Geotechnical and environmental investigations of contaminated river sediment treated by micro air bubble method

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Abstract: River sediments contain various mineral and organic constituents of natural and anthropogenic origin that are or may become potential pollutants. Sediment contamination by hydrocarbons from surface runoff, ships, oil spill or by atmospheric deposition is of great concern. Heavy metal and organic substance are common in freshwater ecosystems and particularly in river sediments where they accumulate. Though they can be naturally present in ecosystems following e.g. natural fires, these contaminations are mainly associated with human and industrial activities.

Microorganisms play a major role in the biogeochemical cycling of both organic and inorganic elements, as they are the main mediators of biodegradation and mineralization of organic compounds and in the weathering and/or neo-formation of minerals. As microorganisms in sediments have a high functional diversity and are exposed to natural humic or fulvic compounds containing aromatic structures, sediments commonly contain some pollutant degraders. Aerobiosis occurs when the flow stream is low and at sites where O_2 consumption is high and exceeds its supply by diffusion. O_2 can be injected into sediment under river basin by micro bubble injection system.

The aim of this work was to study and define the relations and interactions between the biodegradation and the fate and dissipation of pollutant in river sediment. For this purpose polluted sediment was collected before and after injection of micro bubble in order to quantify the extent of pollutant dissipation under oxic and anoxic conditions.

Résumé: Les sédiments des rivières contient des minéraux et des constituants organiques d'origine naturelle et d'anthropogenique qui sont ou bien peuvent devenir des polluants potentiels. La contamination des sédiments par des hydrocarbures des écoulements de l'eau de pluie, des bateaux, d'écoulement d'huile ou par de la sédimentation atmospherique est l'un des plus grands soucis. Le métal lourd et la substance organique sont communs en écosystème de l'eau douce et particulièrement aux sédiments des rivières où ils s'accumulent. Bien qu'ils peuvent être présents naturellement à l'écosystème par exemple l'incendie naturelle, ces contaminations sont principalement associés à l'humain et aux activités industriels.

Micro-organismes jouent un rôle principal au cycle biogéochimique des élements organiques et inorganiques, comme ils sont les médiateurs de biodégradation et de minéralisation des composés organiques et de désagrégation et/ou néoformation des minéraux. Comme les micro-organismes dans des sédiments ont de haute diversité fonctionelle et sont exposés aux composés humifiés contenant la structure aromatique, les sédiments contient généralement quelques polluants dégradeurs. L'aérobiose se produit quand l'écoulement est basse et aux lieux où la consommation de O_2 est haute et qu'elle excède son supplément par diffusion. O_2 peut être injecté au sédiment sous le bassin de la rivière par le système d'injection de micros bulles d'air.

Le but de cette étude est d'étudier et définir les relations et les interactions entre la biodégradation et la dissipation du polluant dans les sédiments des rivières. Pour cela, les sédiments pollués sont collectés avant et après l'injection de micros bulles d'air pour quantifier le degré de la dissipation du polluant.

Keywords: Case studies, contaminated land, geoenvironmental engineering, dredging, remediation, saturated materials.

INTRODUCTION

Air-sparging is an in-situ groundwater remediation technology that involves injecting a gas (usually air/oxygen) under pressure into the saturated zone to volatize groundwater contaminants and to promote biodegradation in saturated soils by instantaneously increasing subsurface oxygen concentrations (Miller 1996). Volatilized vapours migrate into the vadose zone where they are extracted via vacuum, generally by a soil vapour extraction system. Air sparging technology is also referred to biosparging to highlight the bioremediation aspect of the treatment process where biodegradation is the dominant remedial process. Air-sparging has been widely used worldwide to remediate the contaminated groundwater and aquifer. In general, air sparging is applicable at sites where groundwater and/or saturated soils are contaminated with volatile, semi-volatile, and/or nonvolatile aerobically biodegradable organic contaminants (Reynolds 1998; Kim 2001).

Given the apparent promise of air-sparging technology to treat contaminated areas including groundwater and saturated soils, it has been used to remediate riverbed contaminants by the biodegradation process. This paper introduces a technique which is referred to as Mobile Algae Removing System (MARS). Mobile Algae Removing System treats contaminated riverbed soils by means of micro-air sparging together with chemical injection (SIB 2003). The technique makes use of the fundamental principles based on dissolved air-sparging method to remediate polluted materials clinging to soil particles in a riverbed. Pressurized water together with cohesive agent is first injected under high pressure to create flocs through reactive action with chemical substance. Micro-air bubbles are then applied to flocs to form scum which floats on water surface due to reduced gravity (Kang 2002). Floating scum is then collected and treated appropriately. MARS technique is capable to remediate water-quality and polluted sediments. A test-dredging of 30m×40m area was performed to investigate the effectiveness and efficiency of MARS technique for removing organics in contaminated riverbed as a part of HwangGuJi River environmental-retrofit project in Whasung City, Korea. An environmental analysis on the riverbed samples before and after the test-dredging was conducted.

