University of Alberta

Dynamic Column Investigation of Composite or Consolidated Tailings Release Water Treatment by Mature Fine Tailings

by

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A thesis submitted to the

Faculty of Graduate Studies and Research

in partial fulfillment of the requirements for the degree of

Master of Science

in

Environmental Science

Department of Civil and Environmental Engineering

University of Alberta

Edmonton, Alberta

Fall 2008

Your file Votre référence
ISBN: 978-0-494-47386-3
Our file Notre référence
ISBN: 978-0-494-47386-3

To My Wife

ABSTRACT

The dynamic column tests were conducted to investigate the physical, chemical, and microbiological processes in mature fine tailings over composite tailings or consolidated tailings (CT) co-disposal systems. For the four testing systems, unamended CT water, CT water amended with Ca^{2+}, Mg^{2+}, SO_4^{2-}, or acetate, or West-In Pit water was fed into the columns at two flowrates, approximately 6 mL/h and 20 mL/h. This study showed that different removal efficiencies for Ca^{2+}, Mg^{2+} and SO_4^{2-} were observed from the water in the testing columns. Cation exchange between Ca^{2+}, Mg^{2+} and Na^{+} was identified to be an important mechanism. Most probable number results suggested that sulphate-reducing bacteria outcompeted methanogens in the presence of high SO_4^{2-} concentrations. The flowrates affected the removal efficiencies in the dynamic columns. Low flowrates seemed more favorable for achieving higher removal efficiencies. Therefore, it is recommended that the low flowrates should be further investigated using a flow control pump to achieve more accurate flow rates.

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my supervisor Dr. Selma Guigard for her patience, guidance, encouragement, understanding and support throughout the course of this study. Dr. Guigard devoted her time and effort to make this study a success. I consider it a matter of great privilege and rare opportunity to work under her supervision.

I wish to extend my thanks to Dr. Phillip Fedorak for his great help and guidance of my research. Without of his help, this project cannot be fully completed. The study of this project also benefited very much from Dr. Fedorak previous research experiences and results in the tailings.

I am also thankful to Syncrude Canada Ltd., Suncor Energy Inc., and Canadian Natural Resources Ltd. for their generous funding to this project. Without their initiative and financial support, this project would not be a reality.

I wish to extend my thanks to Dr. Mike MacKinnon from Syncrude Canada Ltd. for his support and willingness to help.

I wish to thank Mr. Steve Gamble, Mr. Garry Solonynko and Ms. Debbi Coy for their great help in doing my experiments.

Also, my sincere gratitude and appreciation go to my wife, Minnan Liu, for her patience, support, understanding and sacrifices during this study. I also appreciate the help of many students in the Environmental Engineering group.

Finally, special thanks are to all my committee members for their time and efforts in reading this thesis thoroughly and make helpful comments and suggestions.

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Ac^-	acetate
AVS	acid volatile sulfides
BDL	below detection limit
CT	composite tailings or consolidated tailings
EC	electrical conductivity
Eh	redox potential
g	gram
g	gravity
GC	gas chromatography
H	height
h	hour
ID	inside diameter
L	liter
M	mole per liter
MFT	mature fine tailings
mg	milligram
mL	milliliter
MPN	most probable number
NST	non-segregating tailings
OD	outside diameter
ORP	oxidation - reduction potential

SRB	sulfate-reducing bacteria
t_{incu}	incubation time
t_R	retention time
WIP	West-In Pit

Chapter 1

Introduction

1.1 Statement of Problem

As the demand for oil increases, oil sands production is becoming more and more important for the oil industry. Many oil companies, such as Syncrude Canada Ltd., Suncor Energy Inc. and Shell Canada Ltd., have increased their investments in the oil sands industry to expand oil production. However, the oil industry brings not only billions of dollars of profits, but also environmental issues to the province of Alberta, especially issues related to wastewater and tailings produced from oil sands activities.

Some of the oil sands in northeastern Alberta, Canada, are strip mined and bitumen is separated from sand and clay by an alkaline hot water extraction process (the Clark Hot Water Extraction Process) leaving millions of cubic meters of tailings for disposal (Fedorak et al. 2003). In this hot water extraction process, the froth that is produced by hot water extraction process usually contains about 60 wt% bitumen, 30 wt% water and 10 wt% solids (Bruce 2006). After bitumen is separated from the froth, the remaining solids and tailings are pumped into tailings ponds. Although the sand portion of the tailings settles rapidly and forms a beach, the fine clay minerals do not settle rapidly (Kasperski 1992). The tailings, a mixture of solids, water, salt, and unrecovered bitumen, are stored in large setting basins called tailings ponds (MacKinnon 1989). By gravitational settling, the coarse sands settle to the bottom of the tailings ponds. The remaining part of the tailings pond consists of tailings liquids, a mixture of clay and silt particles, inorganic and organic compounds, residual bitumen, and water. With time, these fine tailings dewater and densify in the tailings ponds. After a few years of relatively rapid densification, a dense mature fine tailings (MFT) zone will form at the bottom of the tailings ponds and the release water may be reused in the extraction process (List and Lord 1997). The MFT has a solid content of greater than 30 wt% however the dewatering and densification of MFT under natural conditions is very slow and it may take hundreds of years for MFT to be consolidated into a trafficable consistency (FTFC 1995).

Any tailings must be held on site because the companies operate under a zero-discharge policy (Fedorak et al. 2003). So the large volume of MFT presents a unique challenge to oil sands companies. To overcome this problem, the oil sand companies have proposed and researched the CT technology (Composite Tailings at Syncrude Canada Ltd. and Consolidated Tailings at Suncor) since 1990 (FTFC 1995; List and Lord 1997), to increase the MFT densification rate and reduce the inventory of existing MFT. In the CT process, MFT is mixed with gypsum ($CaSO_4 \cdot 2H_2O$), which promotes the clay particles to aggregate and the slurry viscosity to increase. Thus, the fine solids and coarse solids stay together at deposition, creating non-segregating tailings (NST) (Matthews et al. 2000). The solids content of the CT can increase from 60 wt% initially to approximately 75 wt% within a few weeks or months, because the CT deposit starts dewatering immediately as the slurry is deposited. CT will become trafficable within a few years, leading to a dry landscape at site restoration (Luo 2004).

As a result of the high gypsum dosage (1000 mg/L as an optimum) (Matthews et al. 2000), the CT release water contains high concentrations of calcium (Ca^{2+}) and sulfate (SO_4^{2-}) (MacKinnon et al. 2000). If this water is recycled for use in the extraction process, these high Ca^{2+} and SO_4^{2-} can decrease bitumen recovery and cause other process problems. To avoid any detriment to bitumen recovery efficiency and plant integrity, the oil sands companies have been examining various release water treatment options and process modifications to reduce the Ca^{2+} and SO_4^{2-} concentrations in the recycled release water. One such process modification is the co-disposal of CT and MFT, with the CT being placed beneath MFT. This CT beneath MFT deposition is expected to take advantage of physical, chemical, and anaerobic microbial processes occurring in the MFT to remove, or at least reduce, the high concentrations of Ca^{2+} and SO_4^{2-} in the CT release water due to ion exchange and SRB changing SO_4^{2-} to S^{2-}. At Syncrude Canada Ltd., a pilot-scale field demonstration test was conducted in 1995 to study CT beneath MFT deposition. The test showed that the CT beneath MFT deposition initiated changes that were beneficial to tailings disposal, with respect to the release water quality and densification rates of both MFT and CT (Shaw et al. 2001). However, prior to adopting the CT beneath MFT deposition scheme as a viable full-scale tailings disposal and management alternative, the physical, chemical, and microbial processes should be investigated and better understood (Shaw et al. 2001).

1.2 Objectives of Research

The focus of this research was to investigate, in a laboratory setting, the CT beneath MFT deposition as a possible process modification to improve the quality of release water in terms of Ca^{2+} and SO_4^{2-} concentrations. Previously, bench-scale column tests were conducted in the Department of Civil & Environmental Engineering at University of Alberta, to monitor the release water composition and densification of

MFT and CT in static CT beneath MFT systems (Luo 2004). As a continuation of this work, the present study will focus on dynamic column studies to mimic the *in-situ* conditions in tailings ponds and to investigate the processes occurring in this co-disposal system as the CT release water flows through the MFT layer.

The overall objectives of this project were to conduct dynamic column tests under various laboratory conditions to:

(a) demonstrate whether the disposal of CT beneath MFT is a feasible technology for CT release water treatment, that is for removing or reducing Ca^{2+} and SO_4^{2-} concentrations in the CT release water by ion exchange and by SRB activity reducing SO_4^{2-} to S^{2-}, and

(b) analyze the physical, chemical, and microbial changes occurring in both the CT and MFT as a result of CT release water flowing through MFT.

The expected study results will lead to a better understanding of these processes and hence the feasibility, in terms of capacity and kinetics, of this CT beneath MFT disposal as a method to improve release water quality.

1.3 Thesis Organization

The thesis first presents a literature review in Section 2. Section 3 then describes the materials and methodology used the experiments including the equipment set up, experimental procedures, experimental condition controls, and sample analyses. The experimental results and discussions are presented in Section 4. The conclusions and recommendations for future study are finally summarized in Section 5.

Chapter 2

Literature Review

2.1 Oil Sands Industry

2.1.1 Oil Sands Processing

Oil sands are geological formations that consist of a mixture of bitumen, formation water, coarse sands, and fine particles (clays and silts). Oil sands can vary in grade, fines or clay content, mineralogy, and salt content. Typical oil sands ore contains an average of approximately 10 wt% of bitumen with the remainder being coarse sands (>22 μm in diameter), fine particles (<22 μm in diameter), and water (FTFC 1995). The bitumen is molasses-like viscous oil that will not flow unless heated or diluted with lighter hydrocarbons.

The extraction process that is currently being used to separate the bitumen from the oil sands ore is based on the Clark Hot Water Extraction Process, which was developed by Dr. Karl Clark in the 1920s and has been proven to be an efficient and economical process of recovering the bitumen from the oil sands. The schematic flow diagram of the oil sands process, from open surface mining to synthetic crude oil production, is shown in Figure 2.1 (Bruce 2006).

In the Clark Hot Water Extraction Process, prior to bitumen separation, the oil sands are slurried and conditioned in large horizontally rotating tumblers by mixing with hot water, steam, and caustic soda (NaOH) for less than 10 min. The conditioning is optimized at 80°C and pH ranging from 9.0 to 11.0, and this conditioning is achieved by the introduction of steam and the addition of the caustic soda. At this conditioning stage, bitumen is dislodged from the sand particles, resulting in a loose association of bitumen, sand, and water.

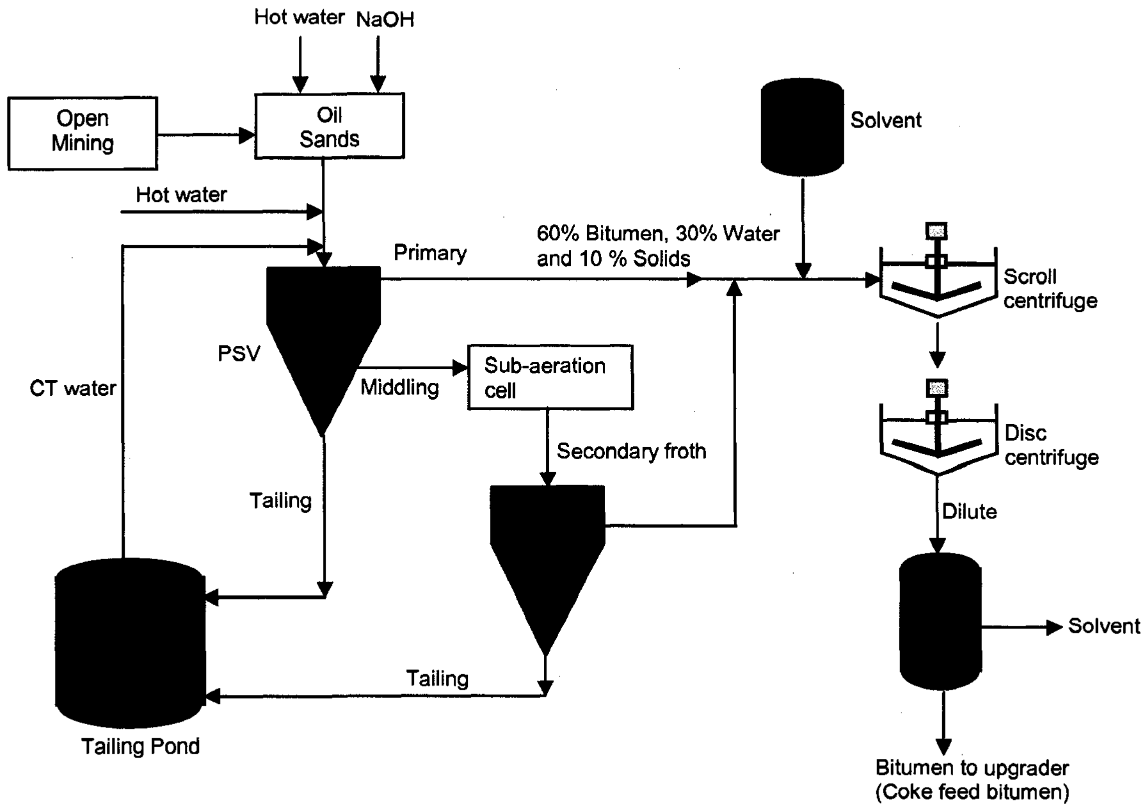


Figure 2.1 Schematic flow diagram of oil sands processes

After the large size particles, such as rocks and lumps of undigested oil sands and clay, are removed from the slurry via vibrating screens, the slurry is further diluted with additional quantities of hot water and pumped into the primary separation vessels, where the bitumen floats to the surface as primary froth and the coarse sands settle to the bottom as primary tailings. The middlings (from the central portion in the primary separation vessels) and the primary tailings are combined and pumped to the tailings oil recovery vessels (the secondary separation vessels) to further recover any remaining bitumen as secondary froth.

The secondary froth, together with the primary froth, is first de-aerated and heated, then fed to the froth treatment plants. The bitumen froth contains large quantities of water and fine solids (mainly clays), which must be removed, by a froth treatment process, before proceeding to the upgrading process. During the upgrading process, bitumen is converted from the viscous, tar-like material to a low-sulfur synthetic crude oil (a light gold-colored liquid), using coking and hydrocracking technologies. The resulting synthetic crude oil is then transported by pipeline to conventional refineries for further refining.

2.1.2 Wastes in Oil Sands Processing

One of the major disadvantages of the Clark Hot Water Extraction Process is that large quantities of tailings are produced during the separation of bitumen from oil sands. Tailings are slurries containing water, coarse sands, fines, and unrecovered bitumen (FTFC 1995).

Due to the "zero discharge" policy, neither the tailings solids nor the released water can be discharged into the environment. Therefore, all of the tailings from the primary and secondary separation vessels and the froth treatment plant are discharged into large settling basins (i.e. tailings ponds), as the "total extraction tailings", with a solids content between 40 and 55 wt% (Luo, 2004). Upon deposition, most (>95%) of the coarse solids (particle diameter >22 μm, also called tailings sands) segregate and settle out from the fines fraction (particle diameter <22 μm). Tailings sands are usually used to build dykes that surround the tailings ponds. About 50% of the fines are entrained with the coarse solids and settle out with them. The remainder of fines (known as fine tailings), consisting mainly of slow-settling fine silt and clay particles, water, and residual bitumen, are carried into the tailings ponds as thin fine tailings, which have a solids content of about 3 to 8 wt% (MacKinnon and Sethi 1993). The "total extraction tailings" from the oil sands extraction process are thus segregated into tailings sands and fine tailings, which are disposed of separately.

In the tailings ponds, the thin fine tailings settle rapidly to about 20 wt% solids content over a period of several months, and then consolidate very slowly over 2 to 3 years to approximately 30 wt% solids content (Mikula et al. 1996). The fine tailings with solids content larger than 30wt% are termed "mature fine tailings" (MFT). The produced surface water (i.e. the release water) in the tailings ponds is low in suspended solids and is reused as recycle water in the extraction plant (MacKinnon and Sethi 1993).

The fine tailings, resulting from the bitumen extraction process, are of great concern to the oil sands industry and environmental agencies. This concern is because the fine tailings occupy a large volume, and their densification is very slow. Therefore, since the 1990s, research has been conducted to manage and dispose of fine tailings efficiently, cost effectively and in an environmentally safe manner.

2.1.3 Oil Sands Industry in Alberta

Second only to the Saudi Arabia reserves, oil sands deposits in Alberta are described as "Canada's greatest buried energy treasure," and "could satisfy the world's demand for petroleum for the next century" (http://www.energy.gov.ab.ca/89.asp). The oil sands occur in Cretaceous fluvial-estuarine deposits of northeastern Alberta, covering an area $>140{,}000$ km^2. Bitumen is also found in Devonian carbonates (most notably within the Grosmont Formation) but this bitumen has not been commercially produced (http://www.mining-technology.com/project_printable.asp?). It is estimated that the oil sands deposits in Alberta contain over 1.7 trillion barrels of bitumen, of which approximately 300 billion barrels are recoverable with existing technologies. Canada's energy supply can be secured for more than 200 years if the oil sands in Alberta are fully developed (Syncrude 2000a and 2000b).

Annual oil sands production is growing steadily as the industry matures. According to the Canadian Association of Petroleum Producers, in 2005 industry investment in Alberta oil sands totaled approximately $10 billion. The marketable oil sands production increased to 966,000 barrels per day in 2005. With anticipated growth, this level of production could reach 3 million barrels per day by 2020 and possibly even 5 million barrels per day by 2030 (http://www.energy.gov.ab.ca/89.asp).

Syncrude Canada Ltd. is now the world's largest producer of crude oil (known as Syncrude Sweet Blend) from oil sands. Syncrude Canada Ltd. – a joint venture of oil and gas companies mining the Athabasca oil sands – holds eight leases covering 258,000 hectares, 40 km north of Fort McMurray. Ranked as the world largest producer of synthetic crude from oil sands – and the biggest single source in Canada – nearly 95 million barrels of the company's "Syncrude Sweet Blend" were shipped in 2006. The consortium runs three separate mines – the original Base Mine and the North Mine, both near Mildred Lake on Lease 17, together with the Aurora Mine some 35 km to the north of Fort McMurray. The upgrader facility, also located on Lease 17, treats oil sands from all three mines (http://www.ags.gov.ab.ca/activities/cbm/alberta_oil_sands.html).

Syncrude Canada Ltd. and Suncor Energy Inc. are currently mining the oil sands using the surface mining operation, and extracting and upgrading the bitumen from the Athabasca oil sands deposit. The two companies produce over 500,000 barrels of crude oil daily from about 1 million tons of ore processed (Luo 2004), providing approximately 20% of the oil supply for Canada (Fedorak et al. 2003).

2.2 Wastes Management in Oil Sands Industry

2.2.1 Fine Tailings Management and Challenges

It is of great importance to manage the by-products of oil sands industry, namely, the tailings. The tailings ponds have to be reclaimed once the mining company's leases expire. Fine tailings pose a big challenge to the industry in terms of disposal technologies and management optimization.

Fine tailings management and disposal are creating two challenges for the oil sands industry: (i) the slow self-weight densification rate of the fine tailings and (ii) the large volumes of fine tailings.

The fine tailings have a slow densification rate due to the nature of the fine particles (mainly kaolinite and illite clays) that make up these tailings and due to the chemistry of the porewater found in the tailings. The high Na^+ content of the fine tailings porewater will cause clay particles to repel each other and remain in suspension in the tailings water, thus prevent the fine tailings from settling. After 2 to 3 years of relatively rapid initial settling and densification, the fine tailings will reach a solid content of approximately 30 wt% and become MFT. Further densification of the MFT is much slower. It is estimated that the natural densification of MFT to a trafficable surface would take hundreds of years (FTFC 1995). An empirical equation for describing the solids content increase of fine tailings over time under self-weight conditions, derived from tailings pond data from Syncrude Canada Ltd. is as follows(Sworska et al. 2000):

$$S_c = 18.6 + 6.35 \ln y \tag{2-1}$$

where S_c is the fine solids content (wt%) and y is the number of years of settling.

Based on the properties of fine tailings, some studies have investigated the use of coagulation or flocculation to improve the aggregation and settling of tailings. These studies involve taking the tailings and using coagulation or flocculation to thicken them into a paste (Sworska et al. 2000). The tests were carried out using a high molecular weight polyacrylamide flocculant and the effects of pH, polymer dosage and presence of divalent cations on the flocculation of tailings was investigated. The results showed that the addition of the flocculant led to the development of a bimodal size distribution of particles consisting of flocs and dispersed fine particles under alkaline conditions. It was concluded that flocculation was more efficient in the presence of divalent cations over the pH range studied.

The second challenge posed by fine tailings management and disposal is the production and continuous accumulation of large volumes of fine tailings. Because of the high water content in the fine tailings, the fine tailings retain fluid characteristics and must be stored behind geotechnically secure dykes with little possibility of being used as a solid matrix for reclamation. The accumulation and disposal of the fine tailings have been on going since 1967 at Suncor's site and since 1978 at Syncrude Canada Ltd.'s site. Due to "zero-discharge" policy, the fine tailings are stored in large tailings ponds on-site. Consequently, a large inventory (more than 500 million m^3) of fine tailings has been accumulated in the tailings ponds at Syncrude Canada Ltd. and Suncor Energy Inc., near Fort McMurray, Alberta (Liu and Fang 1995). The Mildred Lake Settling Basin is Syncrude Canada Ltd.'s largest settling basin and covers about 25 km^2, with a water surface area of about 12 km^2. Suncor's four tailings ponds cover a total area of about 13 km^2, with a water surface area of about 7 km^2 (FTFC 1996). Fine tailings are being accumulated at a rate of approximately 20 million m^3/year (Liu and Fang 1995).

Storage and disposal of the large volumes of fine tailings are considered to be the major environmental challenge facing the surface mining oil sands industry (AERCB 1984). Thus, the oil sands companies, government, and research institutions make considerable efforts to identify suitable technologies for reclaiming the existing fine tailings inventories as well as reducing the future volumes of fine tailings that are being continuously produced (FTFC 1995).

2.2.2 Available Alternatives for Fine Tailings Management

The fine tailings management and reclamation programmer must meet the following requirements (FTFC 1995):

(i) the direct contact of fine tailings with the environment and the release of contaminants into the environment are restricted;

(ii) the reclaimed area is stable, productive, and biologically self-sustaining.

There are a variety of approaches to dealing with tailings problems (Kasperski 1992) including:

(i) designing retention ponds to store all tailings produced;

(ii) developing physical, mechanical, chemical, biological or geotechnical methods to improve the tailings settling characteristic;

(iii) modifying the oil sands extraction process to minimize tailings production;

Each approach has its advantages and disadvantages. No single reclamation technique can handle the volumes of fine tailings in a technically sound, environmentally friendly, and economically acceptable manner. In fact, the reclamation of the fine tailings requires integrating different techniques. From an overall point of view, the reclamation of the fine tailings will be accomplished through a combination of "dry" and "wet" landscape techniques (FTFC 1995).

The dry approach involves dewatering the fine tailings or incorporating the fine tailings with a solid material so that the deposits are claimed as a land surface suitable for terrestrial vegetation. The dry landscape options include: (i) dewatering of the fine tailings through processes such as evaporation and freeze-thaw; (ii) incorporation of fine tailings with overburden clays; and (iii) creating NST or CT (FTFC 1995). The wet approach maintains the fluid character of MFT in aquatic ecosystems. It is achieved by resorting to a lake system, whereby the fine tailings are capped with a layer of water to be isolated from direct contact with the surrounding environment (FTFC 1995). The objective of this reclamation option is to produce a stable, productive, and self-sustaining cap water zone, which can support viable aquatic ecosystems shortly after water capping. The retention of MFT as a fluid will require stable secure holding areas, whereas terrestrial landscapes may allow for easier reclamation.

In practice, the final strategy will depend on a variety of considerations including availability of economically sound technologies, environmental assessments, and stakeholder acceptance. Thus, one must have a clear idea whether the goal is to provide maximum amount of recycle water or to minimize the sludge volume, even though these objectives do not have to be exclusive. Also, it is obvious that the proposed methods will be put into use only if they are scientifically, technically, economically and environmentally sound.

To better understand the alternatives in fine tailings management, the physical and chemical properties of MFT and CT will be discussed in the following sections.

2.3 MFT

After bitumen extraction, tailings are pumped into tailings ponds or settling basins where the sand fraction settles, and most of the aqueous slurry of fines (silts, clays and residual hydrocarbon) slowly densifies to a suspension called MFT (Siddique et al. 2006), with characteristics of low permeability and slow densification or consolidation rate. Among all the geotechnical and physical MFT properties, solids component plays the most important role. The rate of solids settling and consolidation determines the capacity and lifetime of the containment ponds.

The MFT from the Clark Hot Water Extraction Process have been characterized by a variety of methods (Kasperski 1992; Mikula et al. 1995; Morgenstern and Scott 2000). The common results reveal that the bulk geotechnical and physical properties of the MFT are determined by the MFT component interactions at the microscopic level. Two outstanding issues regarding the structure and properties of MFT are highlighted by the research sponsored by the Fine Tailings Fundamentals Consortium (FTFC): (i) the relative importance of mineral or organic fractions in determining MFT properties, and

(ii) the gel versus floc structure of MFT. The studies have found that the MFT can be described as a suspension whose settled volumes and water holding capacity are determined by the mineral components rather than by the residual bitumen (FTFC 1995).

2.3.1 Physical Properties of MFT

The structure of MFT can be explained by two models (FTFC 1995): (i) the bitumen model and (ii) the mineral model. In the bitumen model, the slow densification of MFT slurry is attributed to the presence of residual bitumen and soluble organic surfactants. These components bind the clay particles into a stable aggregate structure that is slow to dewater and consolidate. The mineral model attributes the water holding capacity and stability of MFT to the presence and interaction of fine mineral clays. The clay particles interact with each other and form a three-dimensional gel-like network structure (a "card house-like" structure) in the presence of electrolytes. Other MFT components such as bitumen, water and coarser solids, are trapped in the network. A definite structure of clay mineral flocs or aggregates was observed using cryogenic electron microscopy (Mikula et al. 1996). Consequently, the densification rate of MFT is controlled by the permeability and compressibility of these mineral flocs. Studies since 1991 have favored the mineral model as a model to account for MFT stability (Mikula et al. 1996).

According to the mineral model of MFT structure and stability, the bulk volume and water holding capacity of MFT are determined by the mineral components (FTFC 1995). The amount of ultra-fines in the particle diameter range of 0.2 to 0.3 μm (which originates from the oil sands ores) in MFT contributes to more than 90% of its water holding capacity (FTFC 1995). Furthermore, the bulk properties of MFT are a function of the chemistry of the porewater (FTFC 1995). Generally, the MFT from the Clark Hot Water Extraction Process is a weakly flocculated suspension of sodium-rich clays that densifies slowly by self-weight settling.

Tang (1997) reviewed and examined the MFT microstructure using scanning electron microscopy. The MFT has a highly dispersed three-dimensional gel structure with clay particles aligned in edge-to-edge and edge-to-face patterns. The porewater chemistry of the MFT, including pH, alkalinity, salinity, ionic content, and organic matter, may contribute to the formation and stability of the MFT structure. The residual bitumen in MFT could also reduce the MFT hydraulic conductivity, and hence reduce the MFT consolidation rate. The high water holding capacity and slow densification rate of MFT may be explained by this gel structure.

2.3.2 Chemical Properties of MFT

Most of the waste materials existing in tailings are derived from the oil sands themselves. The majority of fine mineral solids in the MFT are clays (<2 μm in particle diameter), the remainder being silts (from 2 to 22 μm in particle diameter) and fine sands (FTFC 1995). Residual bitumen content is typically in the range of 2 to 10 wt% (weight of bitumen per weight of dry minerals) (FTFC 1995).

The major anions and cations contained in MFT porewater are chloride (Cl^-), sulfate (SO_4^{2-}), bicarbonate (HCO_3^-), sodium (Na^+), potassium (K^+), magnesium (Mg^{2+}) and calcium (Ca^{2+}). Sodium is the predominant cation, accounting for approximately 95% of the cation equivalents (ion concentration divided over ion equivalent weight) in the MFT porewater. Most of the Na^+ comes from the process chemicals. The other cations (K^+, Mg^{2+}, Ca^{2+}) are minor components that represent only about 5% of the total cation equivalents (MacKinnon 1989).

