European Geosciences Union General Assembly 2018
Vienna | Austria | 8–13 April 2018

Environmental Remediation Engineering Laboratory

CHONBUK NATIONAL UNIV.

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Acid Mine Drainage Problems in Democratic Republic of Congo: Review

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1. Introduction

Mining industry is a major economic source in DR Congo (DRC), and the portion increases gradually. Especially, the investment and expert to foreign countries is getting important. However, there are less available data on environmental impacts of the mine industries in DRC. The aims of this study is to provide overall summary on environmental issues related with mine activities in DRC.

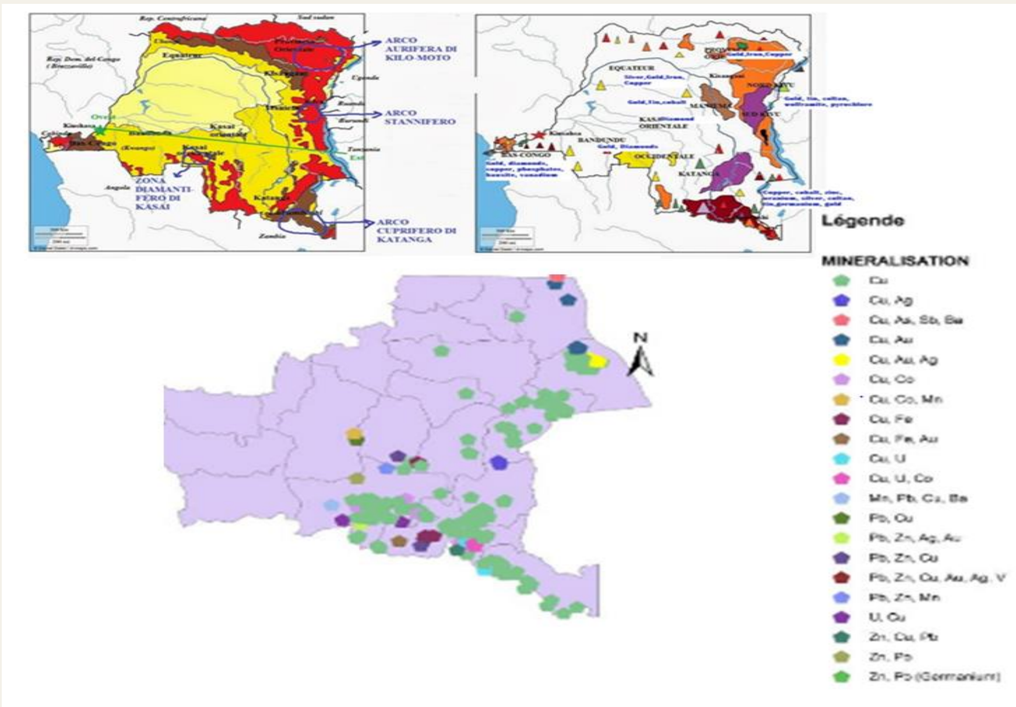
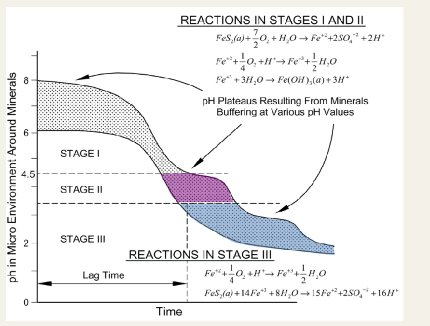


Figure 1. Simplified minerals map to show the relationship between the major mineralization units in Democratic Republic of Congo(OCDE, 2015)

2. General remarks of AMD including cause of AMD

Sulfide minerals including pyrite are main causes on acid mine drainage(AMD) due to oxidation of sulfide. In the generation of AMD, the oxidation of sulfide produces sulfuric acid, which enhances the desorption of toxic metals. That's why AMD contains high concentration of metals and sulfate with strong acidity.