In the following sections we present a conceptual description of MARS technology, the HwangGuJi River environmental-retrofit project, and the results obtained from environmental investigation for the riverbed sediment samples.

MOBILE ALGAE REMOVING SYSTEM (MARS)

Mobile Algae Removing System makes use of a fundamental principle based on dissolved air-floatation method to remove organic and inorganic contaminants. It uses micro-air bubble to have float contaminants and allow chemical injection to biodegrade inorganic components in a riverbed. MARS technology is useful for remediating eutrophicated riverbed or pond with nitrogen or phosphorus. Figure 1 shows MARS components mainly consisting of water-floating equipment and micro-air bubble generator. The water-floating equipments include water-floating ship, scum scraper, and scum storage. Micro-air bubble generator includes chemical injection system, air-compressor, and air-dissolved water nozzle.

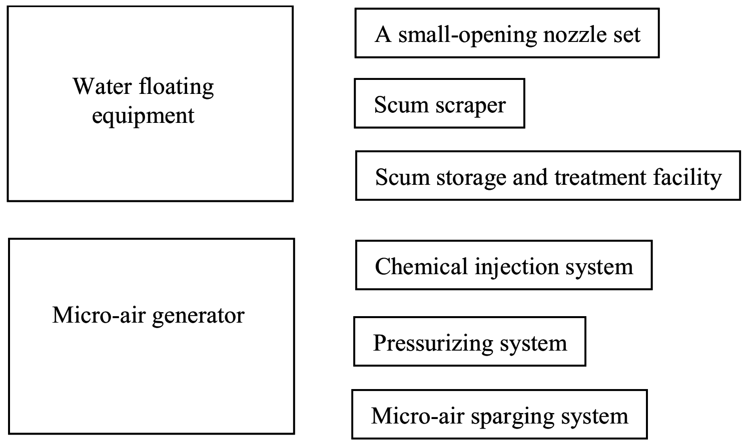


Figure 1. Mobile Algae Removing System components.

Figure 2(a) shows the step by step process of MARS. First, air-bubbles are compressed under high-pressure from compressor and dissolved into the water obtained from pressurized pump. After this process the air-bubble exist under oversaturated condition within a pressurized tank. Second, the pressurized water together with cohesive agents is injected under high pressure to riverbed sediments. It causes organic and inorganic contaminants to create floc through reactive action with chemical substance. Third, the air dissolved within the pressurized tank under oversaturated and high-pressures generates micro-air bubble when it exposes to atmosphere through the water nozzle. Fourth, the contaminant-floc created together with chemical reactant floats onto water surface due to reduced gravity with clinging micro-air bubbles. From this, the floating-flocs form a layer of scum. Lastly, the scum is removed by a scum-scraper, dehydrated, and subsequently condensed at sludge-condenser.