HCO_3^- is the most abundant anion and accounts for 50 to 75% of the anion equivalents. The pH of the MFT porewater ranges from 7.3 to 8.3 (Luo 2004) and thus the dissolved inorganic carbon is present predominantly as HCO_3^-. SO_4^{2-} concentrations are affected by microbial processes. In anaerobic environments, SO_4^{2-} is reduced to S^{2-} by sulfate-reducing bacteria (SRB). Both Na^+ and Cl^- ions are conservative species since their concentration in MFT porewater are not substantially affected by microbiological or chemical interactions (MacKinnon 1989).

The concentrations of nutrients such as nitrite, nitrate, and orthophosphate in the MFT porewater are low. Most of the nitrogen is present as ammonia in the range of 2 to 6 mg/L (MacKinnon 1989).

The concentrations of dissolved trace metals in fine tailings water are low relative to regulatory guidelines for the protection of freshwater aquatic biota and have been maintained quite constant over time. Usually only aluminum (Al^{3+}), barium (Ba^{2+}), boron (B^{3+}), iron (Fe^{2+}), molybdenum (Mo^{6+}), strontium (Sr^{2+}), and zinc (Zn^{2+}) have concentrations above 0.1 mg/L. The trace metal concentrations in the MFT do not appear to be high enough to be detrimental to the environmental acceptability of water quality (MacKinnon 1989).

The major hydrocarbon components of MFT include unrecovered bitumen and naphtha. The concentrations of water-soluble organics released during the hot water extraction process in both the surface water and porewater of the tailings ponds are fairly low, within the range of 55 to 85 mg/L (FTFC 1995). Acid-extractable organics account for most of the acute toxicity in tailings pond recycle water. Up to 95% of the total acid fraction extractable from MFT is composed of naphthenic acids, which have been shown to be toxic to a variety of organisms (FTFC 1995, Clemente and Fedorak 2005).

Chemical, physical, and toxicological properties of the fine tailings and its porewater are a function of the source and composition of the oil sands ores. In addition, both the make-up water used for the extraction process and the chemicals added as process aids during the extraction process can add extra inorganic and organic compounds to the fine tailings stream (FTFC 1995). The composition of the water in the tailings ponds is not constant. Because all the process water and wastes are stored in the tailings ponds and the released water is recycled, the ions in the water of tailings ponds accumulate. Over time, the recycle water from the tailings ponds becomes more brackish (Mikula et al. 1996).

In summary, MFT are a weakly flocculated system of fine clays with a floc or aggregate structure that is not able to support larger particles that could stress the floc structure to initiate consolidation (FTFC 1995). The water holding capacity of the MFT is greatly controlled by the mineral composition and the floc or aggregate mineral structure. Changing the MFT floc structure is the basic mechanism for the creation of NST and other MFT treatment processes. Furthermore, biological activity has been shown in fine tailings and thus it provides an option for reclamation of fine tailings, which will be further discussed in Section 2.5.

2.4 CT

The fine tailings and MFT pose the biggest environmental challenge to the oil sands companies in reclaiming the disturbed areas and tailings ponds due to their large volumes and fluid characteristics that require a geotechnically stable enclosure (Luo 2004). As a result, CT process became an attractive tailings management approach. The CT process resorts to chemical amendments to combine the clays and fines in the MFT or thickened tailings with the coarser sand components, and consequently create a NST mixture that will rapidly consolidate (Mikula et al. 2004). NST are a mixture of fines and coarse sand particles which settle simultaneously to form a uniform deposit. The introduction of coarse solids imparts an internal stress that significantly enhances the densification rate of the NST (Luo 2004). Also, the presence of chemical additives (coagulants) is required to produce a non-segregating behavior. The commonly used chemical additive is gypsum. The addition of calcium in the form of gypsum has been known to be an effective coagulant in modifying the MFT properties (FTFC 1995).

Historically, the term of CT has been widely used in place of NST since 1995 (Shaw et al. 1996). Large-scale field tests of the CT approach were started in 1993 at Suncor Energy Inc. and in 1995 at Syncrude Canada Ltd. (List and Lord 1997). In 1996, Suncor Energy Inc. began to use CT technology based on gypsum treatment on a commercial scale to reduce the large volume of fine tailings in its tailings ponds. In 1997 and 1998, Syncrude Canada Ltd. successfully demonstrated a full-scale prototype operation of CT test using gypsum as the coagulant and the results of this work suggested that over 50% of the extraction tailings could be handled using the CT process (MacKinnon et al. 2000).

Factors affecting the segregation of the CT mixture include total solids content (density), fines content (a fraction of the total solids), particle size gradation, and type and dosage of coagulant aids. These factors can be manipulated individually or in combination to shift the segregation boundaries (Matthews et al. 2000).

Three means of slurry manipulation have been evaluated during the development of the CT process; (i) increasing in solids content by hydrocyclone densification of the extraction tailings, (ii) increasing fines content through enrichment with MFT, and (iii) adjusting the slurry properties through the addition of coagulants (Matthews et al. 2000). Without the addition of chemical coagulants, the tailings would exhibit a gap-graded particle size distribution and lead to the segregation of the fines from the coarse solids during discharge and deposition (Luo 2004). The addition of coagulant aids to the CT mixture (consisting of coarse tailings and MFT) is an essential component of the CT process. Hence, a variety of coagulant aids were assessed, including sulfuric acid, lime (CaO, $Ca(OH)_2$), acid-lime (H_2SO_4-CaO), gypsum, sodium aluminate ($Na_2Al_2O_3$), alum (48% $Al_2(SO_4)_3 \cdot 14.3H_2O$), and organic polymers (polyacrylamides) based on the segregation characteristics, deposit dewatering and densification rates, released water quality, and economics (Luo 2004). The results demonstrated that gypsum is a robust, effective, easy to handle, and readily available coagulant aid to the CT process (Matthews et al. 2000). More recent research investigated the effect of carbon dioxide addition on the strength of the MFT or fluid tailings component and found that carbon dioxide could be a useful CT or NST alternative (Mikula et al. 2004).

Long et al. (2006) measured the forces between a clay fine or silica particle and a silica wafer in aqueous solutions using an atomic force microscope, in order to provide fundamental insights into the treatment of oil sand tailings. The effect of polymer dosage, solution pH, and addition of calcium and magnesium ions on the interaction and adhesion forces was studied (Luo 2004). The synergy of the polymer and divalent ions significantly enhanced the adhesion between fine solids. The measured adhesion forces correlated well with settling characteristics, that is, the stronger the adhesion, the higher the initial settling rate. This study provided a potential new technology for oil sand tailings treatment using the synergic effect of polymers and divalent cations.

In the CT mixture, most of the fines and porewater come from the MFT. This contribution of MFT is an important factor when predicting the quality of CT release water. The optimum solids content of CT is about 60 wt% (Luo 2004). When the CT slurry is deposited and starts settling, the CT deposit experiences two stages of densification: the first stage of initial settling and the second stage of long-term self-weight consolidation. The initial settling starts immediately upon deposition of the CT mixture. The volume of the CT deposit decreases substantially with the releasing of its porewater. As the CT deposit densifies to a solids content of 75 wt% in weeks or months, approximately 50% of the initial water can be released. The rate of the initial settling depends on the amount and type of fines, chemical addition, mixing procedure, and the hydraulic conductivity of MFT. The long term consolidation of CT begins as the sand grains become in contact with one another and form a sand matrix. Excess water is slowly released from the CT as it consolidates over a long-term. If allowed to dewater and drain, the CT deposit will become trafficable in a few years. (MacKinnon et al. 2000; Tang 1997).

The resulting CT and release waters from the CT process are saline-sodic, with Na^+, SO_4^{2-}, and Cl^- being the dominant ions. When freshly deposited, the CT deposits are too soft for access by reclamation equipment, and the time required for these deposits to release sufficient water to support traffic is uncertain. A study was conducted by Renault et al. (2003) to determine the suitability of barley (*Hordeum vulgare L.*) for reclamation of fresh CT deposits and to evaluate benefits of peat amendments. The results showed that amendment of CT with peat improved germination, survival, and growth of barley, but did not prevent leaf injury (probably due to Na^+ and Cl^- and possibly multiple nutrient deficiencies). Therefore, Renault et al. (2003) suggest that field studies should be undertaken to validate their greenhouse results suggesting that barley could be used to improve dewatering of the freshly deposited substrates, reduce soil erosion, and facilitate leaching of ions by root penetration into the substrate.

The CT process produces composite tailings sand, which is a new challenging material for reclamation work. The soil remediation methods show that a reclaimed growing medium should support a healthy plant community that will evolve toward an ecosystem comparable to that of neighboring natural areas. Therefore, Jack pine (*Pinus banksiana Lamb.*), hybrid poplar (*Populus deltoides Bartr. ex Marsh.* ×*Populus nigra L.*) and red clover (*Trifolium pratense L.*) plants were used in an 8-week greenhouse bioassay to evaluate the mycorrhizal inoculum potential of CT (Bois et al. 2005). The results showed that CT was devoid of active mycorrhizal propagules. However, on hostile substrates such as saline alkaline CT, controlled inoculation of seedlings in the nursery with selected strains of mycorrhizal fungi could compensate for the low natural inoculum potential and improve survival and growth of tree seedlings after outplanting (Bois et al. 2005).

In summary, the CT process aims at retaining and consuming the MFT with the coarse solids to eventually create a sustainable and acceptable dry or wet landscape (MacKinnon et al. 2000). It enables the oil sands companies to create broadly diverse landscapes that help fulfill the commitment to the reclamation of the disturbed areas.

2.5 Microbiology in MFT and CT

Biodegradation of the residual hydrocarbons (bitumen) in tailings is of great importance for managing oil sands tailings in the long term. MFT and CT are rich in microorganisms (Fedorak et al. 2002). Fedorak et al. (2002) examined three MFT and four CT samples from three oil sands extractions companies and found that each one contains methanogens and SRB.

Active methanogenesis has been found in the Mildred Lake Settling Basin, operated by Syncrude Canada Ltd. (Holowenko 2000). The production of methane may have detrimental effects on the reclamation of the tailings ponds by affecting the tailings settling behavior, producing fugitive emission of low molecular hydrocarbons, and leading to anaerobic conditions in the cap water (Fedorak et al. 2000). Recently, an unexpected increase in the rate of densification of MFT accompanying the microbially mediated production of methane (CH_4) was reported by Fedorak et al. (2003). The rapid densification observed in methanogenic MFT suggests that microbial activity is able to enhance densification (Fedorak et al. 2003).

Dissimilatory sulfate-reduction is another important biodegradation process occurring in tailings ponds, in which sulfate is reduced to sulfide by SRB coupled to the oxidation of organic matter (Levett 1991).

$$2\ CH_2O_{(aq)} + SO_4^{2-}{}_{(aq)} \longrightarrow 2\ HCO_3^-{}_{(aq)} + S^{2-}{}_{(aq)} + 2\ H^+{}_{(aq)} \qquad (2\text{-}2)$$

$$HCO_3^-{}_{(aq)} + H^+{}_{(aq)} \longrightarrow CO_{2\,(g)} + H_2O \qquad (2\text{-}3)$$

where CH_2O represents the organic substrates. Sulfide is the metabolic product of dissimilatory sulfate reduction and will precipitate in the presence of many metal ions. Hence, SRB activity can be identified by the precipitation of black FeS (Levett 1991).

Microbial activity in a given environment will change the chemical and physical nature of that environment. Due to the release of CO_2 and the accumulation of carbonate or bicarbonate from the sulfate reduction process, the aqueous environment will have an elevated alkalinity and metal ions will precipitate as insoluble metal sulfides (e.g. FeS). If no metals are present or if the pH is low enough, the sulfide may be converted to hydrogen sulfide (H_2S) and remain dissolved in the water phase or escape to the atmosphere (Gray 1989).

Sulfate reduction will consume a substantial amount of organic substrates and produce, sometimes via acetate, CO_2 (Postgate 1984). Given a high ratio of metabolisable carbon to sulfate, SRB can deplete an environment of sulfate almost completely (Postgate 1984). The disappearance of sulfate in nature over time may be used as an index of the SRB activity (Levett 1991; Postgate 1984).

Sulfite and thiosulfate are intermediates in the normal sulfate reduction process, and can also be used as substitute electron acceptors for the growth and carbon metabolism of some SRB species (Levett 1991; Postgate 1984).

Methanogens and SRB are two important microorganisms affecting the reclamation of the tailings ponds and MFT slurry (Fedorak et al. 2000).

Methanogens are a morphologically diverse group of anaerobic bacteria unified by their ability to produce methane (Levett 1991). Methanogens grow on a limited number of simple carbon compounds as substrates, including CO_2, H_2, formate, methanol, and acetate (Levett 1991). More than half of the biogenic methane in nature is believed to originate from acetate (Postgate 1984). Methanogens are usually considered to be the last players in the decomposition of organic matters in anaerobic ecosystems. That is, they consume the metabolic end products (mainly acetate and H_2) of other strictly anaerobic bacteria as energy sources and produce CH_4 as their waste product. CO_2 and HCO_3^- serve as the terminal electron acceptors during anaerobic respiration by methanogens (Fedorak et al. 2000).

Methanogens are found in a variety of anaerobic habitats including sediments, sludge, and animal waste digesters. They require redox potential (Eh) in the range of -150 to -220 mV to thrive (Fedorak et al. 2000). In general, the presence of oxygen inactivates methanogens, but not every species of methanogen is rapidly killed by oxygen (Levett 1991).

The most common method used to enumerate specific types of methanogens is the most probable number (MPN) technique, where the sample is serially diluted and inoculated into a suitable broth medium with a specific substrate (Levett 1991). The positive and negative tubes (caused by presence or absence of methanogen growth) are scored based on the production of CH_4. After incubation, the pattern of positive and negative tubes is checked against the standardized MPN table to determine the MPN of organisms per unit volume of the sample.

SRB also need strict anaerobic conditions for growth. The redox potential (Eh) of the growth media should be around –100 mV (Levett 1991; Postgate 1984). However, some SRB can survive long exposures to oxygen and become active again if the environment becomes anaerobic. SRB can tolerate temperatures from –5 to +75 °C and pH values ranging from 5 to 9.5 (Postgate 1984).

The complex interactions between SRB and methanogens have been well studied and involve competition for substrates. Like methanogens, SRB can also use acetate and H_2 as energy sources. However, SRB use a wider range of organic compounds as their substrates compared to methanogens (Fedorak et al. 2000). Sulfate is used as the terminal electron acceptor. Therefore, sulfate amendment may stimulate the activity of SRB (Salloum et al. 2002; Fedorak et al. 2002).

SRB and methanogens are strict anaerobes bacteria. Studies have shown that SRB can outcompete methanogens for common substrates, H_2 and acetate, except in some particular environments with sulfate deficiency (Postgate 1984). Based on thermodynamic considerations, the utilization of H_2 or acetate by SRB yields more energy than the utilization of these substrates by methanogens. Thus in CT, high sulfate concentrations, resulting from the gypsum addition, has the potential to stimulate SRB to out-compete methanogens and consequently cease methanogenesis (Fedorak et al. 2002). It has long been known that methane production in marine sediments occurs only after sulfate has been depleted from the porewater, i.e. methanogenesis begins when sulfate is depleted (Schlesinger 1997). When sulfate is depleted, methanogens carry out the terminal steps in the anaerobic environment (Fedorak et al. 2000). Acetate, products of sulfate reduction, would be expected to favor methanogenesis (Postgate 1984). The complex relationship between SRB and methanogens is also illustrated by the fact that methane can serve as a substrate for anaerobic oxidation in the presence of SRB (Valentine 2002). In most natural environments there is little or no overlap between the zone of methanogenesis and the zone of sulfate reduction.

In the CT process, a gypsum dosage at about 1000 g/m^3 of CT mixture would result in approximately 1000 mg SO_4^{2-}/L in the CT porewater (MacKinnon et al. 2000). With the high SO_4^{2-} concentration in the CT porewater, the CT will inhibit methane production by creating an environment that is more suitable for SRB and the SRB would out-compete the methanogens. Fedorak et al. (2002) have shown that the addition of sulfate to fine tailings decreased methane production, and that methanogenesis appeared to have started to a large extent only after the sulfate concentration had dropped to approximately 20 mg/L.

2.6 Summary

The oil sands industry is growing rapidly in Alberta. The two major oil sand companies, Syncrude Canada Ltd. and Suncor Energy Inc., are currently mining the oil sands using surface mining operations, and extracting and upgrading the bitumen from the Athabasca oil sands deposit. Oil sands industry operations produce large volumes of fine tailings and the storage and disposal of these tailings has become a major environmental concern currently challenging the industry. The physical and chemical properties of these fine tailings must be understood to identify alternative tailings management processes. The MFT from the Clark Hot Water Extraction Process is characterized by its low permeability and slow consolidation. The most recent studies have found that the settled volumes and water holding capacity of MFT are determined by the mineral components rather than by the residual bitumen. The MFT has a highly dispersed three-dimensional gel structure with clay particles aligned in edge-to-edge and edge-to-face patterns due to the high water holding capacity. The slow densification rate of MFT may be attributed to this gel structure.

The CT process has been used to treat fine tailings since 1995. The CT process uses chemical amendments to combine the clays and fines in the MFT or thickened tailings with the coarser sand components to create a NST mixture that rapidly consolidates. Ultimately, the CT process can assist to create a sustainable and acceptable dry or wet landscape. The segregation of the CT mixture is affected by the total solids content, the fines content, the particle size gradation, and the type and dosage of coagulant aids.

Biodegradation of the residual hydrocarbons in the tailings is an important factor in managing tailings in the long term. In fact, microbial activity is present in the tailings ponds and the identified microorganisms that significantly affect the reclamation of the tailings are methanogens and SRB. In addition, the complex relationship between these two groups of microorganisms has been addressed by some studies.

Although the oil sand industry is looking for alternative processes to provide the maximum amount of recycle water (of good quality, that is low in Ca^{2+} and SO_4^{2-}) and/or minimize the tailings volume, the existing and continually accumulating fine tailings are a big challenge to the oil sands industry. Thus, the oil sands industry, government, and research institutions are making considerable efforts to identify suitable technologies for reclaiming the existing fine tailings inventories and managing release water for recycling.

Chapter 3

Materials and Methods

The experimental program consisted of three types of tests:

1. dynamic column tests
2. jar tests
3. barrel mesocosm tests

These three types of tests will be described in the following sections. The materials used in the tests as well as the design of the test apparatus will be presented. The experimental design and the analyses conducted will also be described.

3.1 Dynamic Column Tests

Oil sands tailings have been studied extensively in the Department of Biological Sciences and the Department of Civil & Environmental Engineering at the University of Alberta. These tests involved extensive physical, chemical, and microbiological investigations of the MFT and CT materials using a variety of innovative experimental methods. Fedorak et al. (2000) specifically developed many proven protocols for column setup and analyses to evaluate the CT and MFT under anaerobic conditions. Luo (2004) adapted the method of Fedorak et al. (2000) and designed the static columns to study the physical, chemical, and microbiological changes of MFT and CT materials. In this project, dynamic columns were developed as a further improvement of the static columns, in order to study and monitor the physical, chemical, and microbiological changes which occurred in the release water after having passed through the MFT.

3.1.1 Materials

CT water, WIP water and MFT material were delivered in 20 L plastic pails from Syncrude Canada Ltd and kept in a 4°C temperature controlled room until use. Several pails of the MFT material and CT water were randomly selected and well mixed in a 100 L plastic container and a 200 L plastic container, respectively, in order to reduce the heterogeneity. The mixed CT water and WIP water will herein be referred to as feed water.

Baseline samples of MFT and feed water (WIP and CT water) were collected and analyzed by Syncrude Canada Ltd for physical, chemical and microbiological characteristics. The results of these analyses are described in Appendix A. The baseline sample notations for Systems 1 to 4 are listed in Table 3.1.

Table 3.1 CT Water and MFT Baseline Sample Notation

System	CT Water Baseline Sample Notation	MFT Baseline Sample Notation
1	D1-Base-1	MFT-Base-1 MFT-Base-2 MFT-Base-3 MFT-Base-4
	D1-Base-2	
2	D2-Base-1	
	D2-Base-2	
3	D3-Base-1	
	D3-Base-2	
4	D4-Base-1	
	D4-Base-2	

3.1.2 Dynamic Column Design

The dynamic column is illustrated in Figure 3.1. An appropriate-sized segment (outside diameter (OD) = 157 mm, inside diameter (ID) = 153 mm; height (H) = 1200 mm) of clear acrylic tubing (Johnston Plastics Inc., Edmonton, Alberta) was used as the

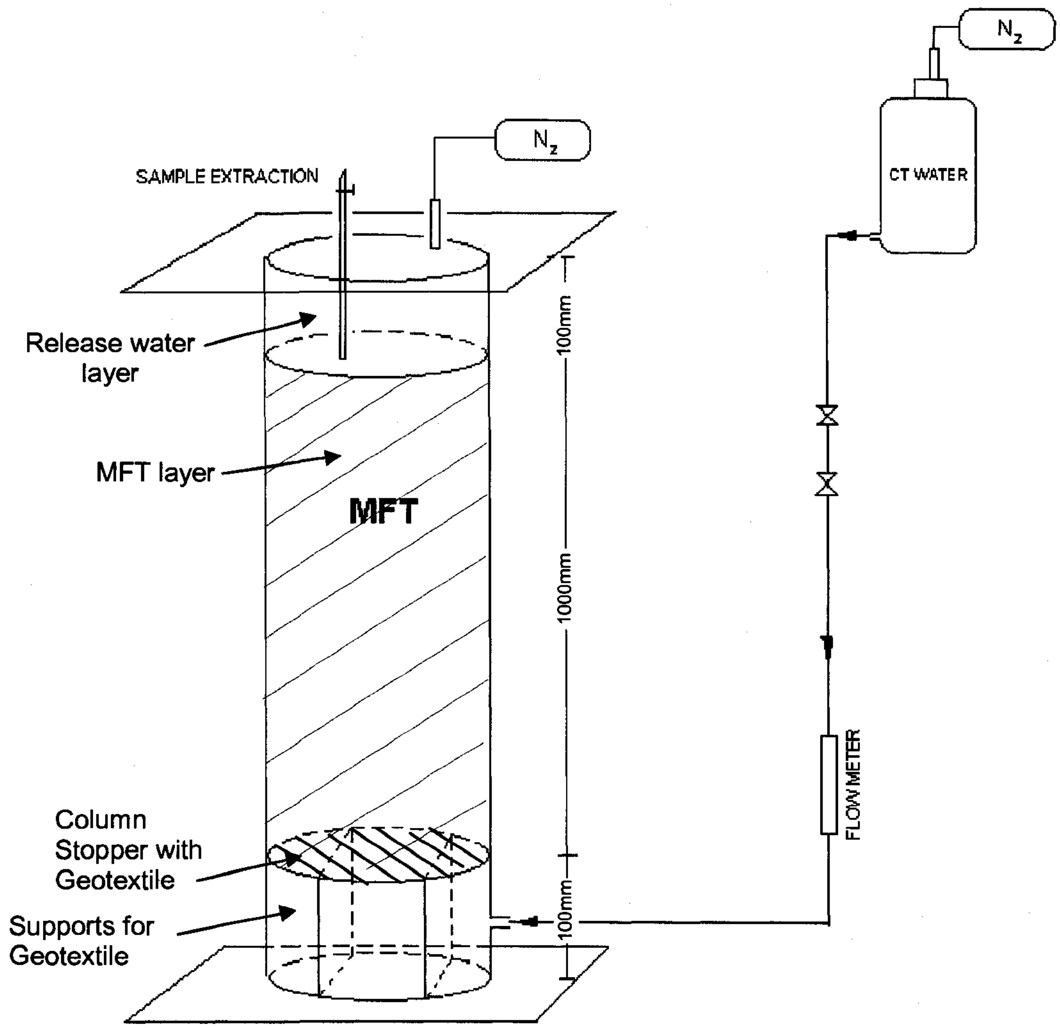


Figure 3.1 Schematics of dynamic column test system

column in this project. The bottom of the column was sealed with a 220×220×7 mm square acrylic plate. A column stopper with a piece of Geo-textile (Nilex Inc., Edmonton, Alberta) was installed onto the bottom at a distance of 100 mm to the bottom acrylic plate. There was a feeding port on the wall between the column stopper and bottom acrylic plate that was used to feed CT water. Under a N_2 atmosphere, the column was filled with freshly mixed MFT up to a height of 1000 mm above the column stopper, which gave a headspace height of 100 mm. After thoroughly flushing the headspace of the MFT-filled column with N_2, the column was sealed with a 220×220×7 mm square acrylic top cover. The top column cover was connected to a 1-L Tedlar® bag (Catalog Number 231-01, Safety Instruments Ltd., Edmonton, Alberta) filled with N_2. Finally, a 20-L plastic carboy of feed water was connected to the feeding port via the flow meter by plastic tubing.

In summary, there were four layers (from bottom to top) along the column:

1. Bottom feed water layer of 100 mm in height
2. MFT layer of 1000 mm in height (the total volume of MFT = 18.4 L)
3. Release water layer
4. Headspace layer filled with N_2 gas

The design of the dynamic column allowed for continuous introduction of feed water in an upflow manner through the feeding port and continuous release of water into the release water layer.

Figure 3.2 shows the top cover of the dynamic column. There were two holes in the top cover. One 3.2-mm NPT threaded hole was used for connecting the 1-L Tedlar® bag through a 250 mm long, 3.2-mm ID and 6.4-mm OD Tygon tubing. This Tedlar® bag was used to equilibrate the headspace pressure in case of biogenic gas evolution from the MFT. Another 3.2-mm NPT threaded hole was used to regularly take samples of the release water using 3.2-mm ID stainless steel tubing and syringe.

The column stopper was also made of an acrylic plate with a diameter close to the column inside diameter. Thus, the column stopper would minimize MFT leaking during filling. Many small holes were drilled through the column stopper to allow the feed water to pass through. A layer of Geo-textile was put on the column stopper to prevent the MFT from blocking these holes and allowing feed to pass through.

Figure 3.2 Top cover of dynamic column

The 20-L plastic carboy served as the reservoir for feed water (Figure 3.3). To ensure anaerobic conditions in the feed water, the reservoir was flushed with N_2 and then filled with 20 L of feed water. To equilibrate the headspace, a Tedlar® bag filled with N_2 was connected to the headspace of the reservoir via a hose connector fastened at the cap. The feed water was fed to the column through Tygon tubing from the port near the bottom of the carboy. The flowrate of the feed water was controlled by a combination of valves and a flow meter. Feed water was added every a few days to maintain the water level in the reservoir. The Tedlar® bag was also re-filled periodically with N_2.

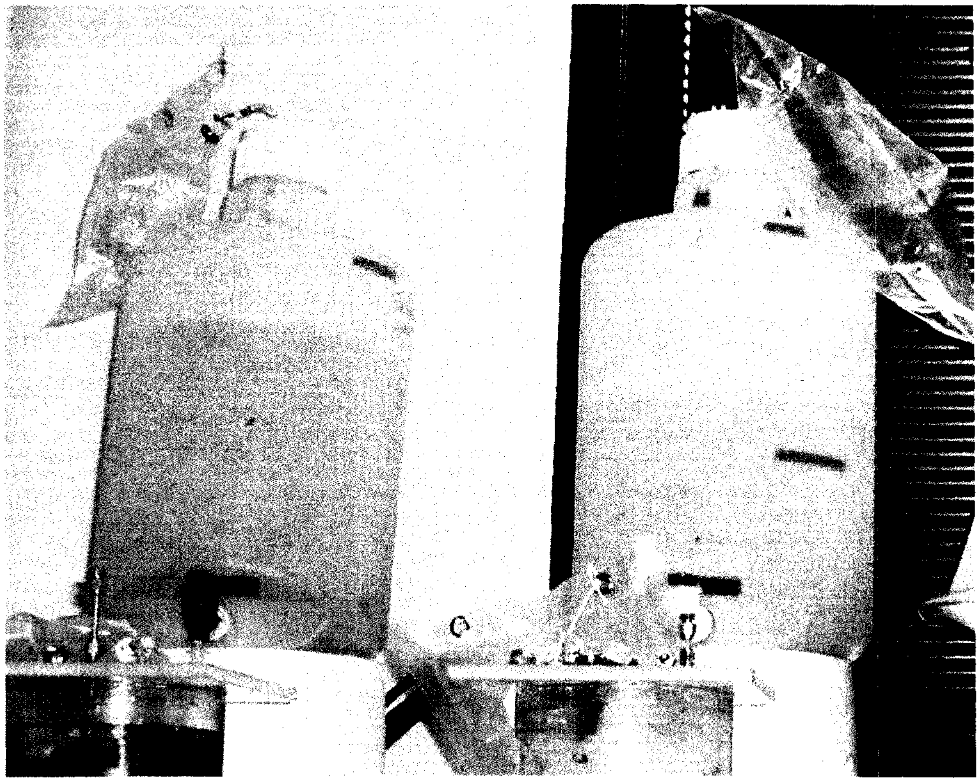


Figure 3.3 Plastic carboy

3.1.3 Experimental Design

The dynamic column system (see Figure 3.4) was designed to study and monitor the physical, chemical, and microbiological changes which occurred in the feed water after passing through the MFT. The experimental matrix for the dynamic column tests is presented in Table 3.2. Specifically, feed water without (System 1) or with amendments (Systems 2, 3 and 4) and a conservative tracer (bromide (Br^-), in the form of KBr) was fed in an upwards fashion into columns filled with MFT. Each type of feed water was fed into columns at two different flowrates: a high flowrate of approximately 20 mL/h and a low flowrate of approximately 6 mL/h. Columns at high flowrate were run for an incubation time of approximately 60 days whereas columns at low flowrate were run for an incubation time of 140 days.