$2CuFeS_2 + 2O_2 \rightarrow Cu_2S + 2FeSO_4 + S^0$ [1]
$Cu_2S + 2O_2 + S_0 \rightarrow 2CuSO_4$ [2]
$CuFeS_2 + 4O_2 \rightarrow CuSO_4 + FeSO_4$ [3]
$Cu_2S + 2Fe_2(SO_4)_3 \rightarrow 2CuSO_4 + 4FeSO_4 + S^0$ [4]
$CuS + Fe_2(SO_4)_3 \rightarrow CuSO_4 + 2FeSO_4 + S^0$ [5]
$CuFeS_2 + \frac{7}{2}O_2 + H_2O + Fe_2(SO_4)_3 \rightarrow CuSO_4 + 3FeSO_4 + H_2SO_4$ [6]
$ZnS + 4Fe_2(SO_4)_3 + 4H_2O \rightarrow ZnSO_4 + 8FeSO_4 + 4H_2SO_4$ [7]
$MS + 4Fe_2(SO_4)_3 + 4H_2O \rightarrow MSO_4 + 8FeSO_4 + 4H_2SO_4$ [8]

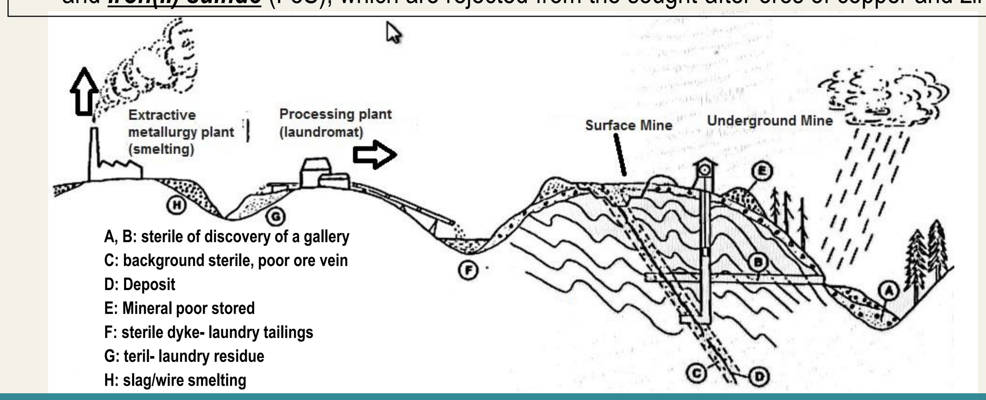


The different phases of acid mine drainage formation described by equations 1 to 8 normally develop in a three-phase sequence. Figure 2 illustrates these different phases of AMD formation, for the case of acid generation by the oxidation of pyrite

Figure 2: different phases of AMD formation(Verburg, 2009)

The case of Democratic Republic of Congo, AMD is generated on two ways

- Firstly in Abandoned mine dumps : waste rock dumps containing materials discharged from pyrite mines and metallurgical wastes.
- Secondly in Tailings to the surface : tailings contain large amounts of *pyrite* (FeS2) and ***Iron(II) sulfide*** (FeS), which are rejected from the sought-after ores of copper and zinc



3. Characteristics of AMD in DR Congo

Table 1: General Characteristic of acid mine drainage in metallic mine(Jennings et al., 2008)

Parameter	Unit	Low values	High values
Flow rates	M3/h	5	600
pH		1	6
EC	V/ref.Ag/AgCl	-	>0.5
Total acidity	mg/l	0	45000
Iron	mg/l	1	30000
Sulfite	mg/l	1	50000
Al, Mn	mg/l	1	2000
Zn, Cu	mg/l	-	200
As,Cd, Cr, Pb, Sb	mg/l	1	20
Dissolve salts	mg/l	100	30000

Table 2. Characteristics of AMD Effluents from: Mine of Bisie (Target Mineral: Tin and Nb-Ta) and Mine of Lumbabshi / Katanga Copper, Cobalt and Uranium)(Promine-DRC et al, 2014)

Parameter	Unit	Mine of Bisie: Target Mineral : SnO2	Mine of Lumbabshi/ Katanga/Target Minerals : Copper, Cobalt and Uranium
pH		4.7	pH≤8.5
Sulfate	ppm	8.00	-
Ca	ppm	490	-
Fe	ppm	1.100	≥ 112.7 in plants
Al	ppm	-	5173 in plants
Cr	ppm	128.03	77.15 in plants
Mn	ppm	100	-
Mg	ppm	420	24250in plants
Na	ppm	70	-
Pb	ppm	47.54	0.160 in waters
u	ppm	-	0.002 in waters
V	ppm	-	0.003 in waters
Co	ppm	28.29	28.2 in waters
Cu	ppm	186	12.8 in waters
Zn	ppm	550	5.24 in waters
As	ppm	-	0.005 in waters
Cd	ppm	16.70	39.6 in waters
Ni, Nb-Ta and Hg	ppm	≥6.87	≤ 5.484 in plants

