentration observation. Subsurface carbon dioxide concentration was also observed down to the 5.0 m depth in the interval of 1.0 m. During the observation period, the carbon dioxide concentration was measured up to above 5,000 ppm although the carbon dioxide concentration on the atmosphere was about 400 ppm, which meant that the respiration of soil microorganisms was very vigorous.

In G1 well, there was no obvious increment of carbon dioxide concentration but the carbon dioxide concentration of G2 and G3 wells were increased drastically during the observation period and it was reciprocally related to the decrement of oxygen concentration.

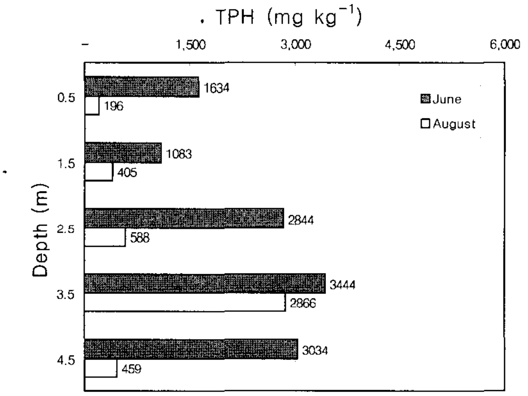
It was also observed that the increment of carbon dioxide concentration in G2 well was more higher than G3 well and it was expect the high treatment efficiency in the G2 well during the bioventing.

Fig. 10 showed the results of the soil TPH analysis. Soil sampling was performed 2 times (in June and August) at the depth of 0.5, 1.5, 2.5, 3.5, and 4.5 m nearby G1 and G2 wells. The obvious reduction of soil TPH level was observed in both G2 and G3 wells and, especially, excellent remediation effects were observed in G2 well. This results could be already expected during the soil gas observation period based on the variation of soil temperature and the concentration of soil gases.

The results above mentioned were actually



(a) G2



(b) G3

Fig. 10 Results of TPH analysis

referred to the decision procedures for the quantity and frequency of the microorganism and nutrient supply in the site and it was shown that bioventing method removed effectively the contaminants (petroleum hydrocarbon) in the subsurface soil and could achieve the cleanup goal within the reasonable period.

V. Conclusions

In this study, soil gas monitoring well was developed to support the enhancing bioventing efficiency and carried out the pilot test in an actual contaminated site. The soil gas monitoring well developed was appeared the good performance and expected the continuous usage for the managing of bioventing process in the contaminated site. The soil gas monitoring well developed can give the information which is related to the activity of biodegradation of petroleum hydrocarbon with the depth. It was also expected that soil gas monitoring could contribute the economical management of bioventing method.

However bioventing method has many areas where knowledge is limited. For example, the environmental limitations on bioventing rates are not completely understood. Further research is also needed to be given to biodegradtion rates under changing vapor extraction rates, to determine the interaction of microorganisms with the vapor phase etc.

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