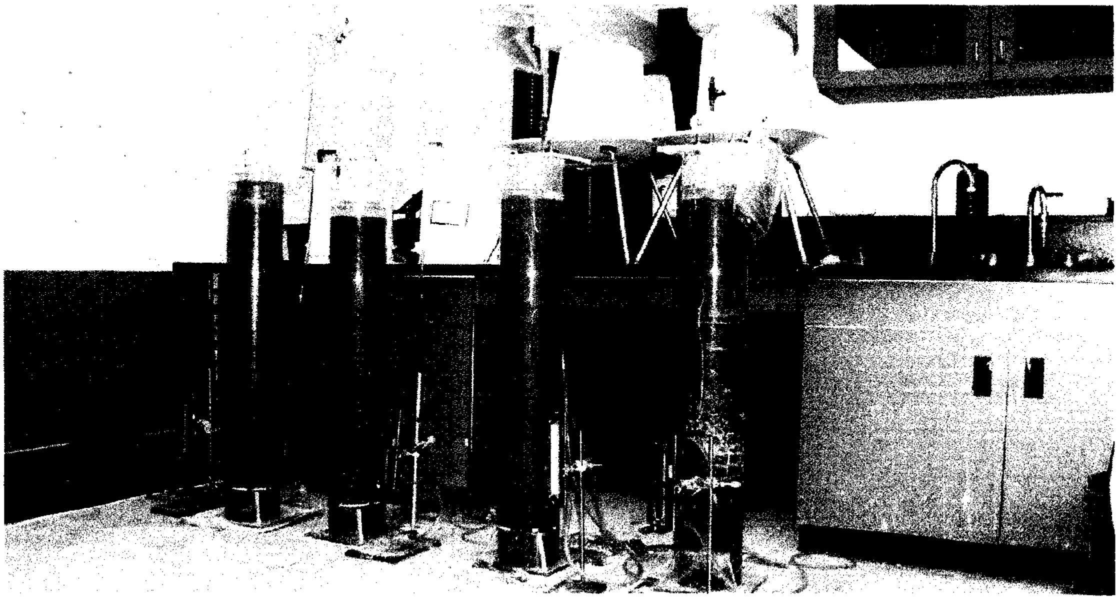


Figure 3.4 Dynamic columns

For System 1, 2500 mg Br^-/L was added into CT-water of the high flowrate system (System DH-1), and 900 mg Br^-/L was added to CT-water for low flowrate system (System DL-1). For System 2, CT-water was amended with $CaSO_4$, $MgSO_4$ and Na_2SO_4 to achieve approximately 250 mg Ca^{2+}/L, 250 mg Mg^{2+}/L and 2500 mg SO_4^{2-}/L. For System 3, CT-water was amended with 300 mg Br^-/L and 100 mg Ac^- /L to the high flowrate system (System DH-3), and 400 mg Br^-/L and 100 mg Ac^-/L to the low flowrate system (System DL-4). The feed water for System 4 was West-In Pit (WIP) water, a different type of water from other systems. This WIP water was amended with 300 mg Br^-/L for the high flowrate system (System DH-4) and 400 mg Br^-/L added to the low flowrate system (System DL-4). Br^- was used as a tracer to characterize the hydraulic properties of the dynamic columns to verify that the feed water had passed through MFT layer.

Table 3.2 Experimental Matrix for Dynamic Column Test

		System 1		System 2		System 3		System 4	
		High Flowrate	Low Flowrate	High Flowrate	Low Flowrate	High Flowrate	Low Flowrate	High Flowrate	Low Flowrate
Name		DH-1	DL-1	DH-2	DL-2	DH-3	DL-3	DH-4	DL-4
Base feed water		CT Water	CT Water	CT Water	CT Water	CT Water	CT Water	WIP	WIP
Amendments to Base feed water* (in mg/L)	Br^-	2500	900	-	-	300	400	300	400
	Ca^{2+}	-	-	250	250	-	-	-	-
	Mg^{2+}	-	-	250	250	-	-	-	-
	SO_4^{2-}	-	-	2500	2500	-	-	-	-
	Ac^-	-	-	-	-	100	100	-	-

*Note: The concentrations provided for the amendments are target concentrations and the actual concentrations were verified by analyses.

- not added

All dynamic columns were kept at room temperature (20°C) in the dark for about 60 days for high flowrate columns and 140 days for low flowrate columns. The flowrates were measured and adjusted through flow meters (VACT H40407 0035, Fisher Scientific, Edmonton, AB).

3.1.4 Dynamic Column Sampling

At the end of the planned incubation periods, that is 60 days and 140 days for the high and low flowrate systems, respectively, the flow through the dynamic columns was stopped and the contents of the columns were analyzed. The analysis involved:

- removing the top cover of the column while maintaining anaerobic condition;
- sampling the release water,
- taking samples of the MFT material (by coring) for MPN analysis; and
- freezing and sacrificially sampling the MFT for chemical analysis.

3.1.4.1 Release water sampling

The feed water and release water (the pore water of MFT, and the release water) were sampled and analyzed at predetermined intervals. The maximum ion concentration in the released water was used to calculate the removal efficiency. Therefore, the removal efficiency in this study represents the minimum reduction.

The analyses include: pH, alkalinity, major cations (Mg^{2+}, Na^+, K^+, NH_4^+, and Ca^{2+}), major anions (SO_4^{2-}, S^{2-}, SO_3^{2-}, $S_2O_3^{2-}$, PO_4^{3-}, NO_3^-, NO_2^-, and Cl^-), total soluble S (by ICP), and conductivity. The analysis methods are described in Section 3.1.5.

3.1.4.2 MFT sampling for MPN analysis

The MPN sampling used a core-sampling method under a N_2 atmosphere. The MPN samples were taken from the center of the column using a suitable length piece of rigid plastic tubing (with a 6.4-mm ID). Four MPN samples were taken from each column, that is, each column was separated to four parts in 250 mm of length and the samples were taken from middle of each part. The samples were then transferred to a 60-mL syringe or a 90-mL plastic jar filled with N_2 and transported to the Department of Biological Sciences at the University of Alberta. All materials used for MPN sampling (plastic tubing, syringe, and jar) were autoclaved at 121°C for 20 min before use.

3.1.4.3 Freezing and sacrificial sampling of MFT

After the sampling of release water and MFT, the columns were placed in a freezer at a temperature of about –20°C and left for several days to freeze. The column was then broken with hammer and the frozen MFT was cut into four parts of approximately 200 mm in length each. As shown in Figure 3.5, each column was separated into four samples and 20 mm was cut off from either side in each part and discarded. Table 3.3 provides a summary of the sample (with sample notation) taken after sacrificial sampling of the MFT.

The frozen MFT subsamples were then placed in 4-L glass jars (filled with N_2) at room temperature overnight. Then, subsampling of each MFT sample was performed in a N_2 chamber.

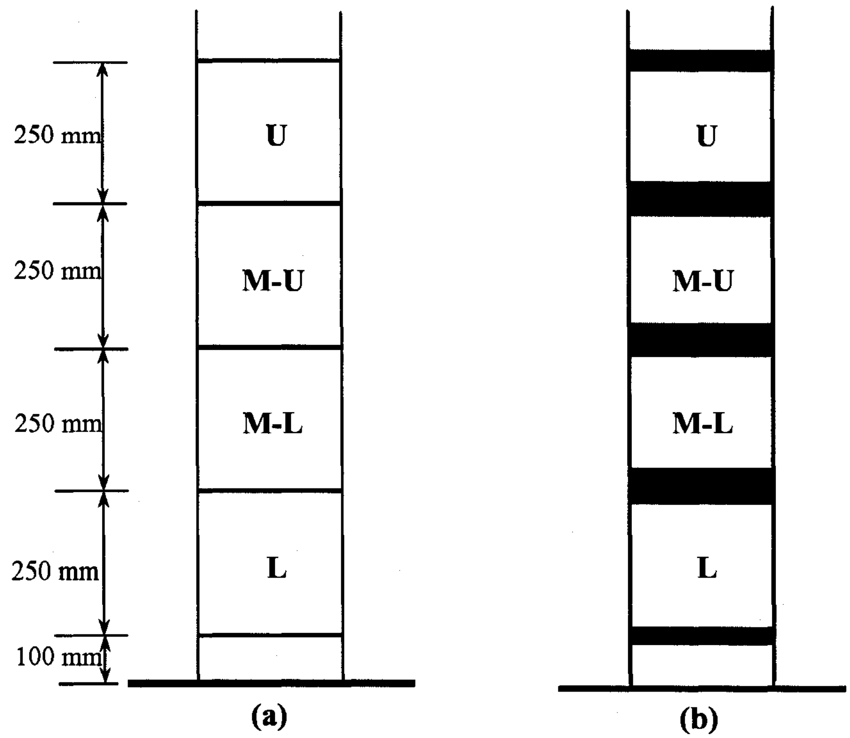


Figure 3.5 Sacrificial sampling of MFT after column freezing: (a) Showing sample notation; (b) showing discarded sample (shaded areas)

Table 3.3 Dynamic Column Sampling Notation

System	1	2	3	4
High Flow Rate (20 mL/h)	DH-1-U	DH-2-U	DH-3-U	DH-4-U
	DH-1-M-U	DH-2-M-U	DH-3-M-U	DH-4-M-U
	DH-1-M-L	DH-2-M-L	DH-3-M-L	DH-4-M-L
	DH-1-L	DH-2-L	DH-3-L	DH-4-L
Low Flow Rate (6 mL/h)	DL-1-U	DL-2-U	DL-3-U	DL-4-U
	DL-1-M-U	DL-2-M-U	DL-3-M-U	DL-4-M-U
	DL-1-M-L	DL-2-M-L	DL-3-M-L	DL-4-M-L
	DL-1-L	DL-2-L	DL-3-L	DL-4-L

Note: where U refers to samples from the upper half zone and L refers to samples from the lower half zone of the MFT layer (refer to Figure 3.5).

The porewater extraction was completed using a combination of centrifugation and filtration procedures. The MFT samples or subsamples were centrifuged at 10000 rpm for 30 min, using a Sorvall RC-5B centrifuge with SS-34 rotor and eight Teflon™

tubes of 50 mL each. After centrifugation, pre-filtration using a AP 15 Millipore glass fiber filter and vacuum filtration under a N_2 atmosphere was performed to remove coarse solids and bitumen. The samples were then filtered through a 0.45 μm Millipore Millex syringe filter (Millipore, Billerica, MA).

3.1.5 Analysis of MFT Samples from Dynamic Columns

MFT subsamples were taken under a N_2 atmosphere. These samples were analyzed for redox potential, particle size distribution, AVS (acid volatile sulphide) analysis, and also pH, major cations (Mg^{2+}, Na^+, K^+, NH_4^+, and Ca^{2+}), major anions (SO_4^{2-}, S^{2-}, SO_3^{2-}, $S_2O_3^{2-}$, PO_4^{3-}, NO_3^-, NO_2^-, and Cl^-), total soluble S (by ICP), and conductivity, which were performed by Syncrude Analytical Laboratory at the Edmonton Research Centre, using established company protocols and standard methods (Fedorak et al. 2000).

3.1.6 Eh Measurement on MFT

An Accumet Model 50 pH/Ion/Conductivity Meter with a Cole-Parmer Ag/AgCl ORP electrode was used to measure Eh. The ORP electrode was calibrated against a standard ORP solution (from Orion Research Inc., Beverly, MA) before and after the Eh measurements.

The MFT subsamples (slurry) were contained in a 120-mL glass jar and the headspace of the jar was filled with N_2 for Eh measurement. The Eh measurements took several hours to stabilize for some samples, therefore Eh measurements were taken every 1 and 2 hours.

3.1.7 Sulfide Analysis in Pore Water and Release Water Sample

The sulfide in the release water and porewater samples was analyzed using CHEMetrics sulfide test kit (from CHEMetrics Inc., Calverton, VA), which uses a methylene blue colorimetric method. The measured sulfide was the total acid soluble sulfides including dissolved H_2S, HS^-, and acid-soluble metallic sulfides in suspension.

A sulfide test kit with two ranges (0 to 1 mg/L and 1 to 10 mg/L, Catalog Number K-9510 Chemetrics Inc.) was used based on the previous sulfide results in MFT and CT porewaters (Fedorak et al. 2000). The minimum detection limit of the test kit was 0.05 mg/L.

The water samples for S^{2-} analysis were first filtered using a 0.45μm syringe filter. Water samples were prepared with minimum aeration in a N_2 atmosphere and then were analyzed immediately after the preparation to avoid or minimize the oxidation of sulfides.

3.1.8 MPN Analysis on MFT

The microbial MPN analyses of SRB and methanogens were conducted in the Department of Biological Science at the University of Alberta. The three-tube MPN method was used to enumerate the SRB and methanogens. Only SRB and methanogens were enumerated because these two groups of microorganisms are considered the most important groups of microorganisms in MFT (Fedorak et al. 2000).

The MPN results were expressed as "MPN/g (dry solids)". Thus unit conversion was necessary for the ratio of dry weight to wet weight of MFT samples because the MPN samples were dispensed as wet materials. The ratio of dry weight to wet weight was determined in the Environmental Engineering Laboratory by drying the MFT samples at 104°C (103 to 105°C) oven overnight, following the procedure given in APHA (1995). The weights of the MFT samples were measured before and after drying, and water content was then calculated.

3.1.9 AVS Analysis on MFT Samples

AVS are the sum of amorphous iron monosulfide (FeS), mackinawite (FeS_{1-x}), greigite (Fe_3S_4) (Duan et al. 1997; Morse et al. 1987), and sulfides of other metals such as ZnS and CdS (Gerard et al. 1998; Lasorsa and Casas 1996). AVS is usually determined by first liberating H_2S from the sulfides using cold acid (1 to 6 M HCl), then distilling and trapping the released H_2S for quantification by one of several analytical methods. The presence of AVS is an indicator of recent SO_4^{2-} reduction (Kennedy et al. 1999) because AVS species are metastable and reactive, either by oxidation or by subsequent reduction to FeS_2 (pyrite). More severe acid treatment, often with heating or with the addition of other chemicals, may release sulfides from other compounds (e.g. pyrite).

The amorphous FeS and mackinawite are quantitatively recovered in cold acid extraction, but the recovery of greigite is incomplete. Under harsher conditions, such as hot HCl, or cold 6 M HCl plus $SnCl_2$, greigite and newly formed fine-grained synthetic pyrite are recovered. $SnCl_2$ in the HCl distillation is present to help diminish the Fe (III) interference that may oxidize sulfide to elemental sulfur (S^0) in acid distillation (Duan et al. 1997).

It is critical to obtain the accurate measurement of AVS by using sampling, handling, and analytical techniques that minimize oxidation of sulfides. Sulfide samples should be stored at 4°C or frozen at –20°C and analyzed within 2 weeks of sample collection (Lasorsa and Casas 1996) when samples are handled under the N_2 atmosphere.

The AVS analysis method for this project used 6 M cold HCl plus $SnCl_2$ to digest the sample, thus, the obtained results were the AVS plus fine-grained (newly formed) synthetic pyrite. The sampling was carried out under a N_2 atmosphere. The AVS samples were kept at 4°C under a N_2 atmosphere during storage and delivery, and were analyzed by ALS Laboratory Group (Vancouver, BC) within 14 days of sample collection.

3.2 Jar Tests

To identify the naturally occurring changes within the MFT porewater, jar tests were used as control tests. In the jar test, the same MFT was used as in the dynamic column test. Under anaerobic conditions, 4 L MFT were added to a jar and Ca^{2+} and Mg^{2+} concentrations were adjusted to different levels comparable to the feed water for all dynamic column systems (See Table 3.4). The jars were stored for the same period of time as the dynamic column tests. The concentrations of Ca^{2+} and Mg^{2+} were monitored and compared with the concentrations in the release water in the dynamic columns. The notation used for the jar test samples are given in Table 3.5.

Under a N_2 atmosphere, the MFT in the jar was mixed fully, and samples were taken. All samples were centrifuged and the porewater samples were sent to Syncrude Canada Ltd. laboratory for chemical analysis (the same items with release water).

Table 3.4 Experimental Matrix for Jar Test

Jar	Concentration	Br^- (mg/L)	Ca^{2+} (mg/L)	Mg^{2+} (mg/L)	SO_4^{2-} (mg/L)
D1	Initial	0	22	14	20
	Amendments	2500	0	0	1000
	Final	2500	22	14	1020
D2	Initial	0	22	14	20
	Amendments	0	140	140	1790
	Final	0	162	154	1800
D3	Initial	0	22	15	20
	Amendments	320	40	11	975
	Final	320	62	26	995
D4	Initial	0	22	15	20
	Amendments	330	0	0	300
	Final	330	22	15	320

Note: The concentrations provided for the amendments were target concentrations. The actual concentrations will be verified by analyses.

Table 3.5 Jar Sample Notation

System	Release Water Sample Notation	MFT Sample Notation
1	Jar D1-1 water	Jar D1-1
	Jar D1-2 water	Jar D1-2
2	Jar D2-1 water	Jar D2-1
	Jar D2-2 water	Jar D2-2
3	Jar D3-1 water	Jar D3-1
	Jar D3-2 water	Jar D3-2
4	Jar D4-1 water	Jar D4-1
	Jar D4-2 water	Jar D4-2

3.3 Static Barrel Mesocosms

3.3.1 Experimental Design

The static barrel mesocosms consisted of three different systems as shown in Table 3.6. At barrel filling, System 5 consisted of two barrels, each containing a 25 L

MFT layer on the top of a 50 L CT layer, whereas Systems 6 and 7 contained only one barrel of 50 L of MFT or CT, respectively. No water was added to the barrels. Therefore, all cap water during ensuing incubation was released water.

Table 3.6 Static Barrel Mesocosm System

System	Barrel Notation	Barrel Configuration	Deposit of the Barrels
5	B1, B2	MFT and CT	25L MFT (U)+ 50L CT(L)
6	B3	MFT only	50L MFT
7	B4	CT only	50 L CT

The barrel mesocosms were larger in size than the static column mesocosms. The barrel mesocosm test was designed to provide supplemental information to the static column mesocosm test and to see if the size of the mesocosms would have an effect on the final interpretation of the results. Thus, the analysis of the barrel mesocosms was basically the same as in the static column mesocosms (Luo, 2004). The barrel mesocosms were sacrificially sampled at the end of 2 years of incubation.

Two static column mesocosms were also sacrificially sampled after 2 years of in cubation. These columns served as a comparison to the barrel mesocosms.

3.3.2 Barrel Mesocosms Design and Setup

The 110-L Ropak plastic barrels (from Great Western Container Inc., Edmonton, AB) were used for barrel mesocosms tests (see Figure 3.6). The barrels in System 5 (two barrels) were simply filled first with a 50 L CT layer, and a piece of Geo-grid was placed on the top of the CT, then the barrels were immediately filled with a 25 L MFT layer. No barrel inverting procedure as used in Luo (2004) was used during barrel filling.

Figure 3.6 Static barrel mesocosms

As shown in Figure 3.7, there were three 3.2-mm NPT threaded holes placed in the lids for the barrels in System 5. One was used to connect a 1-L Tedlar® bag through about a 250 mm length of 3.2 ID × 6.4 OD mm Tygon tubing to collect the evolved headspace gas from the barrels; one was used to fit a 3.2-mm ID stainless steel tubing which was used to monitor the position change of the CT/MFT interface in an in-situ manner; and the third one was to fit a 3.2-mm ID stainless steel tubing to sample the release water in an in-situ manner when needed.

For the barrels in Systems 6 (one barrel) and 7 (one barrel), there was only one 3.2-mm NPT threaded hole placed in the lid (Figure 3.8). The hole was used to connect a 1-L Tedlar® bag through about a 250 mm length of 3.2 ID × 6.4 OD mm Tygon tubing to collect the evolved headspace gas in the barrels.

Figure 3.7 Lids for barrels in System 5 containing CT beneath MFT

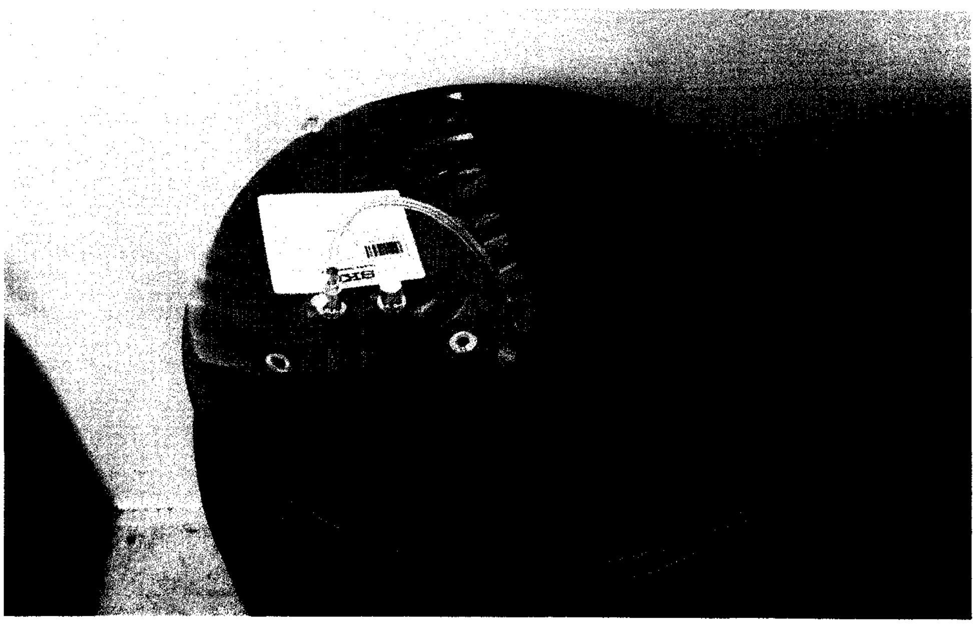


Figure 3.8 Lids for barrels in System 6 and 7, only MFT or CT, respectively

Prior to, and during, the filling process, each barrel was flushed with N_2 for several minutes. Then the lid of the barrels was clamped and tightened with a metal ring. The barrel was then flushed with N_2 and the Tedlar® bag was attached. The Tedlar® bag in the barrels served as a safety valve allowing for any biogenically evolved gases to escape the barrel and be contained.

3.3.3 Incubation and Regular Monitoring

Because of the opaque plastic barrel material, no visual observations of the MFT and CT in the barrels were performed during the incubation. For barrels in System 5, the Geo-grid position changes were regularly recorded by contacting a 3.2-mm ID stainless steel tubing to the Geo-grid piece. For all barrels, the Tedlar® bag was regularly checked to see if the Tedlar® bag was fully filled. No analysis of the gas in the Tedlar® bag was performed on the barrel mesocosms.

3.3.4 Sampling from Barrels

At the end of the incubation period (2 years), the barrels were sampled and analyzed. Under N_2 atmosphere, eight samples were taken from each MFT or CT layer using acrylic tubes (OD = 50 mm, ID = 40 mm; Height = 300 mm). The sampling locations were randomly selected, as shown in Figure 3.9. To take the sample, the acrylic tubes were pushed into the MFT or CT by hand. A rubber stopper was then placed at the bottom to secure the sample. The sample tube was then lifted off the barrel and another rubber stopper was added to the top. All the samples were then frozen at -20°C for further analysis.

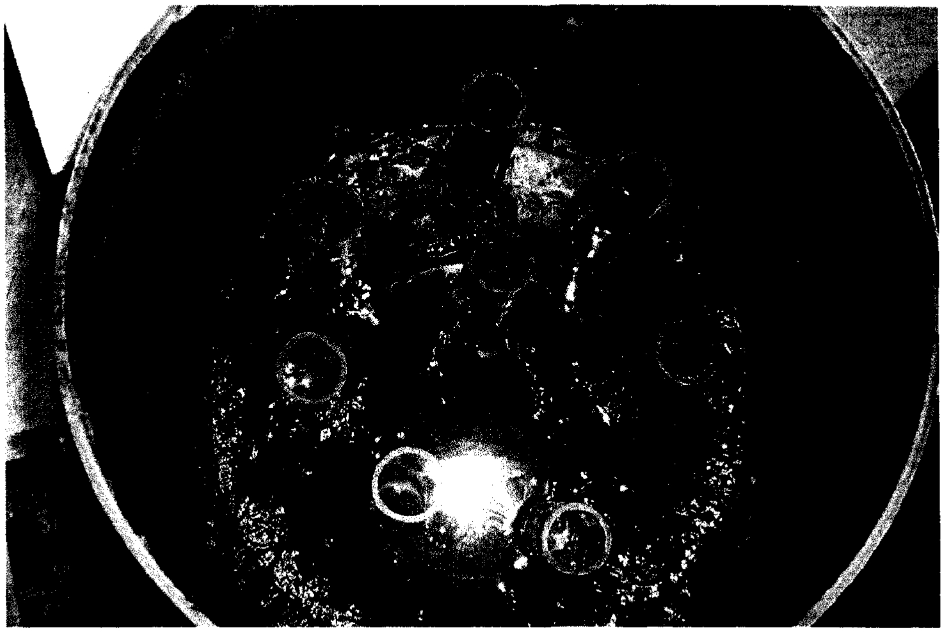


Figure 3.9 Barrels Sampling Using Acrylic Tubing

To release the frozen samples, the bottom rubber stopper was removed first and the sampling tube was rinsed with running tap water until the samples slid out. The frozen samples were then cut into two pieces using a knife. The upper portions of all eight samples from one layer were put together into one jar, whereas the lower portions were placed in another jar. After the samples were thawed, the material in each jar was well mixed, sub-sampled and then sent to the Syncrude Canada Ltd. laboratory for chemical analyses. The notations of barrel samples are provided in Table 3.7.

Table 3.7 Notations of Barrel Samples

Sample	System 5		System 6	System 7
	Barrel 1	Barrel 2		
Water	B1-release water	B2- release water	B3- release water	B4- release water
	B1-MFT-U pore water	B2-MFT-L pore water	B3-MFT-U pore water	B4-CT-U pore water
	B1-CT-U Water	B2-CT-U Water	B3-MFT-L pore water	B4-CT-L pore water
	B1-CT-L pore water	B2-CT-L pore water		
MFT or CT	B1-MFT-U	B2-MFT-U	B3-MFT-U	B4-CT-U
	B1-MFT-L	B2-MFT-L	B3-MFT-L	B4-CT-L
	B1-CT-U	B2-CT-U		
	B1-CT-L	B2-CT-L		

Chapter 4

Results and Discussion

4.1 Dynamic Column Tests

Dynamic column tests involved introducing different feed waters in an upflow manner at high and low flows through columns of MFT. Release water and MFT were then analyzed for select physical, chemical and microbiological characteristics. The results of the analyses are presented in the following sections.