The Kipushi samples confirmed the presence of sulfur and pyrite with the following results: the sulfur contents are 3.18% and 3.33% respectively and the presence of pyrite among the major phases see the table below

$$3MeS + 8HNO_3 \rightarrow 3MeSO_4 + 8NO + 4H_2O$$ [9] Me: metals as Fe, Zn, Cu and Pb.

Table 3 Sulfur content, sulfides and CO2 samples 8C1 and 8C2

samples	Contains %			
	S total	Sulfide(Sobek)	Sulfides	CO2 total
1	3.18	2.96	2.82	19.81
2	3.33	3.13	2.99	17.73

The method of Sobek gives high values both Potential acids as Potential neutralization. For Potential Acid, these values are high. With regard to the Neutralization Potential, the value is high since during the titration the acid consumption is not only due to the carbonates, but also to certain oxides, hydroxides and silicates.

Table 4 : Major minerals associated with AMD with those that occur in Democratic Republic of Congo(Gray et al. 2008)

Mineral	Composition
Arsenopyrite	FeS27FeAs
Bornite	CuFeS4
Chalcocite	Cu2S
Chalcopyrite	CuFeS2
Coveline	CuS
Galena	PbS
Millerite	NiS
Mobybdenite	MoS2
pyrite	FeS2
Pyrrhdite	Fe11S12
Sphalerite	ZnS

When mining whatever its form, the rock mass is highly fragmented, significantly increasing the surface and therefore the acid production rate

4. Environmental issues related to AMD

The overall impact of AMD is very much dependent on local conditions and varies widely, depending on the geomorphology, the climate and the extent and distribution of the AMD-generating deposits.

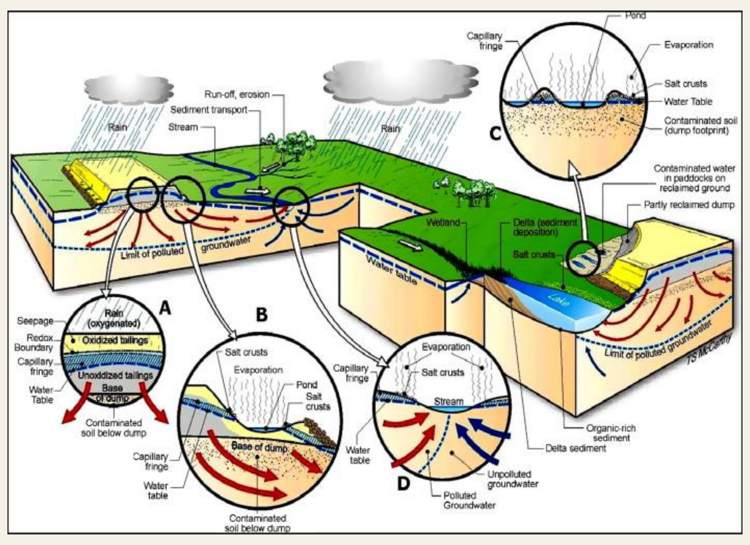


Fig.3. Schematic diagram showing various aspects of the generation and dispersal of acid mine drainage in and around tailings dumps in Kilomoto (gold mining in East of Congo) Mees, F., et al. 2013)

The impact of mine drainage on aquatic ecosystems varies gradually according to local physicochemical conditions (gas chemistry, flow, dilution, local climatic conditions, size and capacity of the receiving stream buffer)

Water pollution

- Significant contamination of terrestrial and
- Aquatic environments adjacent to mine sites in most of the stanniferous, copperbelt and gold bearing deposits

Observations made on wastewater, for example in Katanga, have shown the persistence of odors, color and air bubbles which are indicative of the presence of these reagents. Various authors who have investigated the toxicity of these reagents have shown that almost all are contaminated with heavy metals and traces.