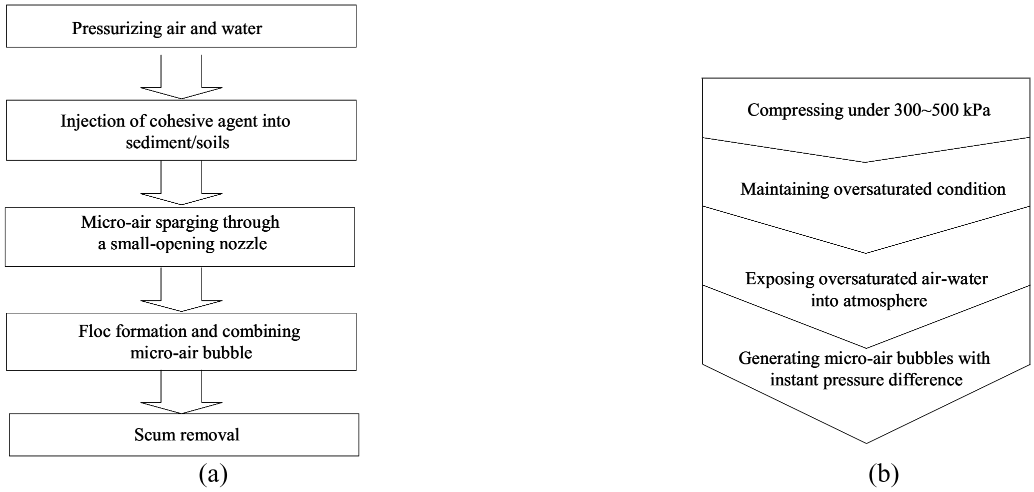
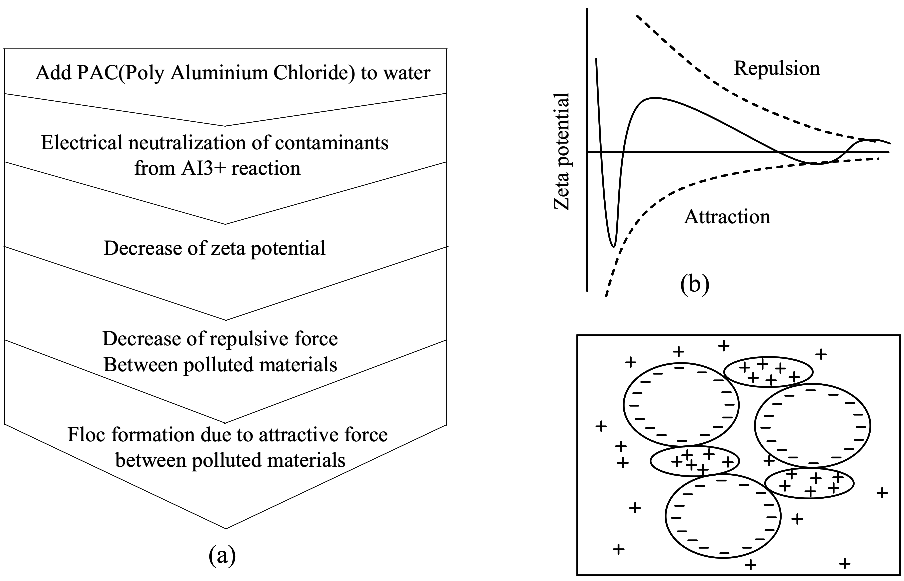


Figure 2. (a) MARS procedure and (b) principle for generating micro-air bubble.

Now, we address in more details how to generate micro-air bubble, how to form flocs, and how flocs adhere to micro-air bubbles. Figure 2(b) shows the fundamental principles on the generation of micro-air bubbles. It includes four processes: i.e.,

1) compressing air under 300~500 kPa using a high-pressure compressor,
2) maintaining oversaturated condition of air into water within a pressure tank,
3) exposing the compressed and oversaturated air-water into atmosphere instantaneously though a very small-opening nozzle,
4) generating the micro-air bubbles with instant pressure difference between the compressed air-water and the atmosphere.

Figure 3(a) illustrates the main principles of floc formation. When PAC (Poly Aluminium Chloride) is added to water body, existing contaminants are electrically neutralised due to Al^{3+} reaction. This causes zeta potential to be reduced as shown in Figure 3(b) and, accordingly, repulsive force becomes instantly very small and attractive force between elements become greater. As shown in Figure 3(c), electrical attractive forces develop instantaneously to create the flocs.



(c)

Figure 3. (a) Floc formation principle, (b) change of zeta potential, and (c) schematic of development of electrical attractive force between polluted materials.

Figure 4 shows a simple schematic on how flocs to adhere with micro-air bubbles. The principle consists of four main actions and they are:

1) Brownian action;
2) Intercept action;

3) Gravity-precipitation action, and
4) Inertial action.

Brownian action occurs when flocs meets micro-air bubbles during its irregular movement. Intercept action happens when flocs are very close to micro-air bubbles during liquid flow. Gravity-precipitation action occurs when flocs hit micro-air bubbles during its precipitation due to self gravity. Inertial action occurs when flocs collide with themselves due to their own inertia without any liquid flow.

Successful use of MARS technology depends on the ability of the system to effectively deliver condensed-air to the treatment area and the ability of the subsurface materials to effectively transmit the air (HAZWRAP 1995). Therefore, site conditions that favour the successful application of air sparging technology include relatively coarse-grained (moderate to high permeability) homogeneous overburden materials that foster "effective contact" between air and media being treated. Fine-grained, low permeability soils limit the migration of air in the subsurface/sediment, thereby limiting the effectiveness of air delivery and floc creation (Mulligan, Yong & Gibbs 2001; Tang & Myers 2002). In addition, heterogeneity of riverbed soils, due to spatial variations may limit the effectiveness of this technology. In the next section, we discuss a riverbed environmental retrofit project performed using MARS technology in South Korea.