4.1.1 Physical and Chemical Characteristics in System 1

4.1.1.1 Tracer study to characterize the hydraulic properties of System 1

Unamended feed water was fed into System 1. A combination of valves and flow meters was employed to achieve the desired flowrates. The obtained flowrates were calculated to be on average 16.5 mL/h and 5.3 mL/h, respectively. Br^- was used as tracer and added to the feed water at 2500 mg/L for the high flowrate system and at 900 mg/L for the low flowrate system. As shown in Figure 4.1a, in the high flowrate system, Br^- was detected in the release water on Day 6 and increased steadily to reach the feed water concentration on Day 60. In the low flowrate system, Br^- first appeared in the release water on Day 20 and reached the feed concentration of approximately 900 mg/L on Day 120. Although it took about 40 days and 120 days for the feed water to penetrate through the MFT layer of the high and low flowrate systems, respectively, some feed water may be released as early as Day 6 and Day 20 in these two systems accordingly due to the dispersion via preferential flow pathways.

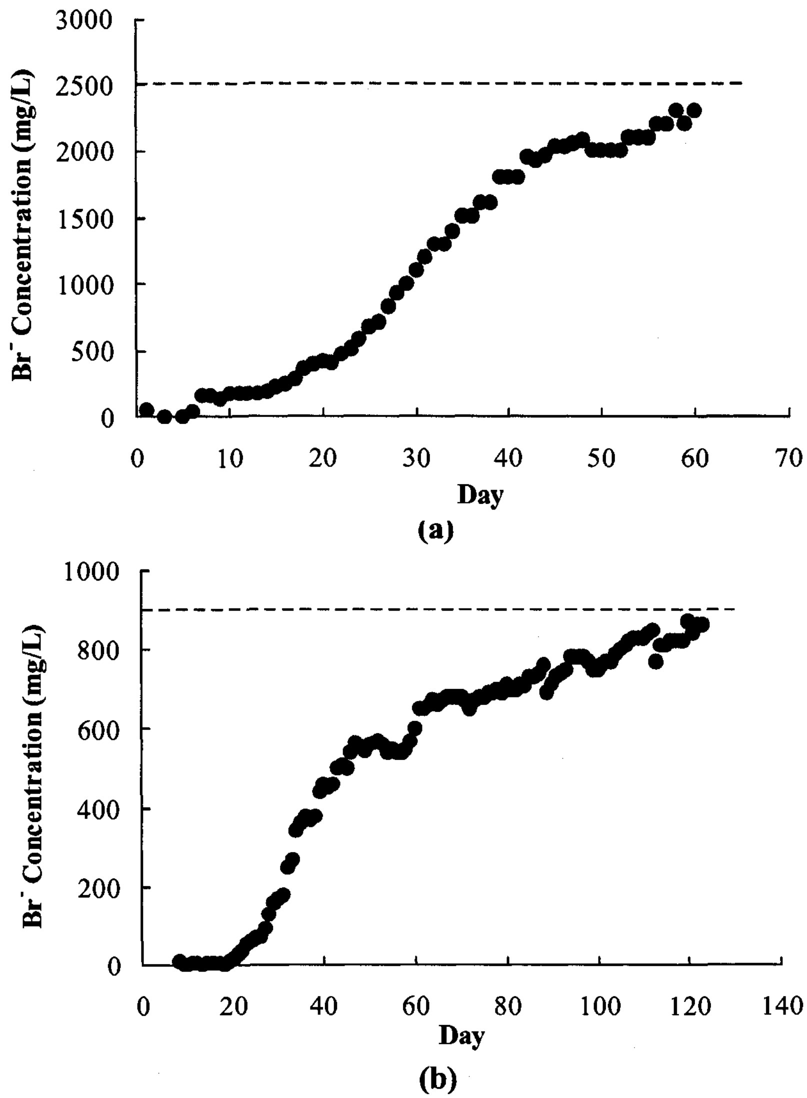
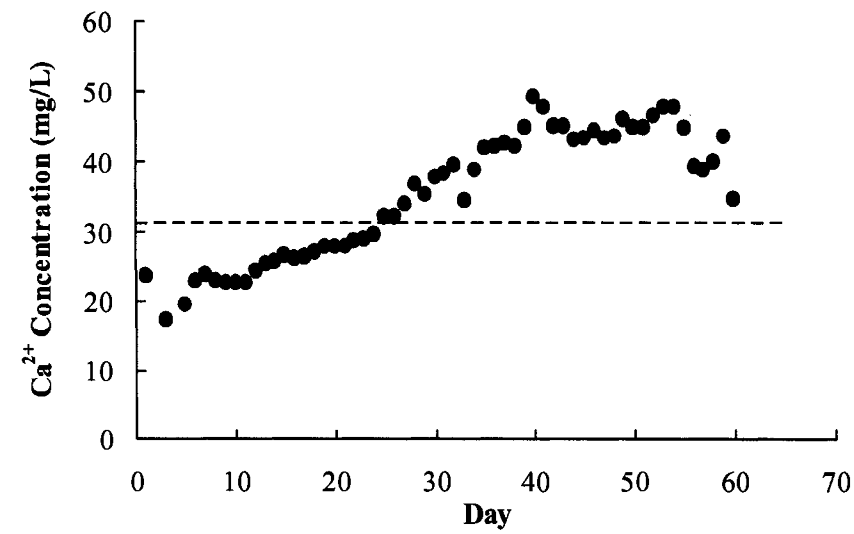


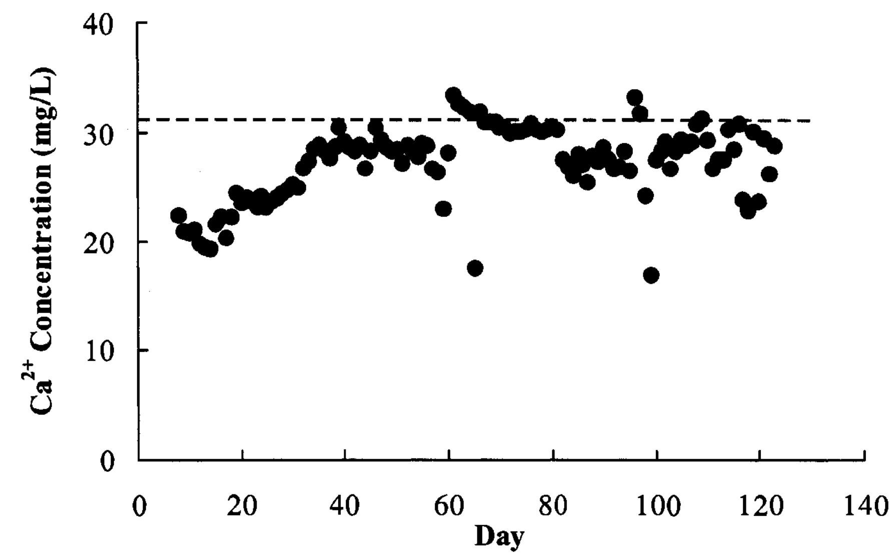
Figure 4.1 Br⁻ concentration as a function of time in the release water of System 1 dynamic columns: (a) at a high flowrate of feed water (16.5 mL/h in Column DH-1); (b) at a low flowrate of feed water (5.3 mL/h in Column DL-1), where the dashed line represents the Br⁻ concentration in the feed water

4.1.1.2 Calcium and magnesium concentration analysis

The original Ca^{2+} concentration in the MFT was 20.7 mg/L and the Ca^{2+} concentration in the feed water was 31.1 mg/L (see Appendix A9 and A10). The change in concentration of Ca^{2+} in the release water for the high and low flowrate systems are illustrated in Figure 4.2.



(a)



(b)

Figure 4.2 Ca^{2+} concentration as a function of time in the release water of System 1 dynamic columns: (a) at a high flowrate of feed water (16.5 mL/h in Column DH-1); (b) at a low flowrate of feed water (5.3 mL/h in Column DL-1), where the dashed line represents the Ca^{2+} concentration in the feed water

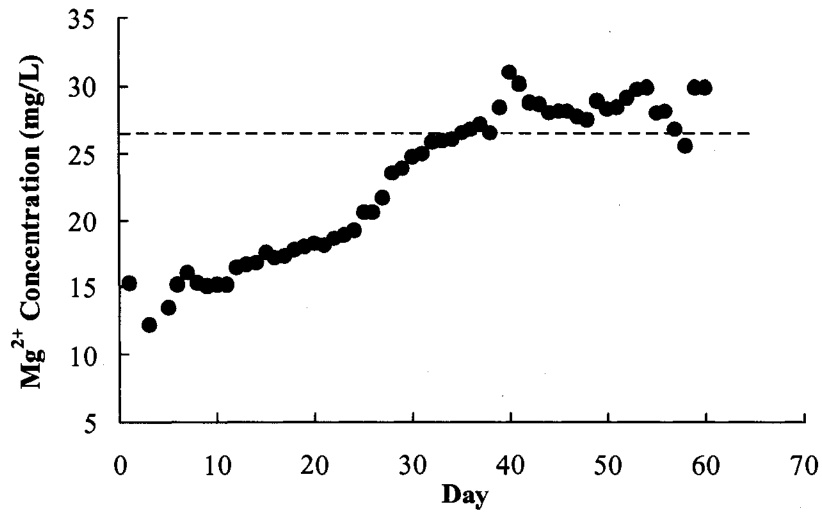
As shown in Figure 4.2a, some data points were missing during the first 5 days because there was not enough water release water to collect a sample. Therefore, the slight drop in Ca^{2+} concentration from 23.7 mg/L to 17.5 mg/L observed on Day 2 was possibly due to analytical deviation. On Day 6, the Ca^{2+} concentration in the release water was consistent with the Ca^{2+} concentration in MFT, indicating that the release water was mainly MFT pore water. Then, the Ca^{2+} concentration increased steadily, reflecting the mixing effects of CT water with the MFT pore water. The Ca^{2+} concentration reached 49.2 mg/L at Day 40, and increased 64% within 38 days. This increased concentration indicates that the CT-water was gradually penetrating the MFT layer and moving through the MFT layer to become release water. The reason why the Ca^{2+} concentration was higher than the feed concentration is unknown. From Day 40 until 60 days of incubation, the Ca^{2+} concentration fluctuated within the range of 49.2 mg/L and 34.5 mg/L, and the average Ca^{2+} concentration was approximately 43 mg/L.

Compared to the high flowrate system, in the low flowrate system CT water took more time to penetrate the MFT layer (Figure 4.2b). The Ca^{2+} concentration started to increase from about 20 mg/L on Day 8 to 30.5 mg/L on Day 39, and then fluctuated within a narrow range (from 26 mg/L to 31 mg/L) with an average Ca^{2+} concentration of 28 mg/L.

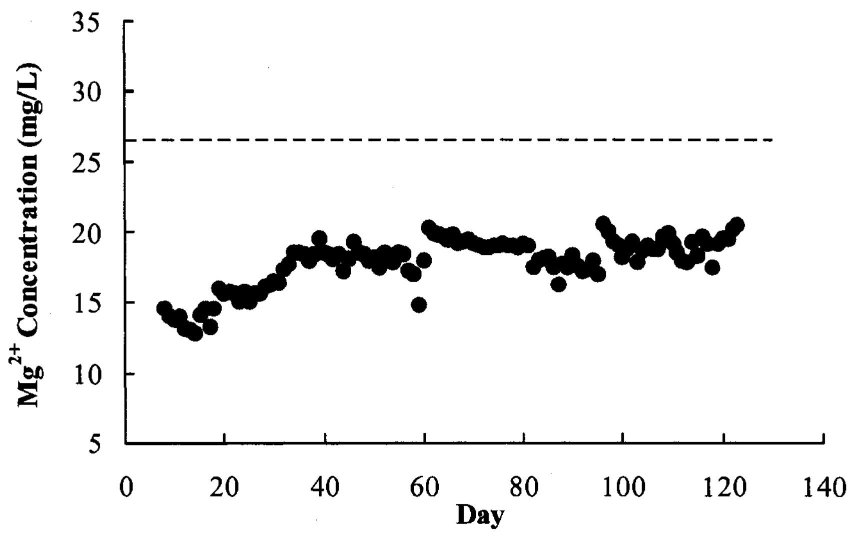
For both the high flowrate system and the low flowrate system, the change of Ca^{2+} concentration with time can be divided into two stages. In the first stage, the Ca^{2+} concentration increased, which indicated that the CT-water was penetrating through the MFT layer. In the second stage, the average Ca^{2+} concentration fluctuated within stable ranges, indicating that the MFT pores were saturated with CT water. No apparent Ca^{2+} removal was observed at the end of the experiment in both high and low flowrate systems.

The original Mg^{2+} concentration in the MFT was 13.7 mg/L, and Mg^{2+}

concentration in the feed water was 26.4 mg/L (see Appendix A9). For the high flowrate system (Figure 4.3a), the Mg^{2+} concentration increased steadily from Day 6 to 28.4 mg/L on Day 39, and remained relatively stable at the average Mg^{2+} concentration of 28 mg/L. As shown in Figure 4.3b, the Mg^{2+} in the release water of the low flowrate system



(a)



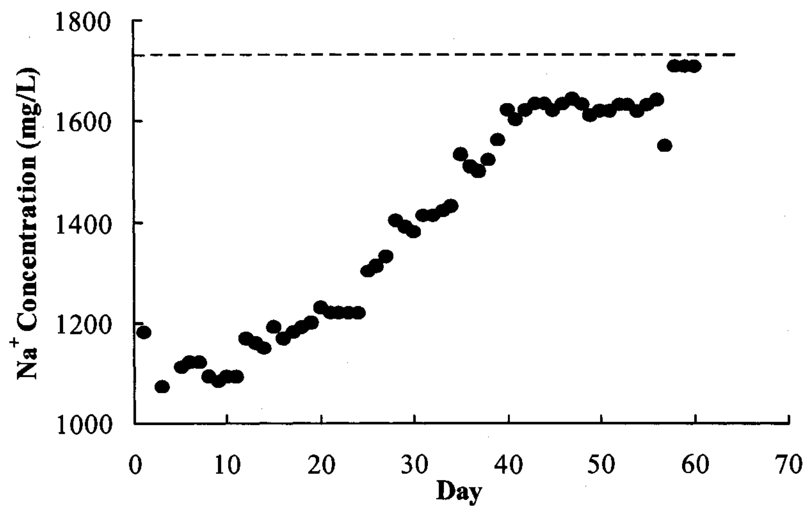
(b)

Figure 4.3 Mg^{2+} concentration as a function of time in the release water of System 1 dynamic columns: (a) at a high flowrate of feed water (16.5 mL/h in Column DH-1); (b) at a low flowrate of feed water (5.3 mL/h in Column DL-1), where the dashed line represents the Mg^{2+} concentration in the feed water

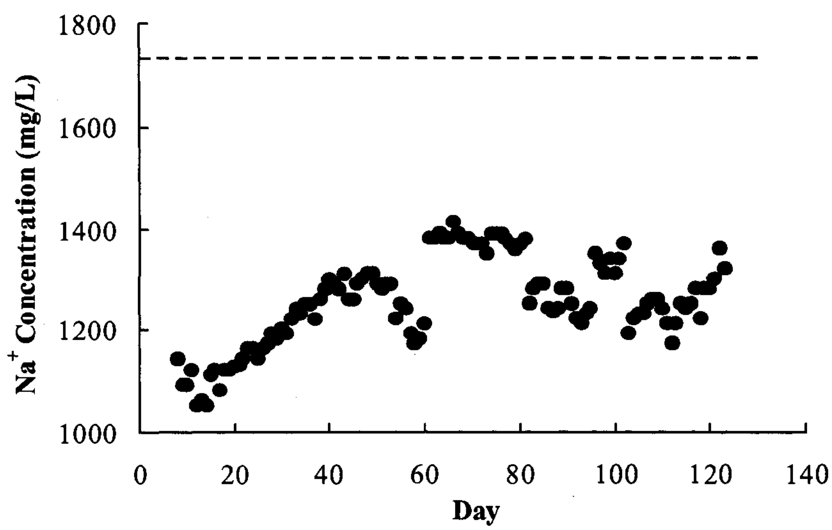
It is interesting to note that both Ca^{2+} and Mg^{2+} had the same concentration trend and elution timeframe in the same system. These similar profiles are most likely due to the fact that Ca^{2+} and Mg^{2+} have very similar physical and chemical characteristics: both can be retained by ion exchange, adsorption and chemical precipitation, and both have the same change.

4.1.1.3 Sodium concentration analysis

The Na^+ concentrations in release water for high and low flowrate systems are shown in Figure 4.4a and Figure 4.4b, respectively. The original Na^+ concentration in MFT was 1040 mg/L, and Na^+ concentration in the feed water was 1730 mg/L. For the high flowrate system, the Na^+ concentrations were approximately 1100 mg/L during the first 5 days, consistent with the original Na^+ concentration in MFT. Na^+ then increased almost linearly until Day 40 to the concentration of 1620 mg/L. From Day 41 to Day 60, the average Na^+ concentration was stable, close to the feed concentration. The Na^+ concentrations also confirmed that the saturation time was 40 days for high flow rate system. For the low flowrate system, the variability in Na^+ concentrations during the first few testing days was due to difficulty in collecting sufficient sample volume. Na^+ concentrations almost linearly increased to 1300 mg/L on Day 40. From Day 41 to Day 53, Na^+ fluctuated within the range of 1260 mg/L and 1310 mg/L, with an average concentration about 1290 mg/L. During Day 54 to Day 60, Na^+ concentration fluctuated but the overall trend was decreasing. From Day 61 to Day 81, the Na^+ concentration fluctuated in between 1390 mg/L and 1350 mg/L, and the average concentration was about 1370 mg/L. From Day 82 to Day 123, Na^+ concentration fluctuated within a wide range of 1370 mg/L to 1170 mg/L. The fluctuation and apparent decrease in Na^+ concentrations could be attributed to the change of feed water, possible ion exchange reactions in the system, or analytical variability.



(a)



(b)

Figure 4.4 Na^+ concentration as a function of time in the release water of System 1 dynamic columns: (a) at a high flowrate of feed water (16.5 mL/h in Column DH-1); (b) at a low flowrate of feed water (5.3 mL/h in Column DL-1), where the dashed line represents the Na^+ concentration in the feed water

Compared with the feed water Na^+ concentration, Na^+ concentration was reduced by 1.5% and 20% in the high flowrate system and low flowrate system, respectively.

4.1.1.4 Sulfate analysis

The original SO_4^{2-} concentration in the MFT was 18 mg/L, and the SO_4^{2-} concentration in the feedwater was 1060 mg/L. The changes in sulfate concentrations followed the same behavior as Br^-, indicating that the SO_4^{2-} is not interacting with the MFT. For the high flowrate system (Figure 4.5a), from Day 6, SO_4^{2-} concentration started to increase to approximately 680 mg/L until Day 40. The average SO_4^{2-} concentration after Day 40 was approximately 625 mg/L.

For the low flowrate system (Figure 4.5b), the initial drop of SO_4^{2-} concentration (from 53 mg/L on Day 8 to 5 mg/L on Day 19) was possibly due to sampling and analytical variability. SO_4^{2-} concentration increased almost linearly to 239 mg/L from Day 20 to Day 40 and remained relatively constant until Day 60. SO_4^{2-} concentration increased to 330 mg/L on Day 61, and then fluctuated in the range of 332 mg/L and 245 mg/L with a slight decreasing trend. From Day 82 until Day 123, SO_4^{2-} fluctuated over a wide range of 97 mg/L to 267 mg/L with average value of 193 mg/L.

Based on the initial feed water concentration, SO_4^{2-} removal efficiency in the high and low flowrate systems was 35% and 69%, respectively. The mechanism for sulfate removal was possibly due to the activity of SRB, which will be further discussed in Section 4.5.

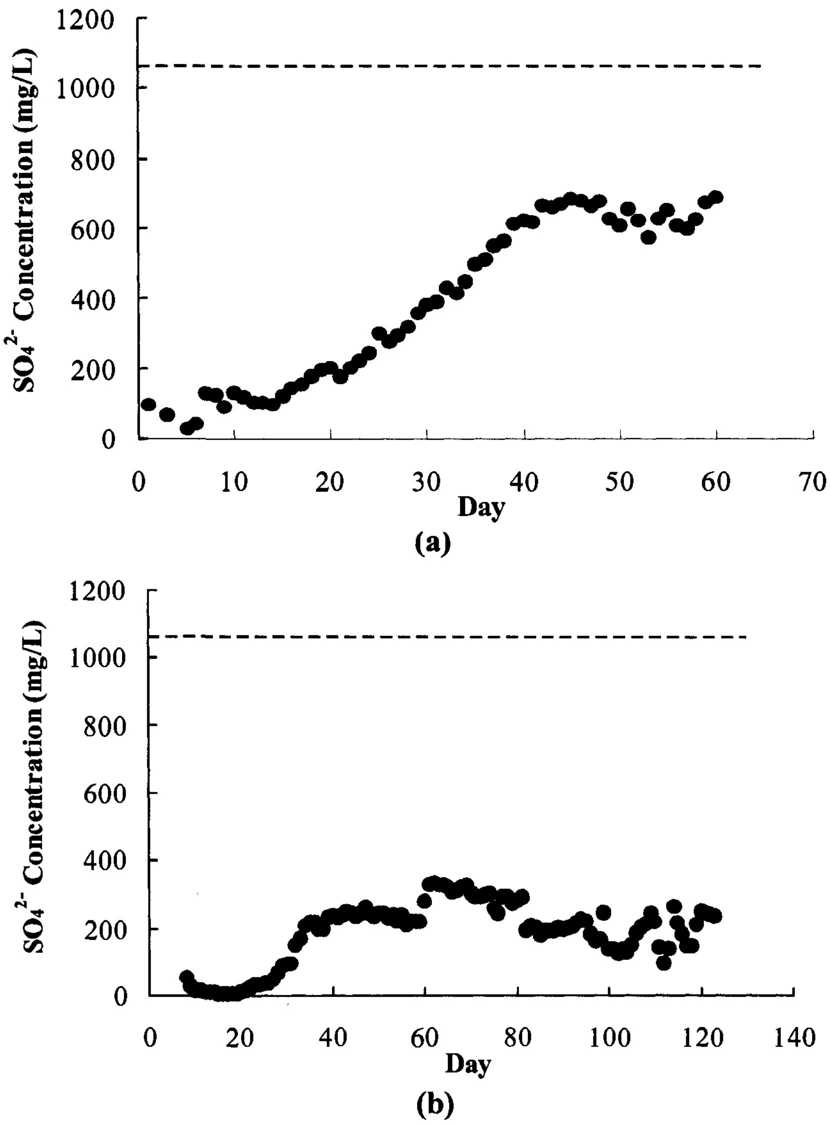
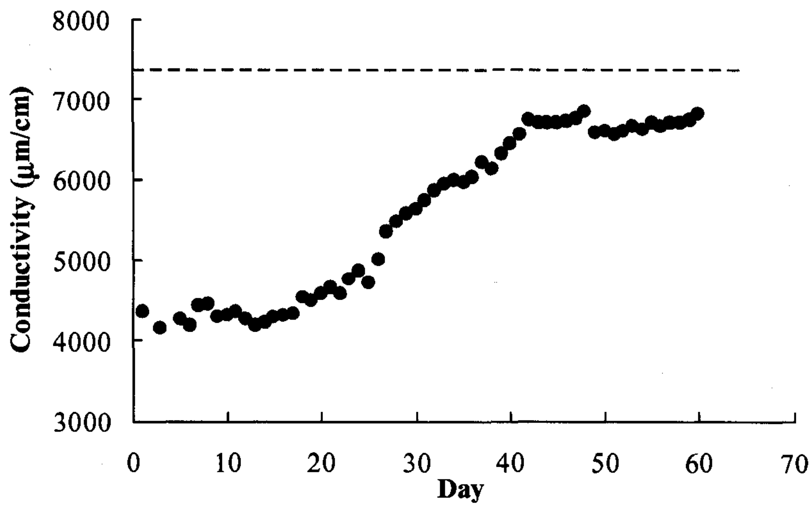


Figure 4.5 SO_4^{2-} concentration as a function of time in the release water of System 1 dynamic columns: (a) at a high flowrate of feed water (16.5 mL/h in Column DH-1); (b) at a low flowrate of feed water (5.3 mL/h in Column DL-1), where the dashed line represents the SO_4^{2-} concentration in the feed water

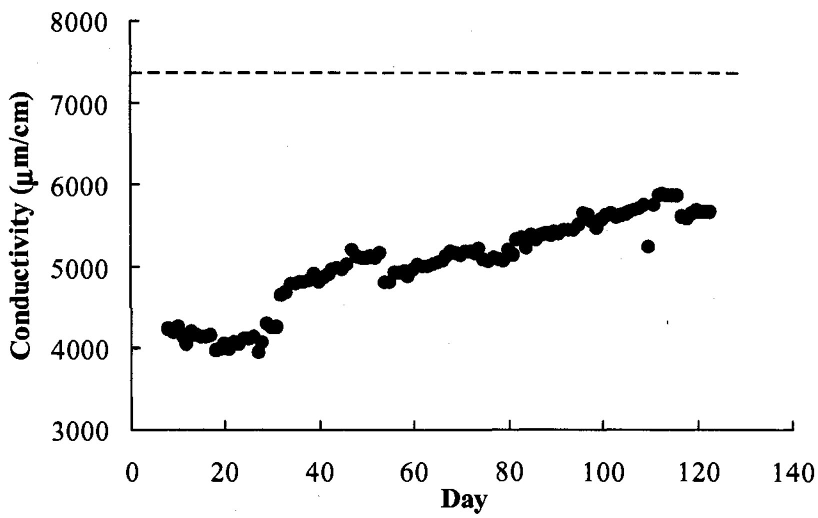
4.1.1.5 Conductivity analysis

Conductivity is a measurement of the ability of water to pass an electrical current, which is affected mainly by the presence of charged inorganic dissolved solids such as sodium, magnesium, calcium, iron, aluminum, chloride, nitrate, sulfate, and phosphate. Organic compounds do not conduct electrical current very well and have very low conductivity in water.

The conductivity in the release water of the high flowrate system fluctuated slightly in the range of 4450 μS/cm to 4140 μS/cm within the first 14 days (Figure 4.6a).



(a)



(b)

Figure 4.6 Conductivity as a function of time in the release water of System 1 dynamic columns: (a) at a high flowrate of feed water (16.5 mL/h in Column DH-1); (b) at a low flowrate of feed water (5.3 mL/h in Column DL-1), where the dashed line represents the conductivity in the feed water

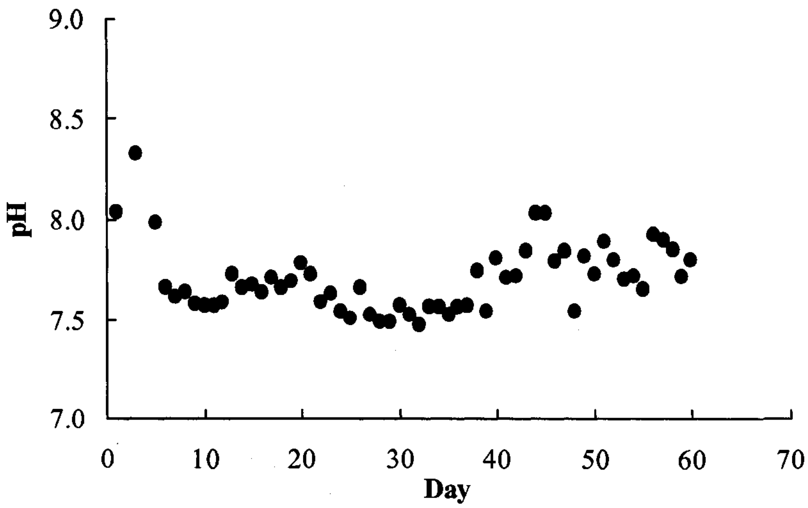
Then, the conductivity increased to 6740 μS/cm at Day 42. From then on, the conductivity varied within a small range of 6570 μS/cm and 6830 μS/cm. The conductivity of the low flowrate system fluctuated between 4290 μS/cm and 3950 μS/cm from Day 8 to Day 31 (see Figure 4.6b). Then, the conductivity increased from Day 32 to Day 123. Conductivity measurements also confirmed that the hydraulic retention time was approximately 40 and 120 days for the high and low flow rate systems, respectively.

The original conductivity of MFT was 4110 μS/cm, and the conductivity of the feed water was 7360 μS/cm. Therefore, after penetrating the MFT layer, the conductivity of both systems was reduced by 7% and 20%.