Photo 5: example of river showing the discharge of effluents from South Mining Company Katanga (CMSK) Kipushi, Katanga(Pourret, O., et al.2016)

Example of some case: Table 5: Mean trace metal concentrations in waters (µg/L-1) of the Naviundu river basin, Luano and Ruashi rivers and Luwowoshi spring in Lubumbashi city during February, March and April 2016(Křibek, B et al. 2011)

Rivers, channel, spring	Sample code	pH	Sr-88 (µg·L⁻¹)	Mo-98 (µg·L⁻¹)	Ag-107 (µg·L⁻¹)	Cd-114 (µg·L⁻¹)	Sn-118 (µg·L⁻¹)	Cs-133 (µg·L⁻¹)	Ba-137 (µg·L⁻¹)	Pb-208 (µg·L⁻¹)	Bi-209 (µg·L⁻¹)	U-238 (µg·L⁻¹)	Al-27 (µg·L⁻¹)	V-51 (µg·L⁻¹)	Cr-52 (µg·L⁻¹)	Mn-55 (µg·L⁻¹)	Fe-56 (µg·L⁻¹)
	WHO	6.5-8.5	Na	Na	Na	3	Na	Na	1,300	10	Na	30	200	Na	50	50	300
	EPA	6.5-8.5	Na	Na	100*	5	Na	Na	2,000	15	Na	30	50-200*	Na	100	50*	300*
	EU	6.5-8.5	Na	Na	Na	5	Na	Na	Na	10	Na	30	200*	Na	50	50*	200*
Naviundu river under bridge on De Plaines avenue	21ER	5.1	286.037	0.451	0.452	6.95	0.029	0.103	94.147	8.18	0.008	1.16	501.641	2.204	1.183	16,687.622	2,678.391
Naviundu river under bridge on Kasenga road	22ER	5.3	168.013	0.559	1.522	0.356	0.038	0.061	89.575	2.712	0.003	1.042	133.83	1.482	0.865	2,071.28	4,687.757
Naviundu river at Cimenkat (Katanga's Cement Factory) exit	23ER	4.7	374.377	0.238	0.311	11.358	0.008	0.107	92.431	5.607	0.005	0.886	400.5	1.731	0.797	29,714.593	962.45
Chemaf (Chemicals of Africa) hydrometallurgical plant effluent	24ER	5.8	242.301	0.329	1.86	9.697	0.068	0.082	255.788	472.287	0.012	4.163	5,961.954	21.014	8.185	2,104.966	5,152.054
Kabecha river	25ER	5.3	235.054	0.264	0.627	0.181	0.059	0.088	119.462	2.207	0.005	0.438	147.826	2.181	0.891	570.083	1,239.863
Ma-Vallée river	26ER	5.1	63.275	0.071	2.359	0.138	0.026	0.043	158.897	2.486	0.003	0.109	417.806	3.907	0.858	118.47	1,496.352
Foire channel	27ER	5.7	91.263	0.312	2.669	0.099	0.012	0.02	78.264	1.476	0.002	0.258	178.076	2.084	0.681	211.415	1,254.168
Mukulu river	28ER	5.5	30.849	0.042	1.16	0.072	0.019	0.015	40.759	0.985	0	0.095	318.921	1.273	0.449	69.596	1,044.442
Kamasaka river	29ER	5.3	138.936	0.043	2.2	1.309	0.018	0.056	85.286	3.164	0.003	0.844	572.538	3.723	1.653	2,714.81	2,056.599
Naviundu river at its confluence with Kamasaka river	30ER	4.2	31.604	0.027	0.851	0.246	0.005	0.028	41.183	3.348	0.001	0.226	601.693	3.09	0.824	154.322	3,398.445
Kalulako river	31ER	4.6	276.153	0.423	1.536	3.229	0.325	0.103	115.618	2.466	0.006	1.073	202.248	1.267	1.161	14,893.741	2,085.919
Naviundu river at its confluence with Mukulu river	32ER	4.9	41.149	0.091	0.911	0.07	0.019	0.016	29.211	0.434	0	0.139	45.121	2.137	0.339	62.228	221.785
Ruashi river	33ER	5.3	151.458	0.093	1.069	0.047	0.021	0.01	64.829	1.059	0	0.101	398.272	0.064	0.495	3,985.105	789.124
Luano river	34ER	4.8	55.064	0.029	0.96	0.365	0.003	0.071	307.641	8.846	0.001	1.15	2,329.495	6.698	1.772	3,606.887	14,258.9
Luwowoshi spring	35ES	5.8	118.378	0.193	1.226	0.133	0.09	0.031	71.578	5.188	0.002	0.31	316.923	2.196	0.944	510.649	5,098.152