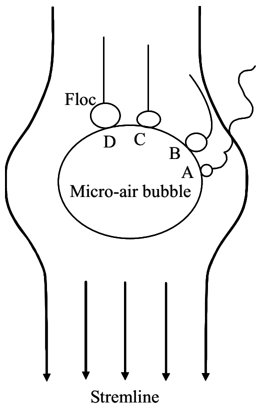


Figure 4. A schematic of floc formation by aid of micro-air bubble.

TEST-DREDGING AND CONTAMINANTS REMEDIATION

Site description

In South Korea, there has been a rapid growth period during last three decades in terms of economics and industry. Large amount of development and use of industrial plants have occurred with little respect to environment effects has caused this has caused to that many waterways and local rivers. As a result these have become contaminated with polluted organic and inorganic materials. Since early 1990's governmental and environmental agencies of Korea have enhanced all environmental related laws and codes. This required the construction of waste-material treatment facilities for any new development of industrial plants. By virtue of these efforts, water qualities in local rivers have improved to a better level compared to the past. However, these works are not capable of removing contamination from existing sediments deposited over last 30 years or so. Nowadays, environmental retrofit is of great concern for the most of local rivers. In the following discussion, we illustrate this by examining a riverbed retrofit project performed in South Korea.

HwangGuJi River is located approximately 50 km south from Seoul, Korea. It runs about 100 km from east of the mountainous region, to the sea in the west. Along the upper and lower reaches of the HwangGuJi River there are farms, towns, and several plants including concrete-mixing plant. The river has been contaminated by industrial water, sanitary, and sewage for last three decades. Governmental agencies planned to remediate the riverbed by dredging the contaminated sediments, but, due to budgetary constraints this method of treatment was not chosen. Instead the MARS technology was chosen. This was because it does not require dredging and, correspondingly, provides economical method for the river rehabilitation. It was decided first to perform test-retrofit using MARS technology to evaluate its effectiveness (Choi & Chung 2005).

Test-retrofit area consisted of 30m×40m rectangular shape located at KaeRang-Ri JungNam-Myeyn, Whasung City, South Korea. The area was separated from main HwangGuJi stream by installing a double-silt curtain/oil fence. The retrofit depth was designed to treat 20cm from the bottom of stream. Figure 5 shows a schematic view of test-retrofit area. The soil layer of upper 20cm from the stream bottom that was being treated consisted of mainly silty sand (SM), which had permeability high enough to transmit air bubble effectively.

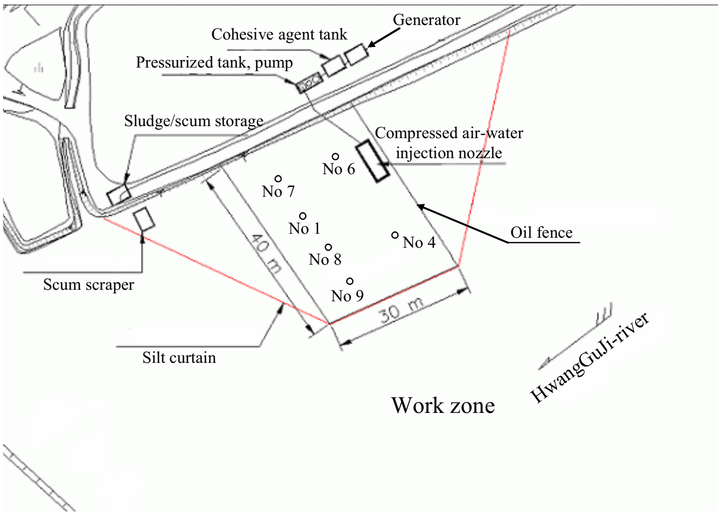


Figure 5. HwangGuJi-river test-dredging area and sediment sampling locations.

Figure 6(a) and (b) show a picture of test-retrofit area and MARS components on the site. The components shown in Figure 6(b) are water-floating equipment and scum scraper. Floating scum is also shown in Figure 6b. In order to investigate the efficiency of MARS technique for remediating the contaminated sediments in the riverbed, sediment samples were collected at the locations shown in Figure 5. Samples were obtained before and after the application of MARS technology using a 5cm inner-diameter plastic pipe. These samples were then sent to the Korea Testing & Research Institute for Chemical Industry and Chung-Myung private analysis agent for environmental analysis.