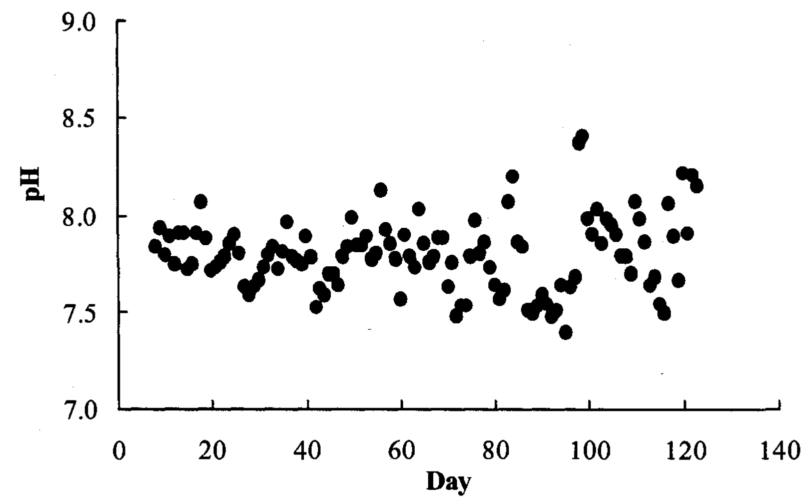
4.1.1.6 pH analysis

Figure 4.7a and 4.7b present the pH for the high flowrate system and low flowrate system, respectively. As shown in Figure 4.7a, the pH of the high flowrate system increased from 8.04 on Day1 to 8.33 on Day 2; and then decreased linearly to 7.61 on Day 7. From Day 8 until Day 60, the pH varied in a range of 7.47 to 8.03 with the average value of 7.75. For the low flowrate system, the pH fluctuated in a range of 7.39 to 8.40 with the average value of 7.80.

It should be noted that the Ca^{2+}, $Mg^{2+}$and SO_4^{2-} concentrations of the low flowrate system (shown in Figure 4.2b, 4.3b, 4.5b and 4.7b) also fluctuated during the period of Day 82 to Day 123. One reason for such a fluctuation of these ions concentrations might be because of the pH fluctuation. This fluctuation in pH may have affected the effectiveness of ion exchange between Na^+ and Ca^{2+} and between Na^+ and Mg^{2+} in the MFT. Moreover, the pH fluctuation might also affect the chemical precipitation of Ca^{2+} and Mg^{2+} with SO_4^{2-}. Since the experimental system consisting of MFT and feed water is a very complicated system, it would be very difficult to determine the causes of the fluctuations of Ca^{2+}, Mg^{2+}, Na^{+}, SO_4^{2-} and pH without further detailed investigation.



(a)



(b)

Figure 4.7 pH as a function of time in the release water of System 1 dynamic columns: (a) at a high flowrate of feed water (16.5mL/h in Column DH-1); (b) at a low flowrate of feed water (5.3mL/h in Column DL-1)

4.1.2 Physical and Chemical Characteristics in System 2

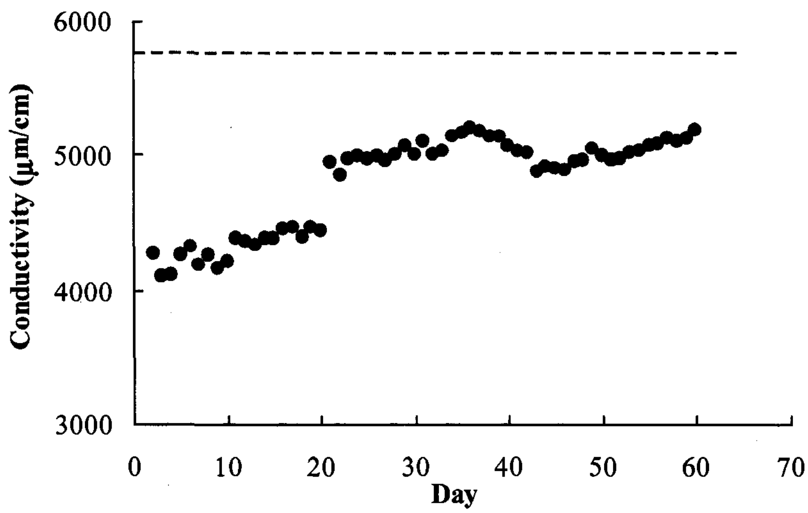
For System 2, the feed water was amended so that the concentrations of Ca^{2+}, Mg^{2+}, and SO_4^{2-} were 250 mg/L, 250 mg/L, and 2500 mg/L, respectively. The feed water penetrated through the MFT layer at two different flow rates, and then the release water was sampled and analyzed for Na^{+}, Ca^{2+}, Mg^{2+}, SO_4^{2-}, pH, and conductivity. The flowrates of the feed water were 16.9 mL/h and 4.7 mL/h. Because no Br^{-} was detected in the release water due to some unknown reason, the hydraulic properties of this system were characterized based on the conductivity measurement.

4.1.2.1 Conductivity analysis

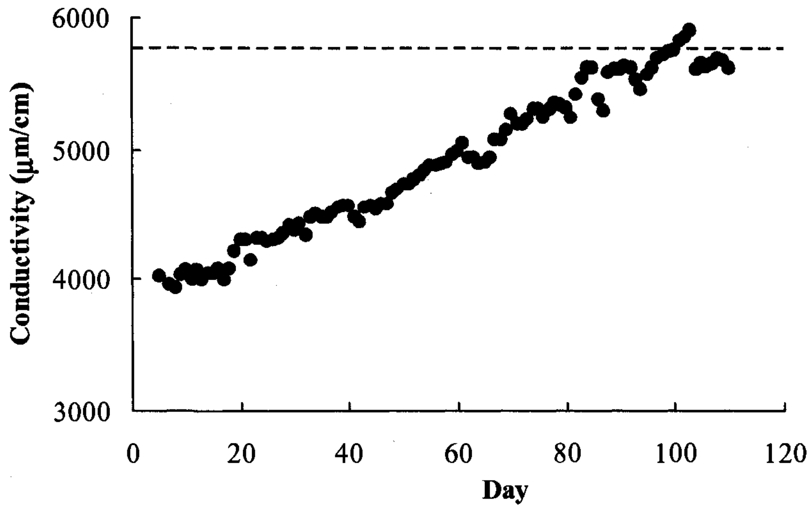
The conductivity of the high flowrate system increased slowly from 4280 μS/cm to 4450 μS/cm within 20 days (Figure 4.8a). Then the conductivity increased to 4940 μS/cm on Day 21. From then on, the conductivity increased slowly to 5190 μS/cm at Day 60. It was identified from Figure 4.8a that the saturation time was approximately 36 days.

The measured conductivity of the low flowrate system increased steadily from 4020 μS/cm on Day 5 to 5900 μS/cm on Day 103 (Figure 4.8b). Figure 4.8b shows that the increase of conductivity was almost linear. Then the conductivity dropped slightly to 5610 μS/cm on Day 110. Base on Figure 4.8b, it is assumed that the hydraulic retention time was approximately 100 days for this column.

The original conductivity of MFT was 4110 μS/cm. The conductivity of the feed water was 5770 μS/cm. The highest conductivity of the release water of the high flowrate system and low flowrate system was 5200 μS/cm and 5900 μS/cm, respectively. Therefore, the conductivity was reduced by 10% after penetrating through the high flowrate system, whereas the conductivity of the low flowrate system increased by 2%, which may be in the range of experimental error.



(a)



(b)

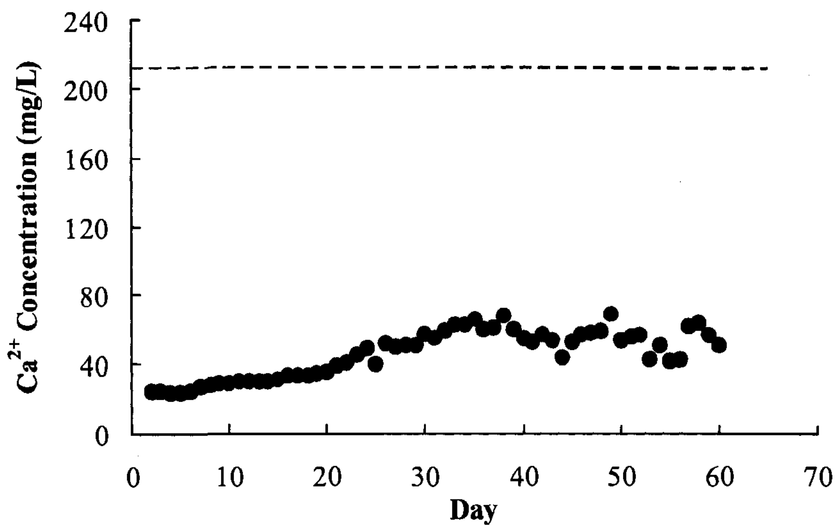
Figure 4.8 Conductivity as a function of time in the release water of System 2 dynamic columns: (a) at a high flowrate of feed water (16.9 mL/h in Column DH-2); (b) at a low flowrate of feed water (4.7 mL/h in Column DL-2), where the dashed line represents the conductivity in the feed water

4.1.2.2 Calcium and magnesium concentration analysis

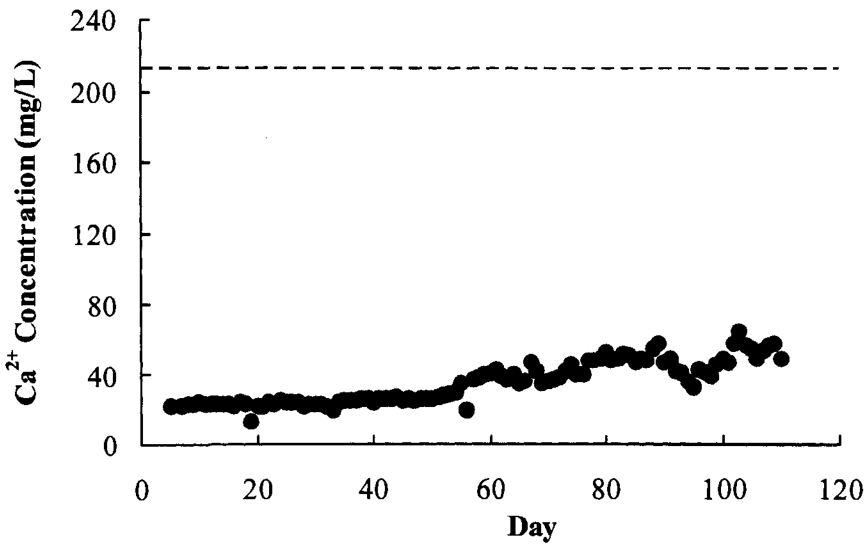
The calcium concentration in the MFT layer before introducing feed water was 23.1 mg/L for both the high and low flowrate columns. The actual Ca^{2+} concentration in the feed water was 212 mg/L. As shown in Figure 4.9a, for the high flowrate system, until Day 6, the Ca^{2+} concentration in the release water was comparable to that in the MFT. Then, the Ca^{2+} concentration increased steadily and reached 65.0 mg/L (62% increases) on Day 35. This result suggests that the feed water was gradually penetrating the MFT layer and accumulating as release water. From Day 35 until 60 days, the Ca^{2+} concentration fluctuated within the range of 68.3mg/L and 42.4 mg/L. A high removal efficiency for Ca^{2+} (approximately 68%) was achieved in this column.

Compared to the high flowrate system, the Ca^{2+} in the low flowrate system took longer to penetrate the MFT layer (Figure 4.9b). The Ca^{2+} concentration fluctuated between 21.5 mg/L and 25.8 mg/L from Day 5 to Day 50. The fluctuation (about 2%) may be in the experimental error range. Moreover, the average Ca^{2+} concentration of 34.7 mg/L suggests that the release water before Day 50 consisted of MFT pore water. After Day 50, the Ca^{2+} concentration increased faster and reached 42.4 mg/L on Day 61, which seems to imply that the feed water was gradually penetrating through MFT layer and entered the release water. From Day 61, the Ca^{2+} concentration increased from 33.0 mg/L to 64.0 mg/L. The Ca^{2+} removal efficiency in the low flow rate column was approximately 70%.

For both the high flowrate system and the low flowrate system, the change of Ca^{2+} concentration with time can be divided into two stages. In the first stage, the Ca^{2+} concentration increased, which indicated that the feed water was penetrating through the MFT layer. During the second stage, the Ca^{2+} concentration fluctuated within a small range, indicating that ion exchange or some other mechanism was occurring between the feed water and the MFT and retained Ca^{2+} in the MFT layer.



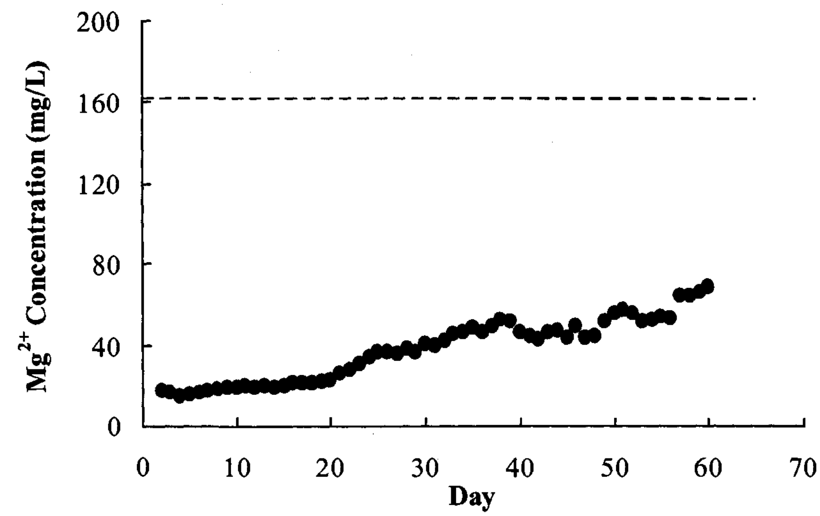
(a)



(b)

Figure 4.9 Ca^{2+} concentration as a function of time in the release water of System 2 dynamic columns: (a) at a high flowrate of feed water (16.9 mL/h in Column DH-2); (b) at a low flowrate of feed water (4.7 mL/h in Column DL-2), where the dashed line represents the Ca^{2+} concentration in the feed water

The original Mg^{2+} concentration in MFT was 15.1 mg/L. Mg^{2+} in the feed water was 162 mg/L. For the high flowrate system, the Mg^{2+} concentration increased from 17.6 mg/L on Day 2 to 53.4 mg/L on Day 38 (roughly the hydraulic retention time), as shown in Figure 4.10a. After then, Mg^{2+} concentration increased from 44 mg/L to 70 mg/L.



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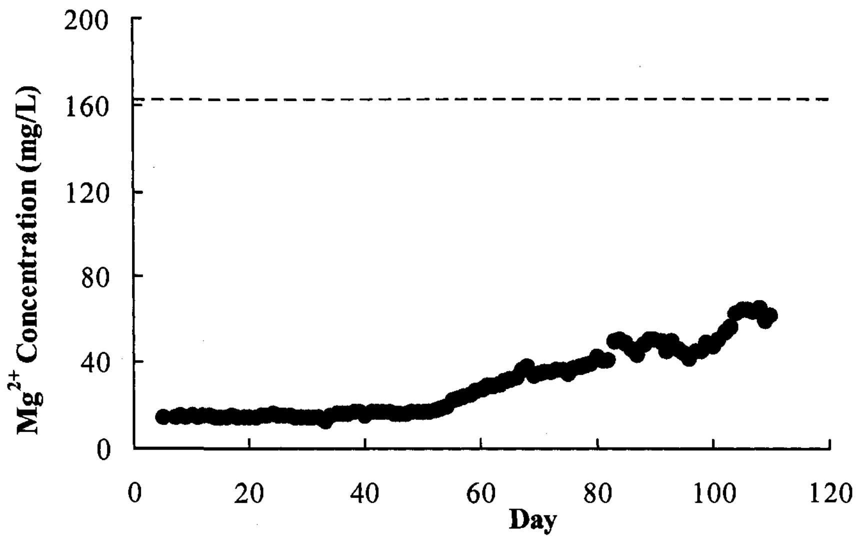


(b)

Figure 4.10 Mg^{2+} concentration as a function of time in the release water of System 2 dynamic columns: (a) at a high flowrate of feed water (16.9mL/h in Column DH-2); (b) at a low flowrate of feed water (4.7mL/h in Column DL-2), where the dashed line represents the Mg^{2+} concentration in the feed water

In comparison with the high flowrate system, the increase of the Mg^{2+} concentration in the release water for the low flowrate system was very slow (Figure 4.10b). The Mg^{2+} concentration was relatively constant (ranging from 14.2 mg/L to 16.7 mg/L) before Day 50, suggesting the release water before Day 50 consisted mainly of MFT pore water. From Day 51 to Day 84, the Mg^{2+} increased slowly from 17.1 mg/L to

50.6 mg/L, which implies that the feed water was gradually penetrating the MFT layer and accumulating as release water. After Day 84, the Mg^{2+} concentration fluctuated but increased to 65.1 mg/L.

The removal efficiency for Mg^{2+} was approximately 57% and 60% in the high and low flow rate columns, respectively.

Relatively high removal efficiency was observed for Ca^{2+} and Mg^{2+} in both high and low flow rate columns. The major removal mechanism was possibly ion exchange between Ca^{2+} and Mg^{2+} with Na^{+} in the MFT layer.

4.1.2.3 Sodium concentration analysis

For the high flowrate system (Figure 4.11a), generally, the Na^{+} concentration increased until Day 11, stabled at a plateau from Day 11 to Day 33, decreased from Day 34 to Day 49, and increased during Day 49 to Day 60.

For the low flowrate system (Figure. 4.11b), the Na^{+} concentration can be divided into three stages: stage one was from day 5 to day 54, where the Na^{+} concentration slightly increased from 1110 mg/L to 1190 mg/L; stage two was from Day 55 to Day 89, Na^{+} concentration was stable at 1340 mg/L; stage three was from Day 90 to Day 110, where the Na^{+} concentration increased from 1180 mg/L to 1320 mg/L with the trend increasing.

The original Na^{+} concentration in MFT was 1110 mg/L. The sodium concentration in the feed water was 1180 mg/L. The highest Na^{+} concentration in the release water was 1290 mg/L in the high flowrate system and 1340 mg/L in the low flowrate system. The high Na^{+} concentration in the release water (higher than the original concentrations in either the MFT or feed water) may be due to ion exchange between Ca^{2+} and Na^+, or Mg^{2+} and Na^+ as expressed in the following equation:

$$Ca^{2+} + 2Na\text{-clay} \rightleftharpoons 2Na^+ + Ca\text{-clay} \quad (4\text{-}1)$$

$$Mg^{2+} + 2Na\text{-clay} \rightleftharpoons 2Na^+ + Mg\text{-clay} \quad (4\text{-}2)$$

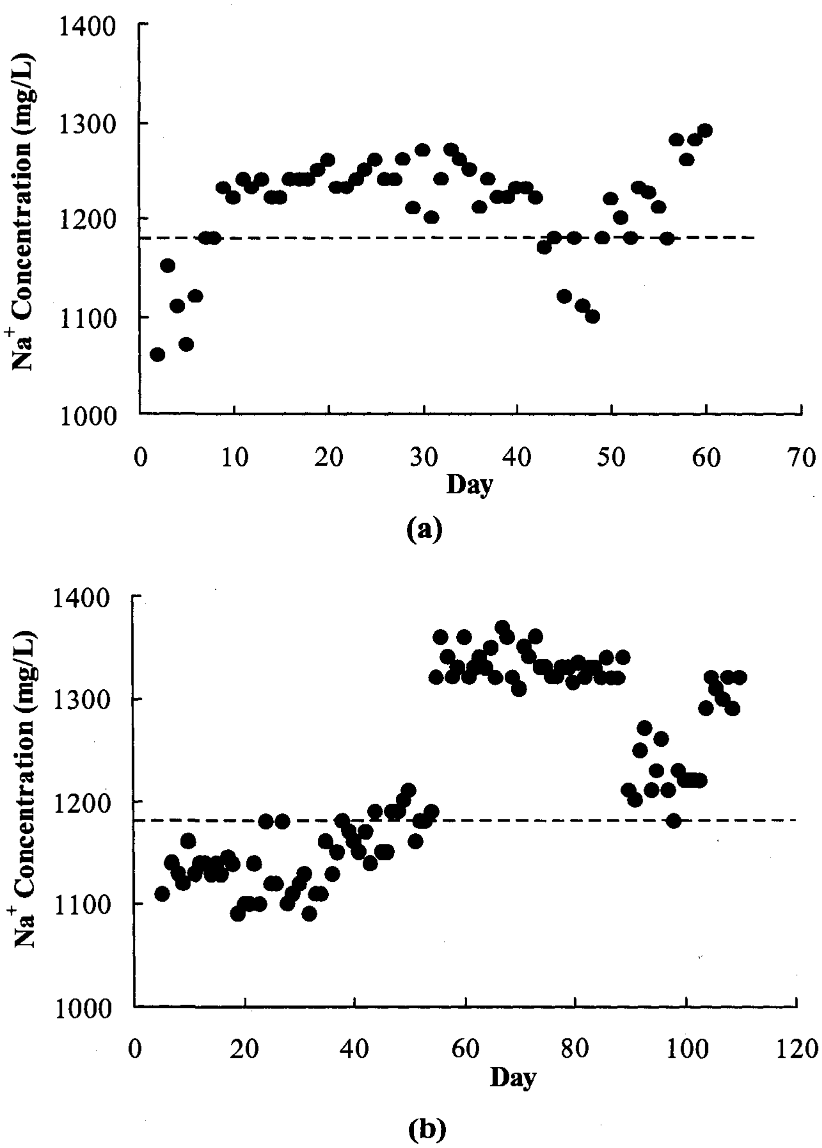


Figure 4.11 Na^+ concentration as a function of time in the release water of System 2 dynamic columns: (a) at a high flowrate of feed water (16.9 mL/h in Column DH-2); (b) at a low flowrate of feed water (4.7 mL/h in Column DL-2), where the dashed line represents the Na^+ concentration in the feed water

Thus, a drop in Ca^{2+} concentration caused by ion exchange between Ca^{2+} and Na^{+} will result in an increase in the Na^{+} concentration in the porewater and release water from MFT. The same holds true for Mg^{2+}. Therefore a drop in Ca^{2+} or Mg^{2+} concentration due to ion exchange will result in a corresponding increase in the Na^{+} concentration as observed here. The increase in Na^{+} concentration suggests that Ca^{2+} and Mg^{2+} were indeed exchanging with Na^{+}.

4.1.2.4 Sulfate analysis

Figure 4.12 shows the sulfate concentration as a function of time in system 2. The SO_4^{2-} concentration in the high flowrate system increased from 117 mg/L on Day 2 to 1080 mg/L on Day 36, and then dropped to 647 mg/L on Day 42 (Figure 4.12a). The decrease in sulfate concentration may be the result of the reduction of sulfate to S^{2-} by SRB in the MFT layer. After 42 days, the sulfate concentration fluctuated within the range of 700 to 995 mg/L.

The concentration of sulfate on Day 5 in the release water of the low flowrate system was 32.1 mg/L (Figure 4.12b). From Day 5, the sulfate concentration decreased and reached 4.7 mg/L on Day 26. From Day 27, sulfate concentration increased rapidly and reached 695 mg/L on Day 67. From then on, the sulfate concentration fluctuated within the range of 268 mg/L and 647 mg/L. Comparison of the high flowrate system and the low flowrate system indicated that the low flowrate system was more effective at decreasing the SO_4^{2-} concentration in release water.

The original SO_4^{2-} concentration in MFT was 30.2 mg/L. The SO_4^{2-} concentration in the feed water was 2160 mg/L. The highest SO_4^{2-} concentration in the high flowrate system and low flowrate system were 1080 mg/L and 695 mg/L, respectively. Therefore, the SO_4^{2-} removal efficiency of the high flowrate system and the low flowrate system were 50% and 68%, respectively.

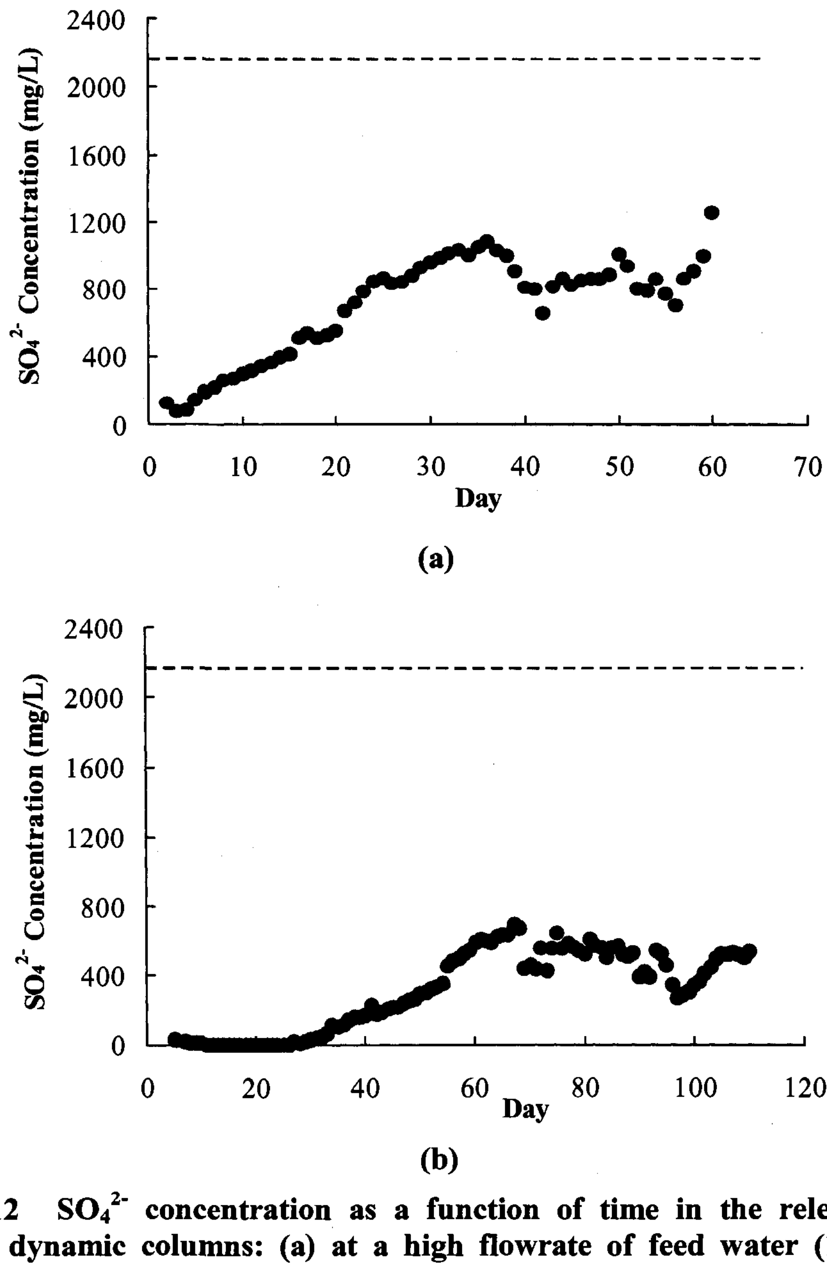
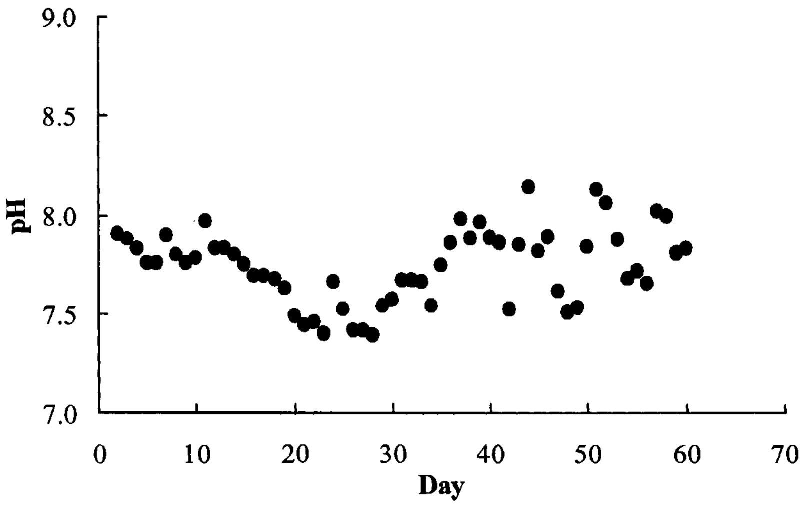


Figure 4.12 SO_4^{2-} concentration as a function of time in the release water of System 2 dynamic columns: (a) at a high flowrate of feed water (16.9 mL/h in Column DH-2); (b) at a low flowrate of feed water (4.7 mL/h in Column DL-2), where the dashed line represents the SO_4^{2-} concentration in the feed water

4.1.2.5 pH analysis

Figure 4.13a and 4.13b show the pH for the high flowrate system and low flowrate system, respectively. As shown in Figure 4.13a, the pH of the high flowrate system fluctuated between 7.76 and 7.97 from Day 2 to Day 11, and then dropped to 7.40



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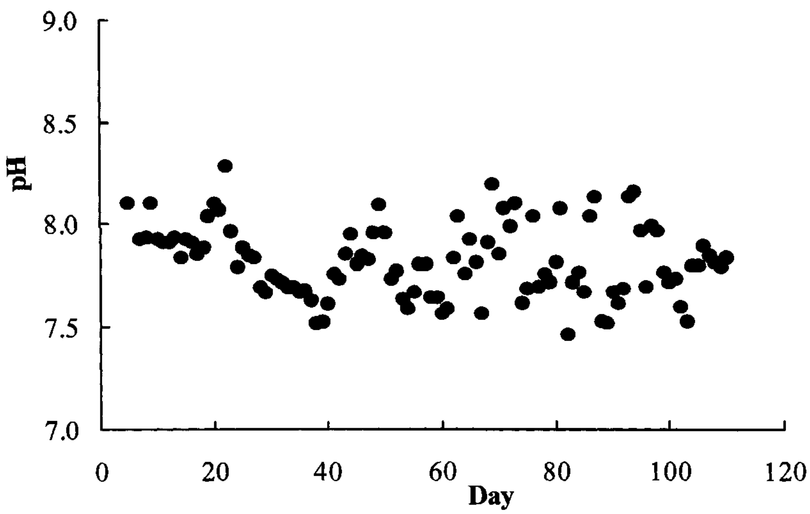


(b)

Figure 4.13 pH as a function of time in the release water of System 2 dynamic columns: (a) at a high flowrate of feed water (16.9 mL/h in Column DH-2); (b) at a low flowrate of feed water (4.7 mL/h in Column DL-2)

until Day 23, and fluctuated within the range of 7.39 and 8.14 during Day 24 and Day 60. The pH of the low flowrate system fluctuated within the range of 7.83 to 8.28 during Day 5 to Day 22, then dropped steadily down to 7.51 at Day 38, and fluctuated in between 7.46 and 8.19 during Day 39 until Day 110 (Figure 4.13b).