The composition of minerals in sulfide decisive influence on the production of acid effluents, however sulfide oxidation also requires oxygen and water

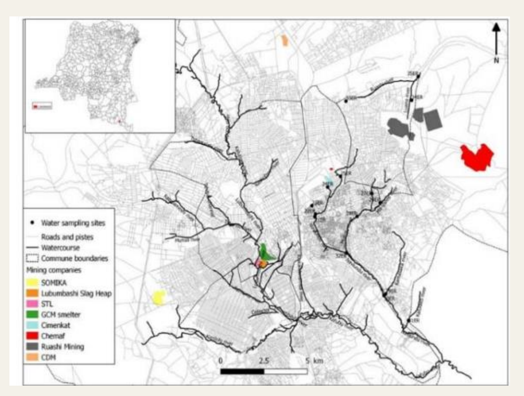
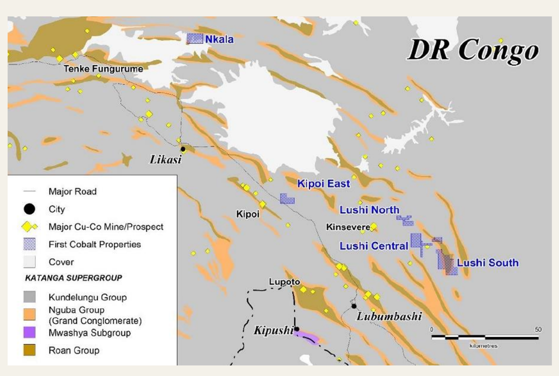


Fig. 1 Map of water : Heavy and Traces Metals Contamination of Water in Naviundu River Basin, Luano and Ruashi Rivers and Luwowoshi Spring in Lubumbashi City, Democratic Republic of Congo(Akcil et al.2006)

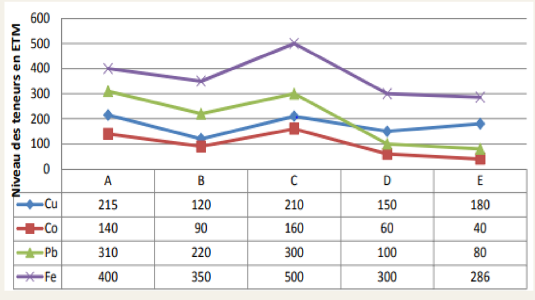


Field and petrographic observations indicate that hypogene copper-cobalt mineralization took place in two main phases; an initial diagenetic event formed strata-bound, disseminated to fine laminated copper sulfides, and a second overprinting sulfide event generated crosscutting epigenetic veins related to the Lufilian orogeny.

The low water pH increases metal bioavailability to aquatic organisms living in the rivers, channel and spring and to human beings who depend on those waters to meet their domestic and recreational needs.

Soil pollution including plant uptake of the metals

Graph 1: Concentration of metals in the soil (ppm) (Kalala et al. 2016)



Soils showed varying degrees of contamination by trace metals, although the measured levels of Cu, Co, Pb and Fe in the soils were below the detection limit in many sampling points represented on graph 5.

Photo 6: Basin tailings Twangiza Mining (BANRO) located in the South Kivu Mountains, Luhwindja

The potential release of acid mine drainage is high given the presence of sulphides in the mineralization showing in photo 6

Human health problem

The accumulation of metals in the feed and food chain is also a possible consequence of contamination of waterways.

Urinary samples collected from 351 subjects aged 2-74 years were analysed for 17 metals including As, Cd, Cu, Co, Pb and U. The results indicated significantly (p<0.0001) elevated urinary concentrations of metals Se, Co, As, Pb and U in study participants that lived within 3 km of the mine and smelters, compared to those that lived further away. And some urinary concentrations (i.e. Al, Zn, Mn, Mo, and Te) were statistically significantly more elevated in sites located 3-10 km away from the mine and smelters than at sites closest to the sources and the control community.