(a)

(b)

Figure 6. (a) Photograph of HwangGuJi-river test-dredging and (b) photograph of water floating equipment, scum scarper, and scum floating on the water surface.

Environmental analysis results

The data shown in Table 1 provide analytical results obtained from the riverbed soils before and after the environmental treatment using MARS technology at the locations of No. 1, No. 4, and No. 6. The sampling locations are indicated in Figure 5. The environmental analysis included testing for COD, heavy metals (Hg, Pb, Cd, and Cr^{6+}), ignition loss, and solid concentrations. Table 1 indicates that the concentrations or percent weight, in general, reduce after treatment. The spatial variation in the depth of sampling might cause a little increase of some values. Among others, it is noticeable that COD concentration and ignition loss reduce by a large amount. For example, the efficiency of COD removal at No. 1 and No. 6 locations are 67% and 82%, respectively, and the remediation efficiency in terms of ignition loss at both locations are 21% and 16%. Analysis results for other items are quantitatively very close to each other when the samples before and after treatment are compared.

Table 1. Analysis results at No. 1, No. 4, and No. 6 locations for before and after MARS treatment

Analysis item	Unit	No. 1		No. 4		No. 6	
		Before	After	Before	After	Before	After
COD	mg/kg	410	135	167	132	281	50.7
Hg	mg/kg	0.0101	0.0113	0.0159	0.0057	0.0244	0.0104
Pb	mg/kg	1.47	1.53	1.59	1.13	1.24	2.77
Cd	mg/kg	0.090	0.140	0.119	0.104	0.173	0.145
Cr6+	mg/kg	ND	ND	ND	ND	ND	ND
Ignition loss	wt%	28.6	22.7	25.3	24.1	25.7	21.7
Solid	wt%	71.9	77.9	75.2	76.3	75.3	78.9

Table 2 provides a comparison of the analytical results for the items on T-N (total nitrogen), T-P (total phosphorous), and sulfur content between before and after the MARS treatment for the riverbed sediments at the locations of No. 7, No. 8, and No. 9. The sampling locations are shown in Figure 5. The analysis results indicate that MARS has a great potential as a technology to remediate contaminants possessing nitrogen, phosphorus, and sulfur substances. The efficiency of remediation for total nitrogen, total phosphorus, and sulfur content ranges 54%~85%, 25%~69%, and 76%~81% at the locations, respectively.

Table 2. Analysis results at No. 7, No. 8, and No. 9 locations for before and after MARS treatment

Analysis item	Unit	No. 7		No. 8		No. 9	
		Before	After	Before	After	Before	After
Total Nitrogen	mg/kg	1221	566	2711	456	1843	275
Total Phosphorous	mg/kg	6.861	5.142	14.932	4.567	6.862	2.826
Sulfur content	mg/g	1.72	0.33	2.20	0.48	1.76	0.43

CONCLUSION

The aim of this work was to study and define the relations and interactions between the biodegradation and the dissipation of contaminants in riverbed sediment using an air-sparging technology. As a example of air-sparging technology, the MARS (Mobile Algae Removal System) technique was introduced. MARS treats contaminated riverbed soils/sediments by means of micro-air sparging and chemical injection. The technique makes use of the fundamental principles based on dissolved air-sparging method to remediate polluted materials. It incorporates several processes: i.e., compressing air under high-pressure, maintaining oversaturated condition of air within water body, exposing the compressed and oversaturated air-water into atmosphere instantaneously though a small-opening nozzle, and generating the micro-air bubbles based on instant pressure difference between the compressed air-water and the atmosphere. Pollutants form flocs, which are separated from riverbed sediments by chemical injection and micro-air sparging allowing flocs to form scum and float on water surface. A test treatment area of 30m×40m area was used to investigate the efficiency of MARS technique for removing organics in contaminated riverbed as a part of HwangGuJi River environmental retrofit project. For this purpose, polluted sediments were collected before and after injection of micro-air bubble in order to quantify the extent of pollutant dissipation under oxic and anoxic conditions. Based on the various environmental investigations on the riverbed samples before and after the test treatment, it is concluded that MARS technique has a certain level of capability to remediate polluted riverbed materials, in particular as a means to reduce COD, total nitrogen, total phosphorus and sulphur contents.

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