4.1.3 Physical and Chemical Characteristics in System 3 (Addition of Ac^-)

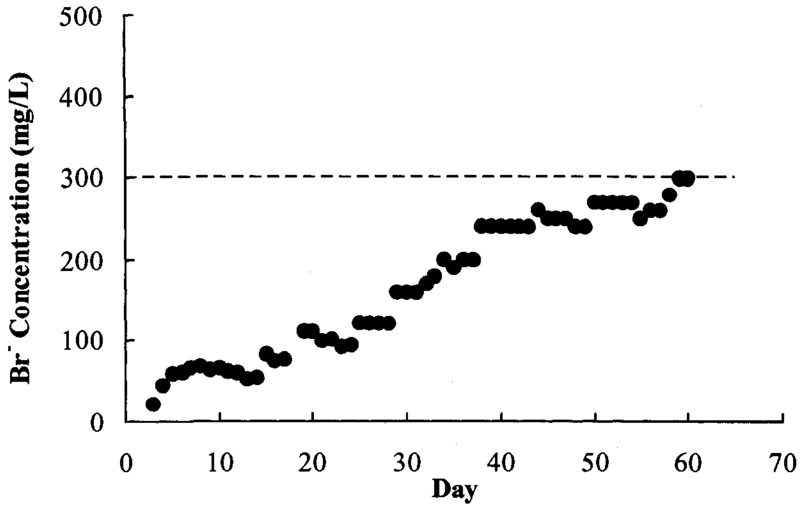
In System 3, Ac^- was added to feed water at concentration of 100 mg/L as an organic carbon source to promote the microorganism-mediated reactions. The actual flowrates for this system were 18.7 mL/h at the high flowate condition and 6.1 mL/h at the low flowate condition.

4.1.3.1 Tracer Bromide analysis

In System 3, Br^- was added as a tracer at 300 mg/L for the high flowrate system and 400 mg/L for the low flowrate system. As presented in Figure 4.14a and 4.14b, Br^- increased steadily, which means that the feed water was gradually penetrating the MFT layer. Br^- in the release water was approximately 300 mg/L after 60 days in the high flowrate system, whereas in low flowrate system, it took 123 days for release water Br^- concentration to reach 400 mg/L. Therefore, it was determined that the approximate saturation times for high and low flowrate systems were respectively 60 and 123 days.

4.1.3.2 Calcium and magnesium analysis

Figure 4.15 and 4.16 illustrate the changes in the concentrations of Ca^{2+} and Mg^{2+} in the high and low flowrate systems. The original Ca^{2+} concentration of the MFT was 22.8 mg/L and the Ca^{2+} in the feed water was 42 mg/L. In the high flowrate system, the Ca^{2+} concentration varied in a very small range of 23.6 mg/L to 26.9 mg/L from Day 3 to Day 37. On Day 38, the Ca^{2+} concentration increased from 26.6 mg/L to 31.8 mg/L, and then varied in the range of 31.8 mg/L and 23.4 mg/L from Day 38 to Day 60.



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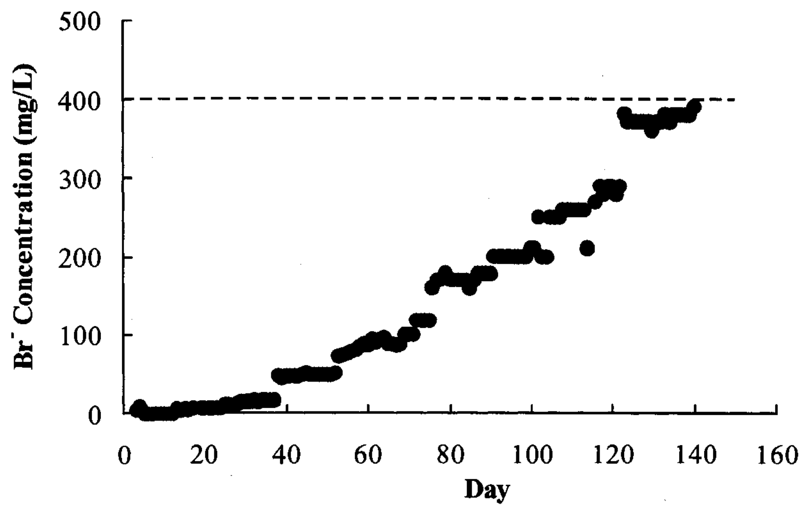
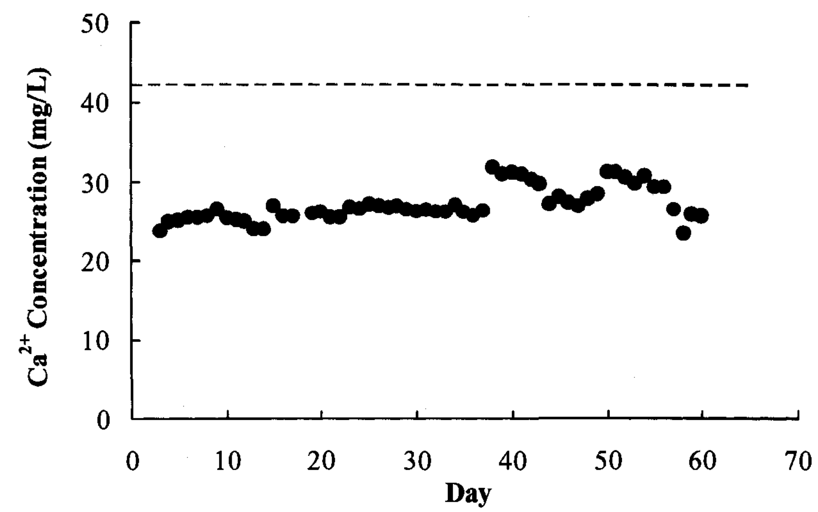


(b)

Figure 4.14 Br^- concentration as a function of time in the release water of System 3 dynamic columns: (a) at a high flowrate of feed water (18.7 mL/h in Column DH-3); (b) at a low flowrate of feed water (6.1 mL/h in Column DL-3), where the dashed line represents the Br^- concentration in the feed water

In the low flowrate system, the Ca^{2+} concentration varied in the range of 18.0 mg/L to 24.5 mg/L from Day 3 to Day 63. From Day 64 to Day 114, the Ca^{2+} concentration was relatively stable with an average concentration about 22.8 mg/L. The reason for the much lower Ca^{2+} concentrations between Day 114 and Day 130 could not be identified.



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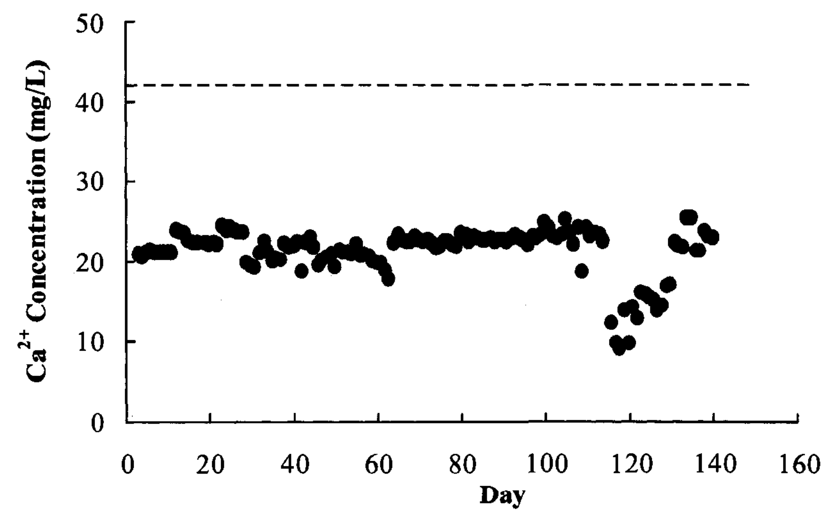
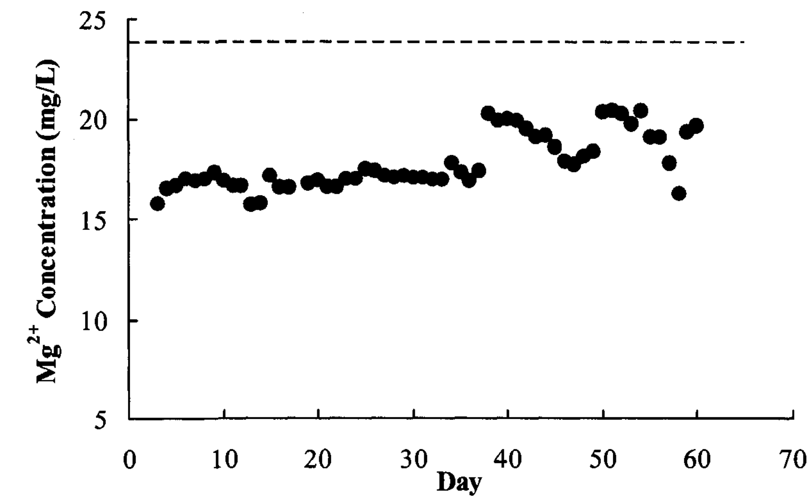


(b)

Figure 4.15 Ca^{2+} concentration as a function of time in the release water of System 3 dynamic columns: (a) at a high flowrate of feed water (18.7mL/h in Column DH-3); (b) at a low flowrate of feed water (6.1mL/h in Column DL-3), where the dashed line represents the Ca^{2+} concentration in the feed water

The highest Ca^{2+} concentration of the high flowrate system and the low flowrate system was 31.8 mg/L and 25.5 mg/L, respectively. In both columns, due to the low concentration of Ca^{2+}, it is difficult to verify that there was significant difference of Ca^{2+} concentration between feed water and the release water. However, retention of Ca^{2+} in the MFT layer may have occurred to some extent as a result of sorption, ion exchange and/or precipitation.



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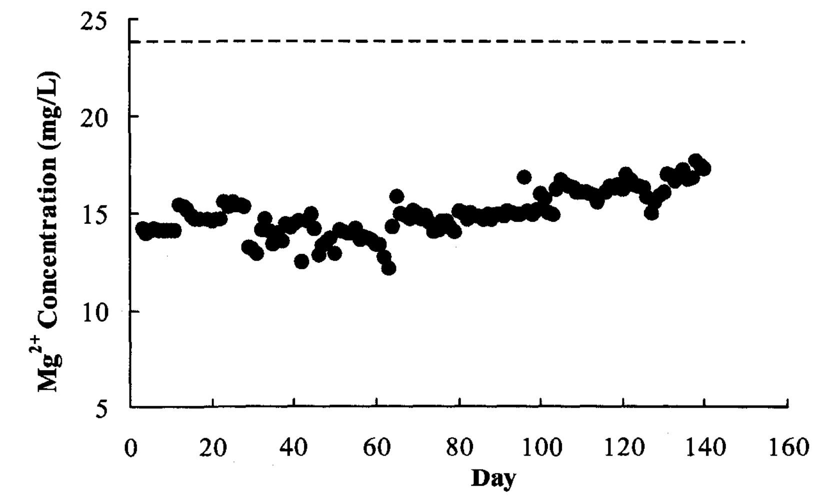


(b)

Figure 4.16 Mg^{2+} concentration as a function of time in the release water of System 3 dynamic columns: (a) at a high flowrate of feed water (18.7 mL/h in Column DH-3); (b) at a low flowrate of feed water (6.1 mL/h in Column DL-3), where the dashed line represents the Mg^{2+}concentration in the feed water

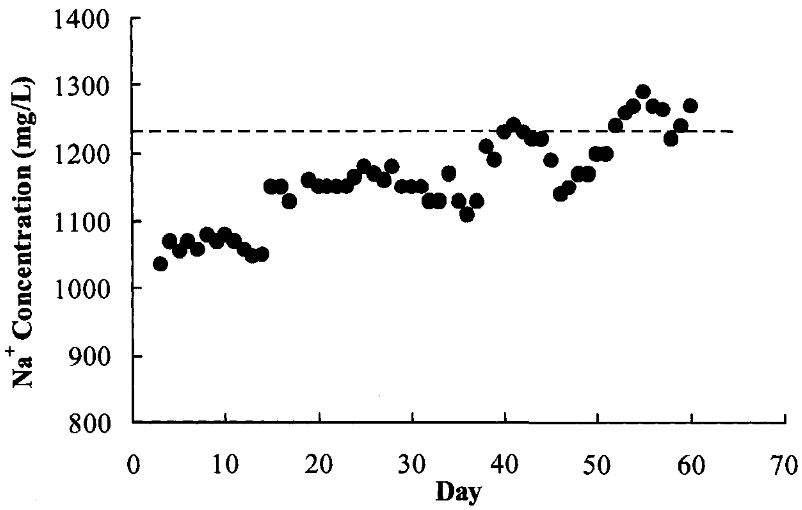
As shown in Figure 4.16a, the change in Mg^{2+} was similar to that of Ca^{2+} in the high flowrate system. During the first 37 days, Mg^{2+} fluctuated between 15.8 mg/L and 17.4 mg/L, while Mg^{2+} concentration in the feed water was 23.8 mg/L. On Day 38, there was a 16% increase in Mg^{2+} concentration to 20.2 mg/L. Then the change of Mg^{2+} concentration was within the range of 19 mg/L ±10%. It could be thought that the Mg^{2+} concentration was stable in this system if an experimental error of approximately 10% is assumed. The Mg^{2+} concentration in the feed water was 26.0 mg/L. The highest concentration of Mg^{2+} in release water was 20.4 mg/L. These results suggest that at least 22% of the Mg^{2+} was retained by MFT mostly likely due to sorption, ion exchange and/or precipitation.

The concentration of Mg^{2+} fed into the low flowrate system was 26.0 mg/L. As the feed water was introduced into System 3, the Mg^{2+} in the MFT pore water was slowly released, and therefore the Mg^{2+} concentration increased in the release water. Subsequently, when the feed water broke through the MFT layer on Day 122, Mg^{2+} in release water was 16.7 mg/L. After that, there was no sharp increase of Mg^{2+} in release water. More than 30% Mg^{2+} was retained in the MFT layer. Ion exchange and precipitation might have contributed to this decrease.

The original Mg^{2+} concentration of the MFT was 14.8 mg/L. The Mg^{2+} concentration in the feed water was 23.8 mg/L. The highest Mg^{2+} concentration of the high flowrate system and the low flowrate system was 20.4 mg/L and 16.7 mg/L, respectively. Therefore, Mg^{2+} removal efficiency of the high flowrate system and the low flowrate system was 14% and 26%, respectively.

4.1.3.3 Sodium concentration analysis

Figure 4.17a and 4.17b present the Na^+ concentrations in release water for high and low flowrate columns. The original Na^+ concentration in the MFT was 1090 mg/L. The Na^+ concentration in the feed water was 1230 mg/L.



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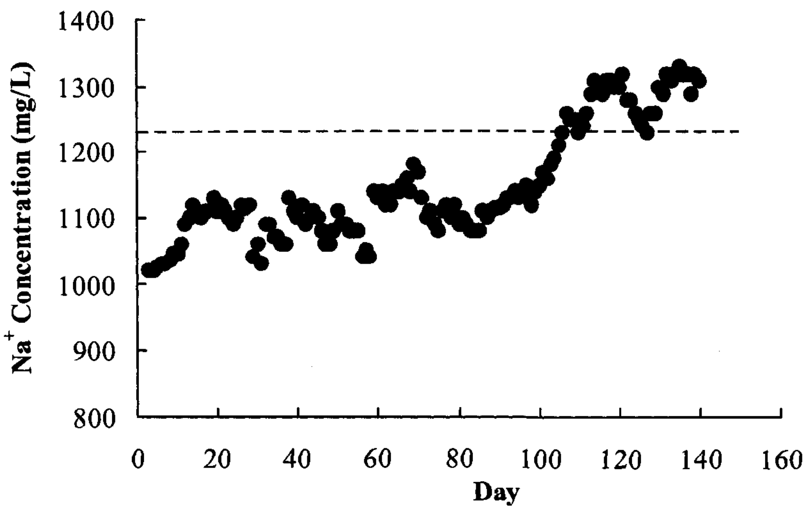


(b)

Figure 4.17 Na^+ concentration as a function of time in the release water of System 3 dynamic columns: (a) at a high flowrate of feed water (18.7 mL/h in Column DH-3); (b) at a low flowrate of feed water (6.1 mL/h in Column DL-3), where the dashed line represents the Na^+ concentration in the feed water

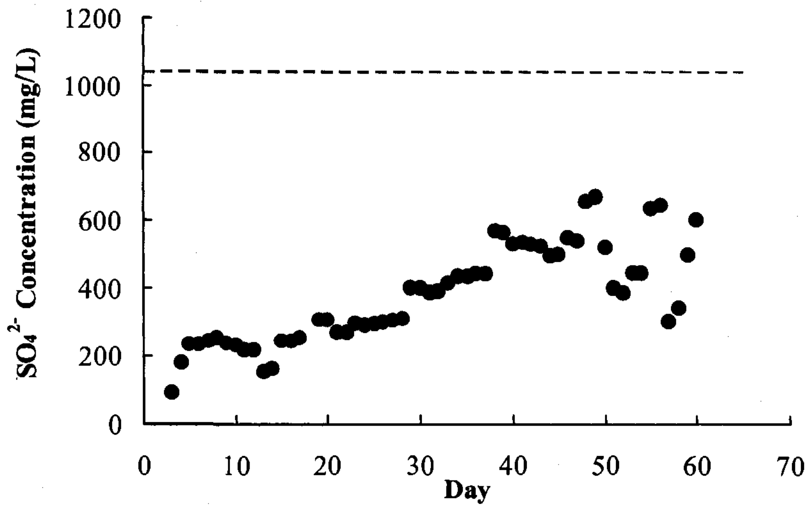
In the high flowrate system, Na^+ showed a general increasing trend with minor fluctuation before the feed water broke through the MFT layer, from 1036 mg/L to 1290 mg/L (Figure 4.17a). As the feed water initially moved through the MFT, the original pore water in the MFT layer was slowly released. With more and more feed water entering the MFT layer, more and more Na^+ in MFT layer was replaced by Ca^{2+} or Mg^{2+} due to ion exchange, and subsequently moved into the release water with the bulk feed water.

As shown in Figure 4.17b, an appreciable increase in the Na^+ concentration of the release water in the low flow rate system occurred. There was a steady increase from Day 83 to Day 121 when the feed water was approaching the breakthrough point. From Day 106, the Na^+ concentration in release water was higher than that in feed water. This result implies that some Na^+ in the MFT layer was replaced by Ca^{2+} and Mg^{2+}, and subsequently Na^+ was released into the release water.

The highest Na^+ concentrations in the high and the low flowrate columns were 1290 mg/L and 1330 mg/L, translating to a 5% and 8% increase in the Na^+ concentration respectively.

4.1.3.4 Sulfate analysis

The original SO_4^{2-} concentration of the MFT was 17.7 mg/L. The SO_4^{2-} concentration in the feed water was 1035 mg/L. It can be seen from Figure 4.18a, the SO_4^{2-} concentration in the release water for the high flowrate system increased from 93.6 mg/L at the beginning of incubation to 600 mg/L at the end of experiment, due to the gradual penetration of the feed water through the MFT. Because of some limitations in the chemical analyses, a mass balance could not be conducted. However, the difference between the feed water and release water SO_4^{2-} concentration at breakthrough point indicated that MFT could reduce SO_4^{2-} concentration. The reason for this reduction in SO_4^{2-} concentration might be that SRB in the MFT layer were actively reducing SO_4^{2-} to sulfide (S^{2-}).



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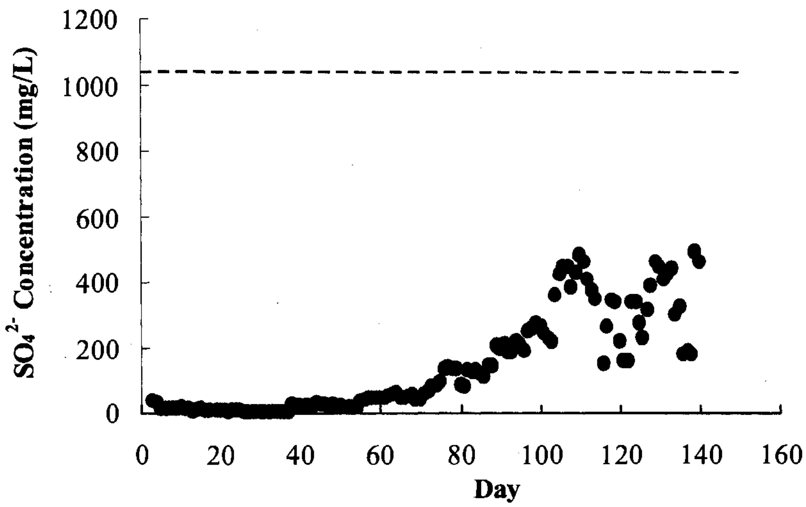


(b)

Figure 4.18 SO_4^{2-} concentration as a function of time in the release water of System 3 dynamic columns: (a) at a high flowrate of feed water (18.7 mL/h in Column DH-3); (b) at a low flowrate of feed water (6.1 mL/h in Column DL-3), where the dashed line represents the SO_4^{2-} concentration in the feed water

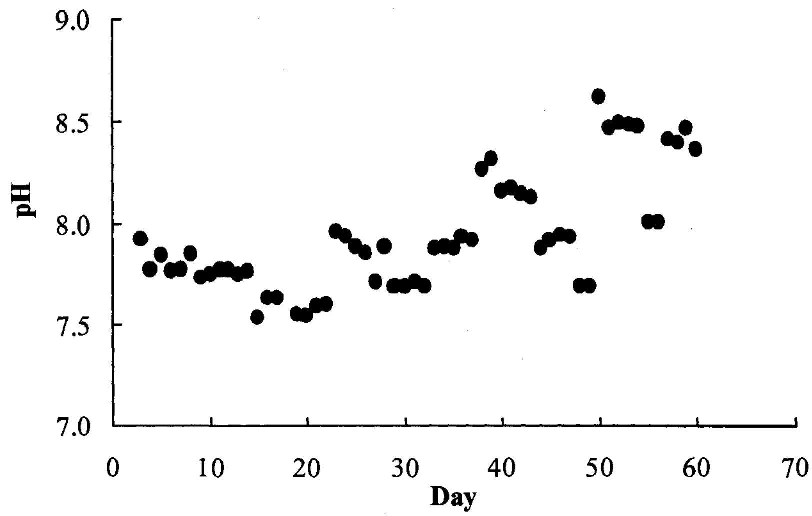
The initial sulfate in the release water was 41.1 mg/L in the low flowrate column (Figure 4.18b). Then, the sulfate concentration in the release water decreased slowly to 6.6 mg/L on Day 37. A sharp increase occurred on Day 38, from 6.6 mg/L to 28.3 mg/L. From then, the effluent sulfate increased with minor fluctuation until the breakthrough point. The sulfate concentration at breakthrough was 342 mg/L. Later, the concentration fluctuated within a large range of 183 mg/L to 496 mg/L.

Generally, before breakthrough, the effluent sulfate at both systems was far lower than that in the feed water before breakthrough point. The sulfate concentration in the feed water was 1015 mg/L, whereas the highest SO_4^{2-} in the release water was 665 mg/L and 496 mg/L in the high and low flowrate columns, respectively. It is believed that the low flowrate system provided more time for sulfate reduction in MFT layer and thus produced lower sulfate concentrations in the release water.

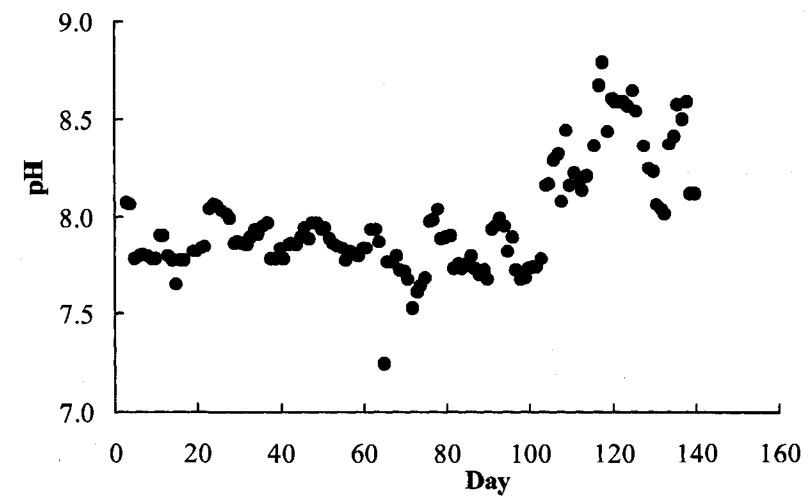
The highest SO_4^{2-} concentration of the high flowrate system and the low flowrate system was 665 mg/L and 392 mg/L. Therefore, SO_4^{2-} removal efficiency of the high flowrate system and the low flowrate system was 36% and 62%, respectively.

4.1.3.5 pH analysis

As shown in Figure 4.19a, the pH of release water fluctuated within the range of 7.6 to 8.6, with an overall trend of slight increase. The pH of the release water in the low flowrate system fluctuated within the range of 7.7 to 8.2 during the first 115 days (Figure 4.19b). From Day 116, when approaching the breakthrough point, pH increased to over 8.3. It is possible that the activity of SRB may be contributing to the pH increase in the low flow rate column.



(a)



(b)

Figure 4.19 pH as a function of time in the release water of System 3 dynamic columns: (a) at a high flowrate of feed water (18.7mL/h in Column DH-3); (b) at a low flowrate of feed water (6.1mL/h in Column DL-3)

4.1.3.6 Conductivity analysis

As discussed previously, electronic conductivity provides an indication of the total ions in the solution. At the first 6 days of incubation in high flowrate system (Figure 4.20a), the conductivity increased slightly from 6040 μS/cm to 6500 μS/cm. This slight increase was likely due to small increases in Na^+, Ca^{2+}, Mg^{2+} and SO_4^{2-} at the beginning.