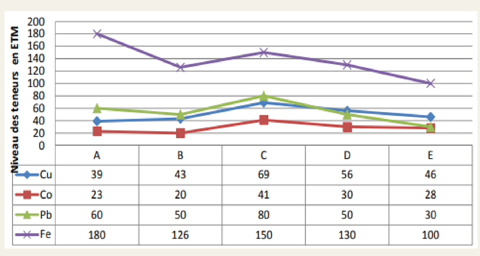
Four people died in the Musebe mining quarry in northern Katanga province on the night of Monday to Tuesday, June 25. They have succumbed to a disease that has been rife in this mine for about a week and is manifested by coughing and violent headaches.

Ecosystem including plants

low pH of Ferralsol that increases trace element mobility, intensity of erosion by rainfall in the rainy season, and aerial dispersal of metal particles by wind in the dry season.

ferric hydroxide precipitation of a sand discharge

Metal concentration in the leaves (ppm)



Graph 2: Concentration of metallic trace elements in plant leaves (ppm) (Kalala et al. 2016)

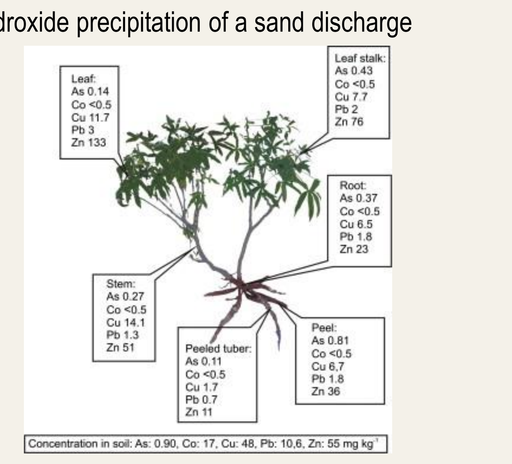


Fig. Concentrations of metals (median values, mg kg−1, dw) in cassava tissues from the same sampling site in the uncontaminated part of the katangian Copperbelt. Median values in soil are given for comparison. Number of samples taken: cassava = 5, soil = 5(Banza et al. 2014)

5. Environmental policy of DRC

The Congolese Mining Code defines the generative mining waste of acid mine drainage as not only consisting of mining waste rock but of any solid or liquid tailing resulting from the mineral or metallurgical treatment (cf. Art. of the Mining Code, 2002).

1. A discharge with low risk in mg / l

Table 6: metals concentration below which the tailings are low risk (Mining Code, 2002)

Concentration in mg/l									
As	Cd	Cr(hex)	Cu	Ni	Hg	Pb	Cr(tot)	Fe	Zn
1.00	0.10	0.05	0.30	0.50	0.002	0.60	1.00	2.00	1.00

2. The release is leachable

Table 7 concentrations beyond which the tailings (can generate AMD) are at high risk concentration in mg / l (Mining Code, 2002)

Concentration in mg/l								
As	Ba	B	Cd	Cr(tot)	Hg	Pb	Se	U
5.00	100	500	0.50	5.00	0.10	5.00	1.00	2.00

3. Tailing with High risk: when producing an acid leachate, the concentrations are higher than the values determined in Table 6.

6. Conclusion

Drainage of acidic runoff that percolates former waste water ponds pollutes water resources and soils. Today the situation is deteriorating with increasing river pollution, ground water and arable land. The parks are sometimes discharges upstream villages, dry weather prevailing winds carry dust until populated or agricultural areas, with all the health and environmental risks that may ensue. In addition, these sites are frequently invaded by artisanal miners in order to recover the minerals that remain in the releases, which created conflicts with the releases parks owners mining companies.

7. Recommendation or research needs

In the case of D R Congo, we recommend the following treatment system
a) Reduction of the volume of water to be treated by the installation of a soil coating on waste rock piles and tailings ponds generating acid mine drainage;
b) Transport of the contaminated effluent to a chemical treatment system using an anoxic limestone or biochar drain to reduce acidity.
c) Passage of partially deacidified effluent into a sulfo-reducing passive bio-filter;
d) Flow of water to a settling basin or even an aerobic or anaerobic scrubber.
e) Spill into the environment.

Acknowledgments

This work was supported by National Institute for International Education, Chonbuk National University and Environmental Remediation Engineering Laboratory(Rep. Korea)