The conductivity decreased to 4860 μS/cm on Day 23, and increased to 5210 μS/cm on Day 29, and from then on, the conductivity remained relatively constant at 5300 ± 150 μS/cm. This result suggests that the total ion concentration substantially did not change much in the last period of incubation. This result was consistent with the results of ion concentration (Na^+, Ca^{2+}, Mg^{2+} and SO_4^{2-}) in this period.

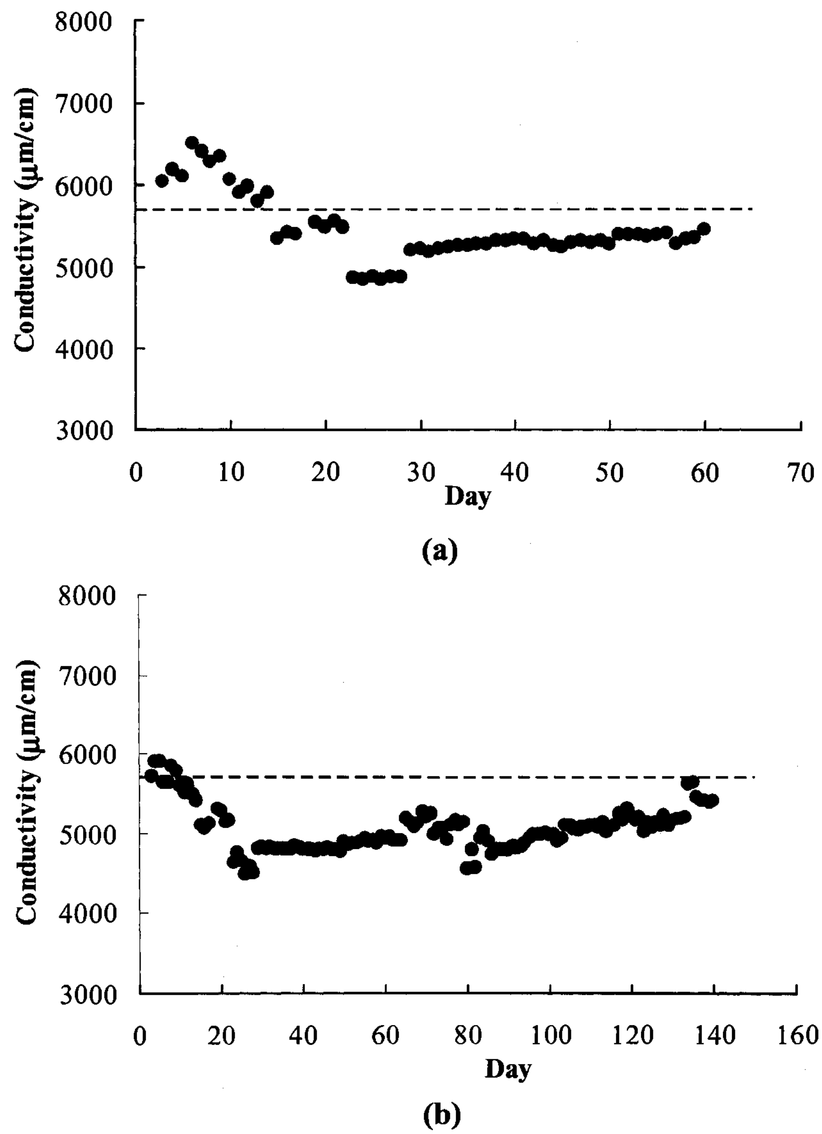


Figure 4.20 Conductivity as a function in the release water of System 3 dynamic columns: (a) at a high flowrate of feed water (18.7 mL/h in Column DH-3); (b) at a low flowrate of feed water (6.1 mL/h in Column DL-3)

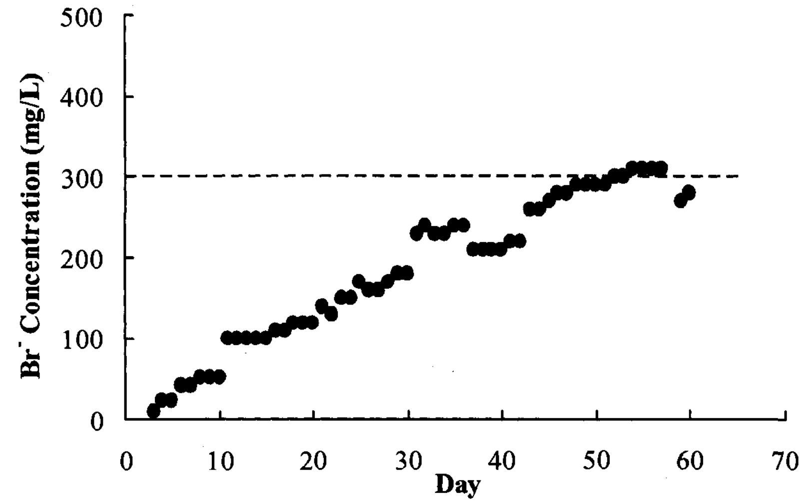
Unlike the high flowrate system, the low flowrate system showed a decrease in the release water conductivity during the first 28 days (Figure 4.20b), from an initial value of 5910 μS/cm to 4500 μS/cm. In the following days, the conductivity fluctuated within the range of 4540 μS/cm and 5630 μS/cm with the average value at 5000 μS/cm. The conductivity of the feed water was 5700 μS/cm, and therefore the lower conductivity of the release water might be attributed to the Ca^{2+}, Mg^{2+}, CO_3^{2-} and SO_4^{2-} reduction resulting from chemical precipitation, ion exchange, sorption and/or SO_4^{2-} reduction by SRB.

The original conductivity of the MFT was 4160 μS/cm. The conductivity of the feed water 5700 μS/cm. Overall, the conductivity of release water at both flowrate conditions was within the range of 4500 μS/cm and 6500 μS/cm.

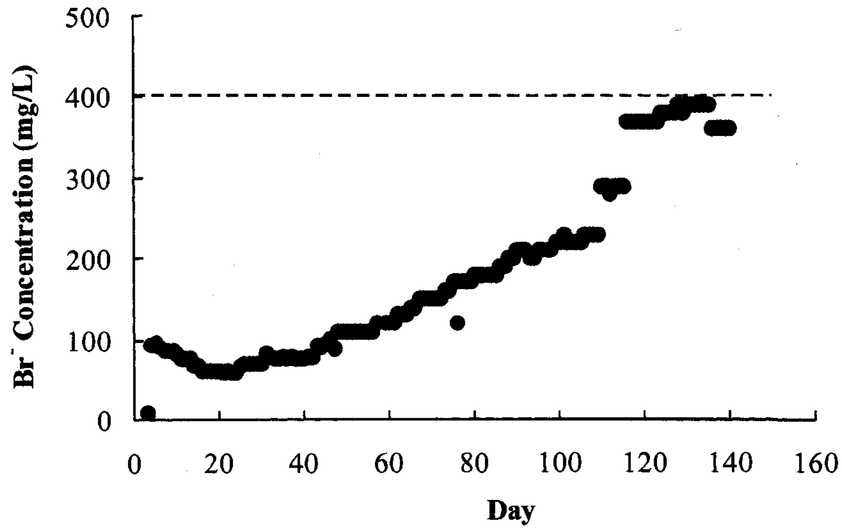
4.1.4 Physical and Chemical Characteristics in System 4 (WIP Water with Br^- as Tracer)

4.1.4.1 Bromide concentration analysis

For System 4, WIP water with Br^- added as the tracer (rather than CT water) was fed into the dynamic columns at two flow rates (19.4 mL/h and 6.2 mL/h). The tracer concentrations were 300 mg/L and 400 mg/L Br^- for the high and the low flowrate systems, respectively. Figure 4.21a and 4.21b indicate that it took approximately 45 days and 116 days for Br^- to reach the respective concentrations in the feed water. In the low flowrate system, it was observed that Br^- had a sudden increase from 230 mg/L to 370 mg/L during the week of Day 109 to Day 116, which means during this week, the original MFT porewater had been completely replaced with feed water.



(a)

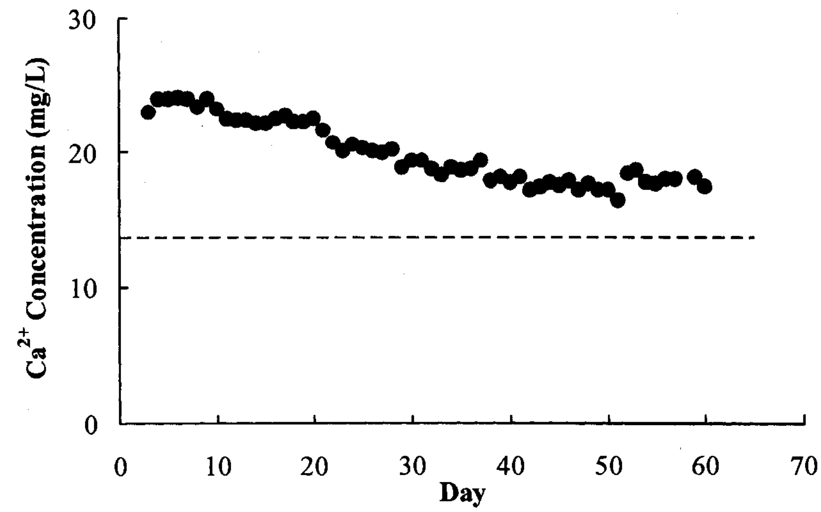


(b)

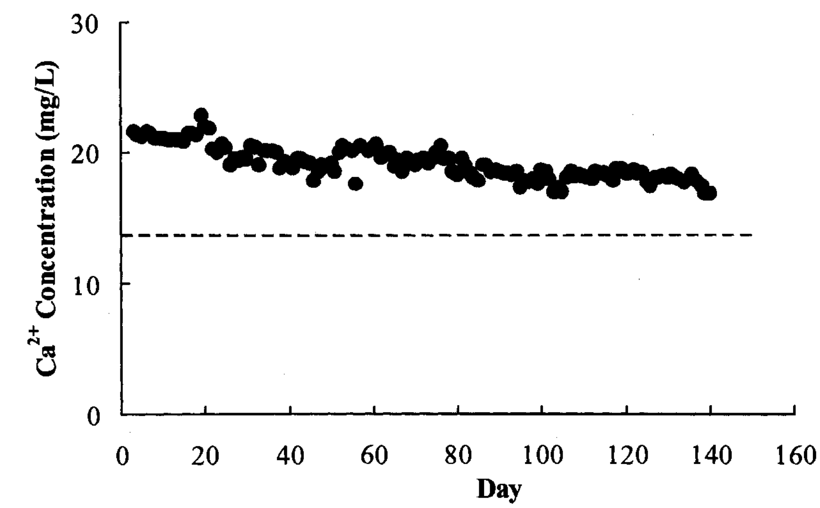
Figure 4.21 Br^- concentration as a function of time in the release water of System 4 dynamic columns: (a) at a high flowrate of feed water (19.4 mL/h in Column DH-4); (b) at a low flowrate of feed water (6.2 mL/h in Column DL-4), where the dashed line represents the Br^-concentration in the feed water

4.1.4.2 Calcium and magnesium concentration analysis

The original Ca^{2+} concentrations in the MFT and feed water were 22.8 mg/L and 13.7 mg/L, respectively. Both columns showed a similar trend regarding the changes in Ca^{2+} concentrations (Figure 4.22a and 4.22b). The changes in Ca^{2+} concentrations seemed concomitant to follow the general trend of gradual penetration of feed water through the MFT. The initial Ca^{2+} concentrations were consistent with the Ca^{2+} in MFT pore water. The subsequent slight decrease in Ca^{2+} was due to the replacement of MFT porewater with feed water, which had a lower Ca^{2+} concentration.



(a)



(b)

Figure 4.22 Ca^{2+} concentration as a function of time in the release water of System 4 dynamic columns: (a) at a high flowrate of feed water (19.4mL/h in Column DH-4); (b) at a low flowrate of feed water (6.2mL/h in Column DL-4), where the dashed line represents the Ca^{2+} concentration in the feed water

At the end of the experiments, Ca^{2+} concentration in the high flowrate system and the low flowrate system was 17.4 mg/L and 16.8 mg/L. Therefore, feed of WIP water did not remove Ca^{2+} from the MFT layer completely. The release water Ca^{2+} concentration might have eventually approached the Ca^{2+} in the feed water given a longer incubation time.

The original Mg^{2+} concentrations in the MFT and feed water were 14.8 mg/L and 8.2 mg/L respectively. The Mg^{2+} concentration decreased gradually in both the high and low flowrate columns (Figure 4.23a and 4.23b), following a similar trend as Ca^{2+}. As discussed previously, it could be attributed to the replacement of MFT pore water by the feed water.

At the end of experiment, Mg^{2+} in the release water was 11.0 mg/L for the high flowrate system and 10.9 mg/L for the low flowrate system. Therefore, it is anticipated that given sufficient time, the feed water would completely replace the MFT porewater and that the release water Mg^{2+} concentration would approach the Mg^{2+} concentration in the feed water.

The analysis of feed water also indicated that there was 35.7 mg/L of CO_3^{2-} and 296 mg/L of SO_4^{2-} in the WIP water. It is known that the following reactions can occur:

$$Ca^{2+}(aq) + CO_3^{2-}(aq) \rightarrow CaCO_3(s)\downarrow \qquad Ksp = 3.36\times10^{-9} \qquad (4\text{-}2)$$

$$Mg^{2+}(aq) + CO_3^{2-}(aq) \rightarrow MgCO_3(s)\downarrow \qquad Ksp = 2.38\times10^{-6} \qquad (4\text{-}3)$$

These reactions could also contribute to the decrease in Ca^{2+} and Mg^{2+} concentrations over the incubation periods for both high and low flowrate columns.

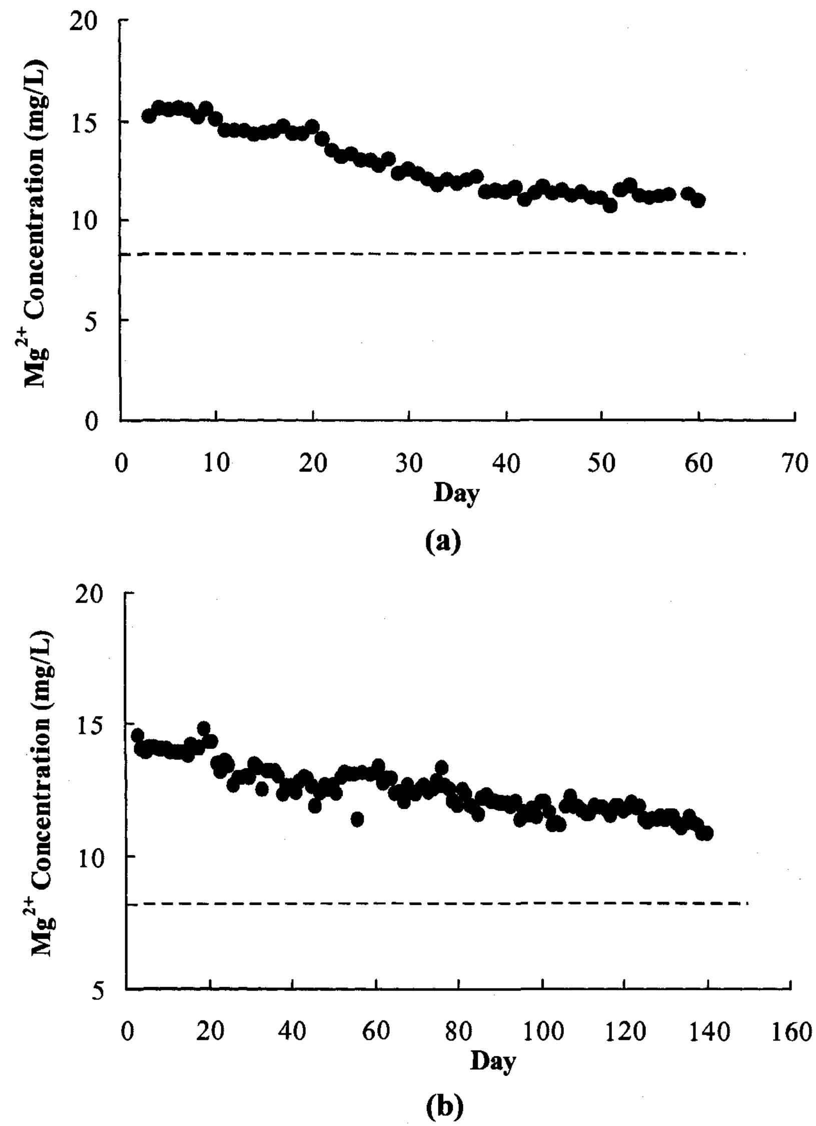
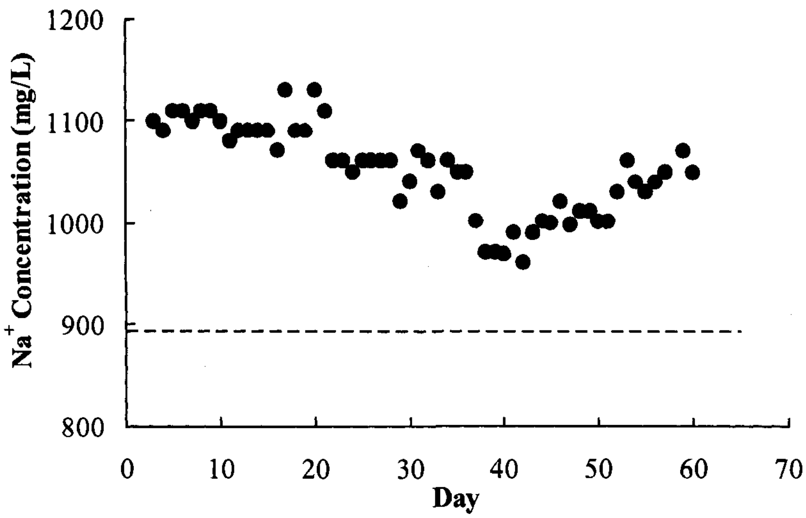


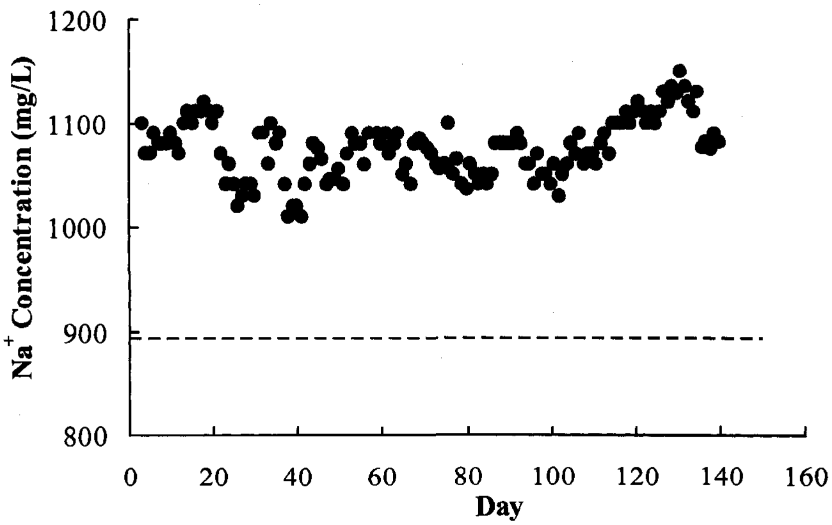
Figure 4.23 Mg^{2+} concentration as a function of time in the release water of System 4 dynamic columns: (a) at a high flowrate of feed water (19.4 mL/h in Column DH-4); (b) at a low flowrate of feed water (6.2 mL/h in Column DL-4), where the dashed line represents the Mg^{2+} concentration in the feed water

4.1.4.3 Sodium concentration analysis

In both high and low flowrate columns, The Na^+ concentrations were relatively stable over the incubation period. For the high flowrate system (Figure 4.24a), the Na^+ concentrations fluctuated between 960 mg/L and 1100 mg/L, with an average of 1052 mg/L; whereas for the low flowrate system (Figure 4.24b), the Na^+ concentration varied in the range of 1010 mg/L to 1150 mg/L, with an average Na^+ concentration of 1075 mg/L. Baseline Na^+ concentrations in MFT and feed water were 1090 mg/L and 893 mg/L, respectively. It was anticipated that with the feed water penetrating through the MFT layer, Na^+ concentrations in the release water should approach 893 mg/L, that is the concentration of Na^+ in the feed water.



(a)



(b)

Figure 4.24 Na^+ concentration as a function of time in the release water of System 4 dynamic columns: (a) at a high flowrate of feed water (19.4 mL/h in Column DH-4); (b) at a low flowrate of feed water (6.2 mL/h in Column DL-4), where the dashed line represents the Na^+ concentration in the feed water

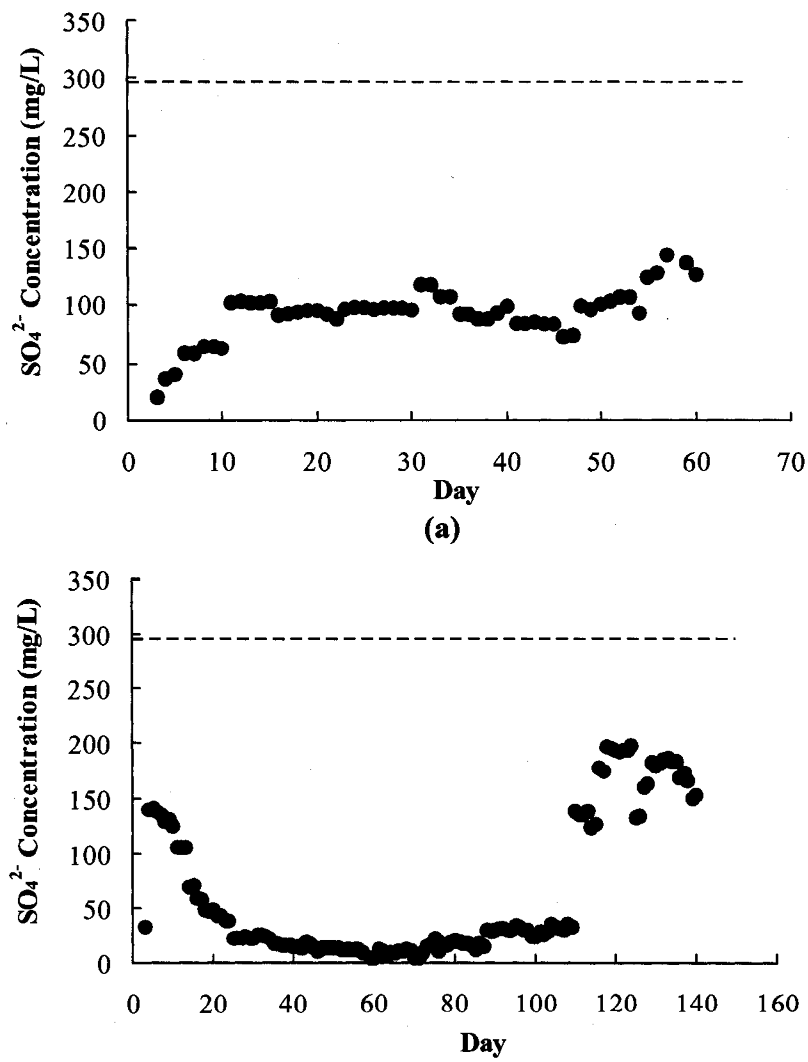
For both columns, a slight increase of Na^+ concentration was observed towards the end of the incubation period. It is possible that there was ion exchange between Na^+ and Ca^{2+} as well as Na^+ and Mg^{2+}, in which Ca^{2+} and Mg^{2+} were retained in the MFT layer and Na^+ was released. However, since the decreases in Ca^{2+} and Mg^{2+} were very small, the Na^+ concentration increase in the release water due to ion exchange would be difficult to detect considering the high baseline concentrations. Therefore, there was no definitive evidence that the ion exchange process occurred in the columns.

4.1.4.4 Sulfate analysis

The baseline SO_4^{2-} concentrations in the MFT and the feed water were 17.7 mg/L and 296 mg/L respectively. For the high flowrate column (Figure 4.25a), the SO_4^{2-} concentration steadily increased from 19.9 mg/L on Day 3 to 102 mg/L on Day 11, and then remained relatively stable around 100 mg/L till Day 48. From Day 48 until Day 60, the SO_4^{2-} concentration increased slightly to 145 mg/L.

For the low flowrate system (shown in Figure 4.25b), the SO_4^{2-} concentration decreased gradually from approximately 140 mg/L to 5 mg/L on Day 60. From Day 61, the SO_4^{2-} concentration increased almost linearly to 31.9 mg/L on Day 109. From Day 110 until Day 140, the SO_4^{2-} concentration increased rapidly to 137 mg/L and then fluctuated in the range of 123 mg/L to 197 mg/L. The reasons for initial high SO_4^{2-} concentrations in the release water were unknown. The mechanisms for subsequent decrease in SO_4^{2-} concentrations might include precipitation with Ca^{2+} and Mg^{2+} as mentioned before and activity of SRB which reduced SO_4^{2-} to S^{2-}. The presence of SRB in System 4 was verified by the MPN and AVS analysis (See section 4.1.5). The increase in SO_4^{2-} concentration at the final stage suggests that the amount of sulfate fed into the system exceeded the kinetically controlled microbial consumption of SO_4^{2-}.

The SO_4^{2-} concentration in the release water at the end of the incubation period was 128 mg/L for the high flowrate system and 152 mg/L for the low flowrate system. Therefore, SO_4^{2-} removal efficiencies of 57% and 49% were achieved in the high and the low flowrate columns, respectively.



(b)

Figure 4.25 SO_4^{2-} concentration as a function of time in the release water of System 4 dynamic columns: (a) at a high flowrate of feed water (19.4 mL/h in Column DH-4); (b) at a low flowrate of feed water (6.2 mL/h in Column DL-4), where the dashed line represents the SO_4^{2-} concentration in the feed water

4.1.4.5 Conductivity analysis

The baseline conductivities of the MFT and feed water were 4160 μS/cm and 4890 μS/cm respectively. The conductivities of the release water at the end of the incubation period were 4850 μS/cm and 4390 μS/cm in the high and the low flowrate columns, respectively.

Specifically, in the high flowrate column, the conductivity decreased from 5740 μS/cm on Day 4 to 4330 μS/cm on Day 21, and then stable at 4630 μS/cm (Figure 4.26a). The conductivity decrease seem to be the result of a decrease in the Ca^{2+} and Mg^{2+} concentration since, over this period, Na^{+} concentrations were relatively stable and Br^{-} and SO_4^{2-} concentration were increasing.

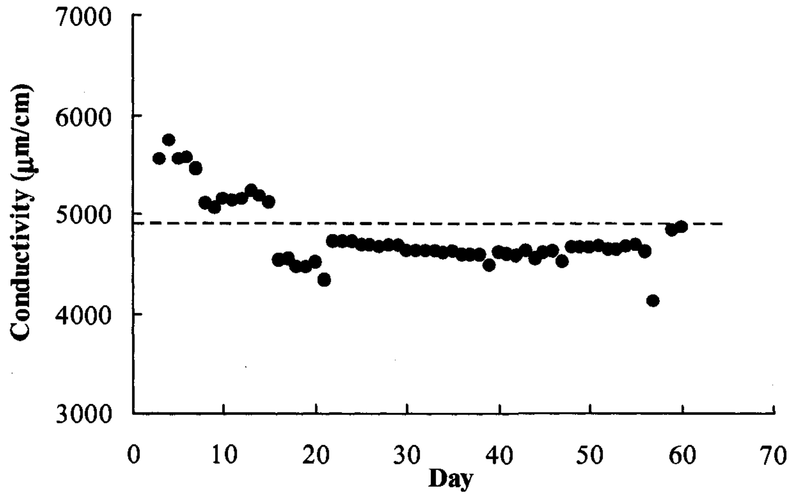
The conductivity of the low flowrate system (Figure 4.26b) decreased from 5480 μS/cm on Day 3 to 4380 μS/cm on Day 19. Then, the conductivity seemed to be stabilizing at 4680 μS/cm until Day 57. The conductivity increased to 4990 μS/cm on Day 62 and then decreased to 4360 μS/cm on Day 79. After Day 79, the conductivity was stable at approximately 4450 μS/cm until Day 140.

The difference between the conductivity of the feed water and release water could be attributed to chemical processes, i.e. precipitation (between CO_3^{2-} and Ca^{2+} or Mg^{2+}) and ion exchange or to microbiological processes.

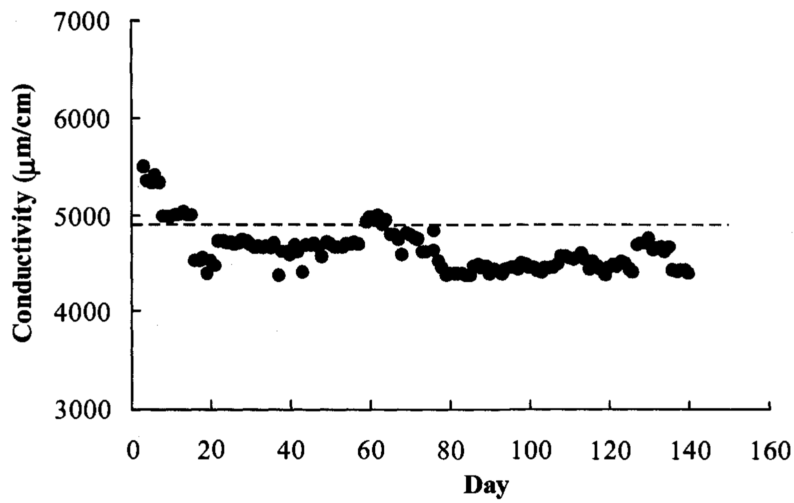
4.1.4.6 pH analysis

Figure 4.27a and 4.27b give the pH in the high and low flowrate columns, respectively. The pH of the high flowrate system varied in the range of 7.60 and 8.09

with a slightly increasing trend. For the low flowrate system, the pH ranged from 7.65 to 8.18 with the trend slightly decreasing.



(a)



(b)

Figure 4.26 Conductivity as a function of time in the release water of System 4 dynamic columns: (a) at a high flowrate of feed water (19.4 mL/h in Column DH-4); (b) at a low flowrate of feed water (6.2 mL/h in Column DL-4), where the dashed line represents the conductivity in the feed water

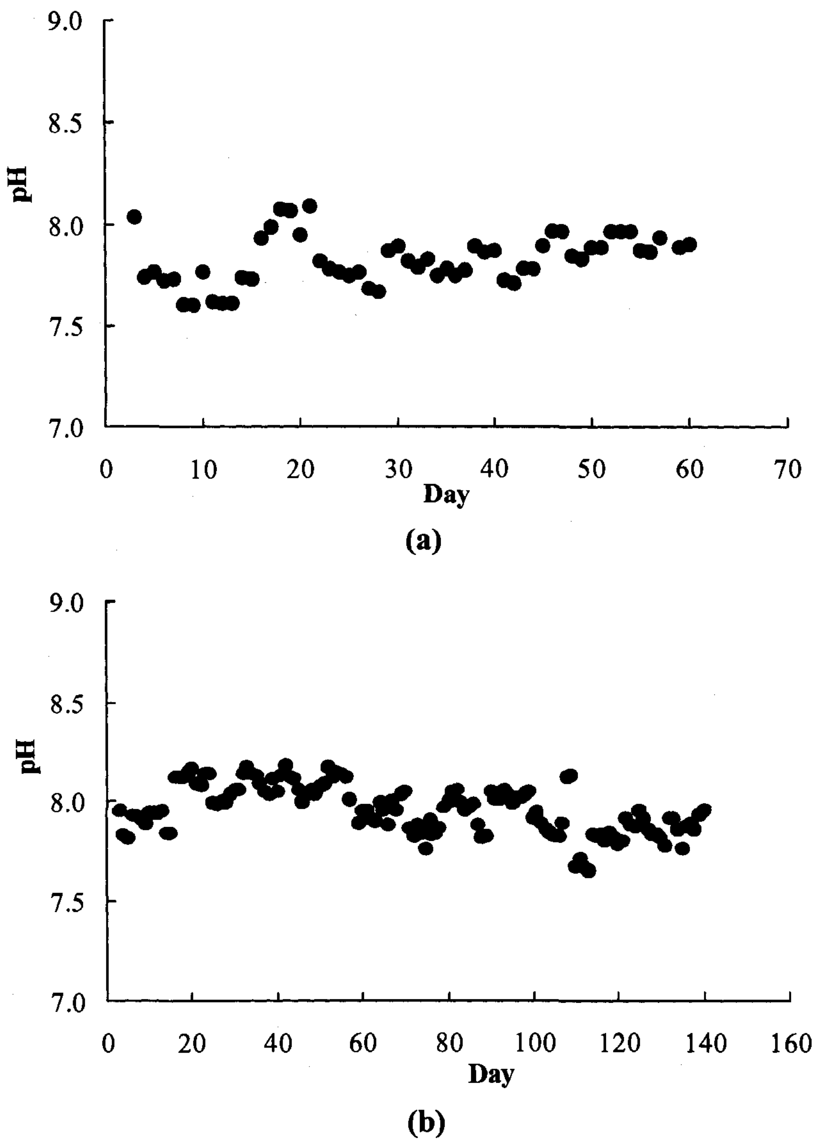


Figure 4.27 pH as a function of time in the release water of System 4 dynamic columns: (a) at a high flowrate of feed water (19.4 mL/h in Column DH-4); (b) at a low flowrate of feed water (6.2 mL/h in Column DL-4)

4.1.5 Microbiological Characteristics by MPN and AVS Analyses in all Systems

4.1.5.1 MPNs of Methanogens and SRB

Enumeration of methanogens and SRB were conducted on all testing systems at the end of incubation period using 3-tube MPN analyses. The results of MPNs are summarized in Appendix A13. As discussed previously, biodegradation of residual hydrocarbons in the MFT will contribute to the production of CH_4 by methanogens and the reduction of SO_4^{2-} by SRB. The microbial activity will affect the physical andchemical properties of MFT and many affect its densification. Recently, Fedorak et al. (2003) reported an unexpected increase in the densification rate of MFT accompanying the microbial CH_4 production.

MPN results from the blank jar tests were used as the baseline numbers of methanogens and SRB for the corresponding dynamic columns, as shown in Figure 4.28. This result can be verified since neither hydrocarbon nor terminal electron acceptors (i.e. CO_2 or SO_4^{2-}) were introduced to the MFT, although Ca^{2+} and Mg^{2+} concentrations in each jar were adjusted. It can be seen from Figure 4.28 that the baseline methanogens and SRB or MPN value in all systems ranged from 10^5 to 10^6 per g dry MFT. This was comparable to previous microbiological charactization of MFT. Fedorak et al. (2000) reported that the MPN for Syncrude Canada Ltd. MFT was mostly in the range of 10^5 to 10^7/g (of dry solids) over 1 year of incubation, whereas Holowenko (2000) reported that the MPN of SRB was for the most part in the range of 10^5 to 10^7/g (of dry solids) for Syncrude Canada Ltd. MFT. The changes in MPN of methanogens and SRB will be discussed separately in the following sections.

Figures 4.29 and 4.30 present the MPN of methanogens at the end of the incubation period in all high and low flowrate dynamic columns. It seemed that different flow rates did not resulted in changes in MPN. There was also no apparent difference of MPNs along the depth profile of the column. However, a drastic decrease in methanogens was found in Systems 1 and 2, whereas the methanogens showed only slight decrease in Systems 3 and 4. This difference could be attributed to the competition between methanogens and SRB for substrates and the availability of TEAs. The errors in sampling might also be the reason for the drastic decrease in methanogens in Systems 1 and 2. In Systems 1 and 2, high concentrations of SO_4^{2-} may have stimulated the growth of SRB, which therefore supressed the methanogens.

There are two types of methanogens: (i) acetotrophic methanogens, which can grow on acetate, and (ii) hydrogenotrophic methanogens, which can utilize H_2 and bicarbonate. Acetate (100 mg/L) added to System 3 may have been sufficient to serve as the substrate for both acetotrophic methanogens and SRB. Some other organic compounds might also be utilized by SRB as the carbon source. Therefore, despite the high SO_4^{2-} amendment to System 3, the MPNs of methanogens and SRB were quite similar. Similarly in System 4, it is postulated that no out-competition of SRB over methanogens occurred due to lower SO_4^{2-} concentration and the different composition of organic matter in the feed water (WIP water versus CT water).

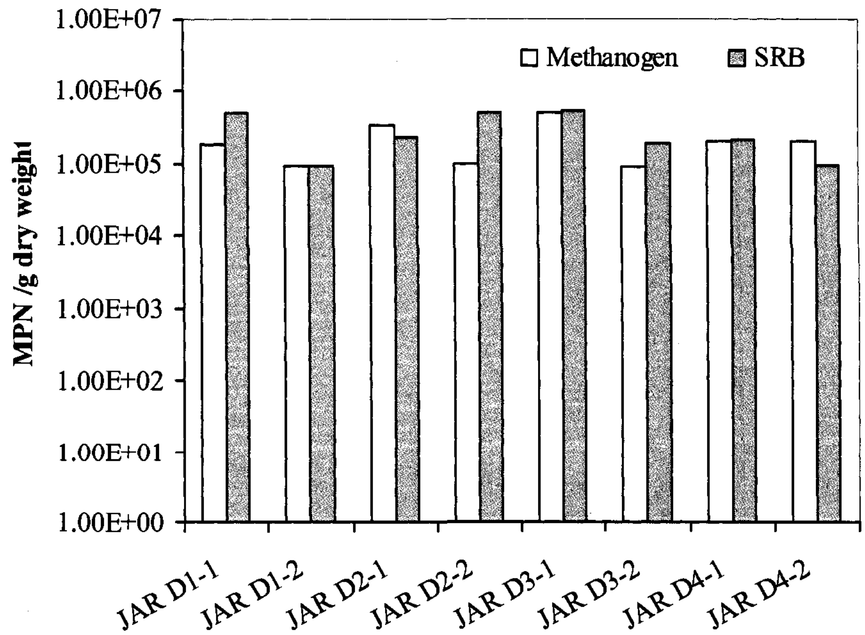


Figure 4.28 Background MPNs of methanogens and SRB (as measured in Jar tests)

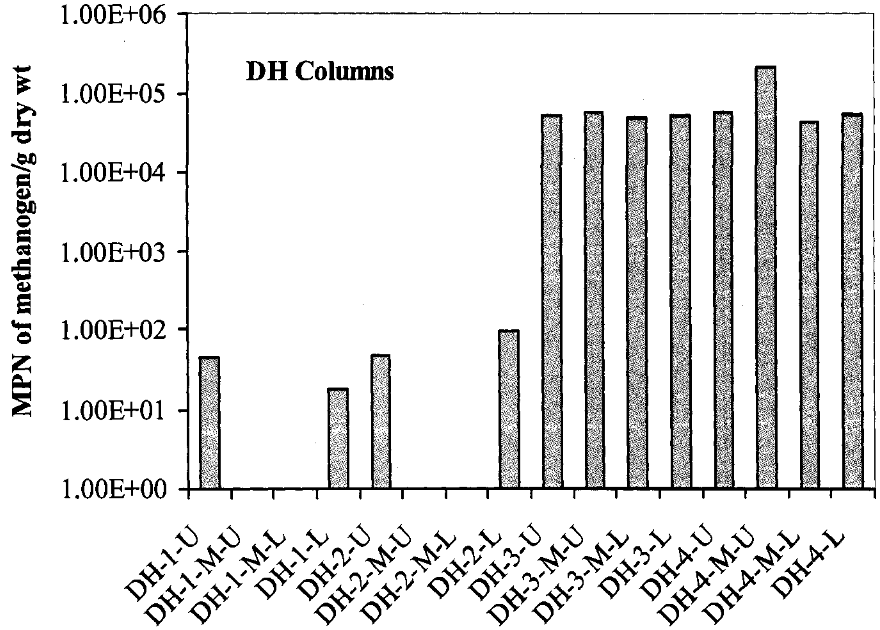


Figure 4.29 MPN of methanogens in high flowrate systems after 60 days of incubation

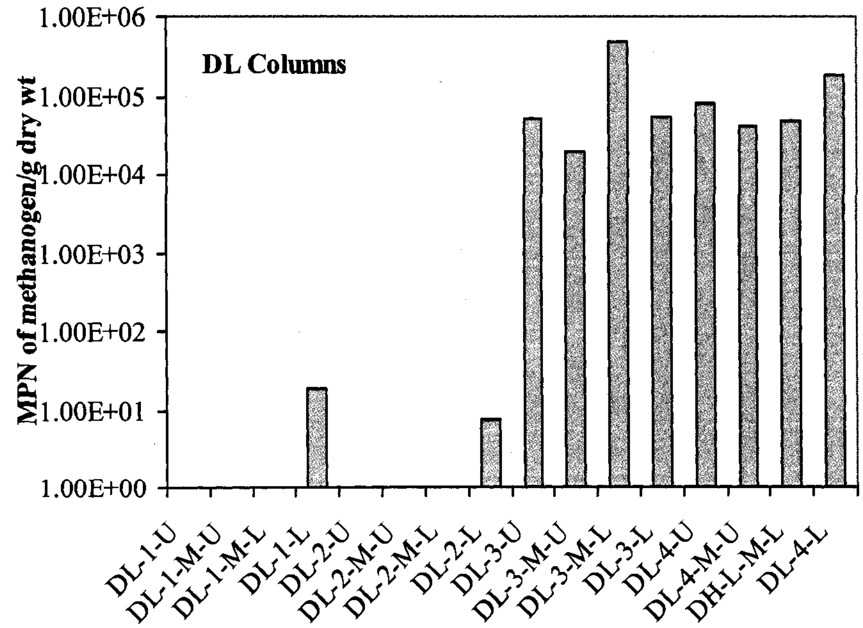


Figure 4.30 MPN of methanogens in low flowrate systems after 140 days of incubation

The MPN of SRB in high and low flowrate columns are shown in Figures 4.31 and 4.32, respectively. No apparent difference in the MPN of SRB was observed with the different flow rates. The irregular changes in MPN of SRB along the depth of the columns may be due to the heterogeneity of the MFT materials with regard to the distribution of substrates and microbial population. Slightly lower MPN of SRB in System 3 could be explained by the competition of methanogen enhanced by acetate amendment, as discussed previously. It was assumed that in systems with higher SO_4^{2-} concentrations, the activity of SRB would be enhanced and thus MPN of SRB would increase. In contrast, there was no increase in the estimated SRB numbers in Systems 1 and 2 compared to those from the blank jar tests, indicating that the substrate was the limiting factor in those systems.

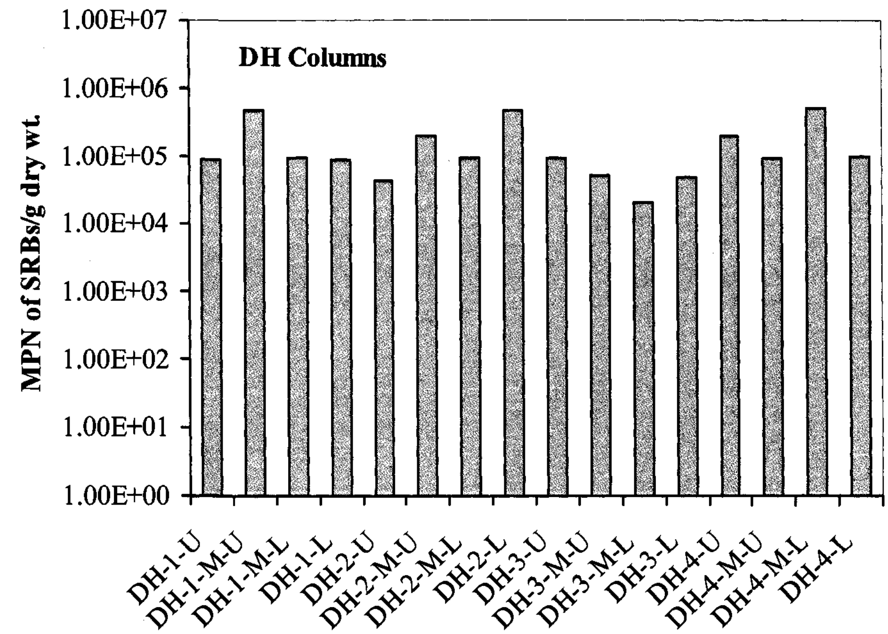


Figure 4.31 MPN of SRB in high flowrate systems after 60 days of incubation

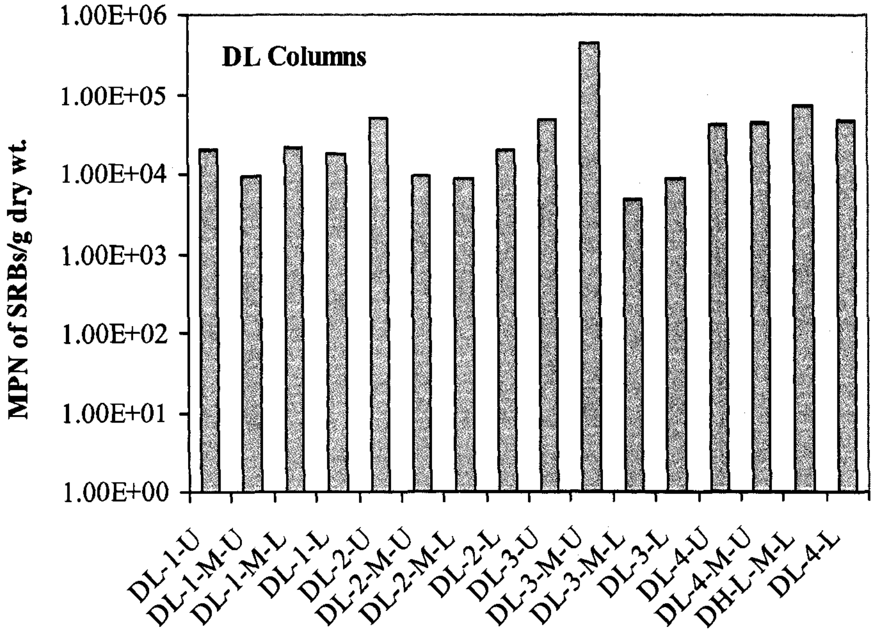


Figure 4.32 MPN of SRB in low flowrate systems after 140 days of incubation

4.1.5.2 AVS analysis

Oxidation of the organic matter coupled to sulfate reduction will decrease the concentrations of both substrates and TEAs (i.e. SO_4^{2-}) and produce biogenic CO_2 and reduced sulfur. Thus, the increase in HCO_3^- and sulfide concentrations indicates the occurrence of SRB activity in the dynamic columns.

The pH in the dynamic columns ranged from 7.2 to 8.8. In this pH range, the predominant form of sulfide is HS^- rather than H_2S (Fedorak et al. 2000). In the presence of metals, such as Fe^{2+}, the HS^- will further react with the metals to precipitate as metal sulfides, such as FeS. FeS may be further converted to pyrite, as shown in the following equations:

$$HS^-(aq) + Fe^{2+}(aq) \longrightarrow FeS(s) + H^+(aq) \qquad (4\text{-}4)$$

$$FeS(aq) + S^0(aq) \longrightarrow FeS_2(s) \qquad (4\text{-}5)$$

AVS (mainly the iron sulfides) is an effective sink for reduced sulfur so that the reduced sulfur will not be released to the atmosphere in forms of H_2S (Schlesinger, 1997). Due to the meta-stability and reactivity of AVS compounds, its presence is assumed to be an indicator of recent SO_4^{2-} reduction (Kennedy et al. 1999).

Based on the analytical method used by ALS laboratories, results of the analyzed sulfur include both AVS and fine-graded (newly formed) synthetic pyrite. Dissolved sulfide was also measured using the CHEMetrics test kit, which measures dissolved H_2S, HS^-, and acid soluble metallic sulfides in suspension. There was no appreciable dissolved sulfide in most systems (Appendix A15, A16, and A17).

The detection of AVS for Systems 1 and 2 (see Table 4.1) further verify that sulfate reduction was occurring in all the tested columns. The Systems 3 and 4 were not detected due to lack of funding.

4.2 Jar Test

The jars were sampled after 128-day incubation. All samples were centrifuged and the pore water samples were sent to Syncrude Canada Ltd. laboratory for chemical analysis. The concentrations of major cations and anions, pH and EC for all jars were summarized in Table 4.2. Because no samples were analyzed immediately after the setup of jars, the designed concentrations (based on dynamic columns) were assumed to be the initial conditions. The lack of initial concentrations and analytical variability made the interpretation of the results less reliable. However, some trends were still observed.

Table 4.1 AVS in Jars and Dynamic Columns

System	Sample	T_{incu} (d)	AVS (μmol/g dry)
DH-1	DH-1-U	60	0.5
	DH-1-L	60	2.8
DL-1	DL-1-U	140	6.34
	DL-1-M-U	140	7.32
	DL-1-M-L	140	7.83
	DL-1-L	140	3.69
DH-2	DH-2-U	60	5.5
	DH-2-L	60	4.4
DL-2	DL-2-U	140	10.2
	DL-2-M-U	140	9.41
	DL-2-M-L	140	7.76
	DL-2-L	140	10.4
Jar1	D1-1	128	12.2
	D1-2	128	12.6
Jar2	D2-1	128	13.8
	D2-2	128	13.5
Jar3	D3-1	128	16.7
	D3-2	128	7.8
Jar4	D4-1	128	11.9
	D4-2	128	6.74

Table 4.2 Major Results of Chemical Analysis of MFT Porewater Samples for all Jars after 128-d Incubation

Jars	Incub. Time (d)	pH	EC (μS/cm)	Br^- (mg/L)	Na^+ (mg/L)	K^+ (mg/L)	Mg^{2+} (mg/L)	Ca^{2+} (mg/L)	SO_4^{2-} (mg/L)	HCO_3^- (wt ppm)
Jar 1	0 [a]	8.3	7360	2500	1730	27.0	26.4	31.1	1060	584
	128 [b]	8.3	8270	3000	2285	19	25	32	688	1565
Jar 2	0 [a]	7.7	5250	1	1070	24.9	150	160	1800	859
	128 [b]	8.1	6205	5	1560	20	45	44	842	1695
Jar 3	0 [a]	8.1	6430	320	1240	26.5	26.0	61.7	995	784
	128 [b]	8.0	6765	600	1730	19	26	35	586	1920
Jar 4	0 [a]	8.1	5270	330	1090	15.0	8.1	13.7	321	843
	128 [b]	8.0	5490	620	1375	16	17	25	190	1340

Notes: a: The initial concentrations were estimated from dynamic column results.
b: The 128th day results were average of the duplicate jars.

The concentrations of Ca^{2+} and Mg^{2+} were not amended in Jars 1, 3, and 4. Thus, the changes in Ca^{2+} and Mg^{2+} were not as much as in Jar 2. In Jar 2, the decrease in Ca^{2+} and Mg^{2+} concentrations is possibly due to the ion exchange with Na^{+}. Therefore, it is evident that MFT has the capacity to retain a certain amount of Ca^{2+} and Mg^{2+} (when at relatively high concentrations), which verifies the theoretical rationale that MFT could be used to treat CT water. The concentrations of SO_4^{2-} decreased in all jars, which could be explained by the anaerobic microbial-mediated sulfate reduction processes.

4.3 Barrel Mesocosms

The investigation of static column mesocosms was undertaken to study and monitor the physical, chemical and microbiological changes occurring in the CT beneath MFT co-disposal system. Four barrels, denoted as B1, B2, B3 and B4 respectively, have different constitutions as presented in Table 3.6. Among them, B1 and B2 were duplicates and consist of both MFT and CT, whereas B3 contained only MFT and B4 contained only CT. Two columns, denoted C1-17 and C1-18, also consisted of MFT and CT, but these were much smaller in size. The sampling and analyses of water samples from different fractions of four barrels and two columns were conducted after 2-year incubation period.

4.3.1 Calcium and Magnesium Concentrations and pH

The pH values and the concentrations of Ca^{2+} and Mg^{2+} in the release and pore water samples from the barrels and columns are given in Table 4.3. In Table 4.3 B1/2 represents the average of the results of B1 and B2.

Table 4.3 pH and Concentrations of Ca^{2+} and Mg^{2+} in Barrels

	pH			Ca^{2+} (mg/L)			Mg^{2+} (mg/L)		
	B1/2	B3	B4	B1/2	B3	B4	B1/2	B3	B4
Release water	8.05	8.23	8.24	31.2	18.20	25.5	17.6	15.3	16.9
MFT-U water	8.18	8.09	NA	14.1	12.10	NA	14.5	14.8	NA
MFT-L water	8.20	8.11	NA	6.65	12.50	NA	14.1	14.1	NA
CT-U water	8.26	NA	8.25	18.2	NA	23.3	14.2	NA	14.8
CT-L water	8.25	NA	8.27	18.0	NA	20.2	14.9	NA	14.0

Note: NA- not applicable

It can be seen from Table 4.3 that the pH of the release water of B1 and B2 was around 8.05, which was lower than that of B3 (pH 8.23) and B4 (pH 8.24). However, the pH values of water samples from the upper layer of the MFT (MFT-U water) and the lower layer of the MFT (MFT-L water) in B1 and B2 were close to those in B3. The water samples from the upper layer of the CT (CT-U water) and lower layer of the CT (CT-L water) had similar pH values to those in B4.

The Ca^{2+} concentrations are important to assess the CT beneath MFT co-disposal system. The average Ca^{2+} concentration in the CT water was above 100 mg/L. In all the barrels, the Ca^{2+} concentrations in the release water decreased by approximately 70% compared to the initial Ca^{2+} concentrations. The release water showed higher Ca^{2+} concentrations than pore water samples from other fractions of the barrels (Table 4.3). This difference might be explained by the ion exchange occurring in the MFT layer. The concentrations of Ca^{2+} varied along the depth profile in B1 and B2, indicating that MFT and CT had different physical and chemical characteristics. The Ca^{2+} concentration in the

B1 and B2 release water was on average 31.2 mg/L, which was higher than those in B3 (18.2 mg/L) and B4 (25.5 mg/L). Hence, the high calcium concentrations in the release water of B1 and B2 might be attributed to both MFT and CT layers. Water samples from the lower layer of MFT in B1 and B2 (mean 6.6 mg/L) had the lowest calcium concentrations. It is reasonable that B4, comprising only CT, showed higher calcium concentration than B3, which just has MFT.

Table 4.3 also shows the Mg^{2+} concentrations of the water samples from different parts for B1/2, B3 and B4. The Mg^{2+} concentrations are comparable in water samples from each fraction of the barrels.

The effect of the column size on the static column mescocosm was studied by comparing the characteristics of barrels (bigger size) and those of columns (smaller size). The comparisons of pH as well as the concentrations of Ca^{2+} and Mg^{2+} between barrels and columns are shown in Table 4.4. The data in the column of C1-17/18 are the averages of measurements of both C1-17 and C1-18.

Table 4.4 Comparisons of pH and Concentrations of Ca^{2+} and Mg^{2+} between Barrels and Static Columns

	pH		Ca^{2+} (mg/L)		Mg^{2+} (mg/L)	
	B1/2	C1-17/18	B1/2	C1-17/18	B1/2	C1-17/18
Release water	8.05	7.59	31.2	31.8	17.6	15.7
MFT-U water	8.21	8.16	14.1	24.3	14.5	18.6
MFT-L water	8.11	8.13	6.65	18.4	14.1	15.9
CT-U water	8.17	8.36	18.2	17.8	14.2	14.3
CT-L water	8.22	8.28	18.0	21.8	14.9	14.7

The constitutions of B1 and B2 were identical to those of C1-17 and C1-18 except that both B1 and B2 were much bigger than C1-17 and C1-18. Seen in the Table 4.4, the release water in B1/2 has a pH value of 8.05, which is higher than that in C1-17/18 (7.59). Other than that, the pH values of the water samples from the other four parts are almost same for B1/2 and C1-17/18. As for the Ca^{2+} concentration, both the B1/B2 and C1-17/18 had the similar Ca^{2+} concentrations in the release water. Ca^{2+} concentrations of both MFT-U water and MFT-L water in C1-17/18 were slightly higher than those in B1/2. The Mg^{2+} concentrations in water from each part of B1/2 were comparable to their corresponding values in C1-17/18. Therefore, the sample size did not show significant influence in the physical and chemical process in the MFT layers.

4.3.2 Sulfate Analysis

Sulfate is one of the major anions accounting for most of the dissolved fraction in the MFT pore water. The sulfate concentrations in the water sample from different parts of barrels and columns are shown in Table 4.5.

Table 4.5 SO_4^{2-} Concentrations in the Fractions of Barrels and Static Columns

	SO_4^{2-} (mg/L)			
	B1/2	B3	B4	C1-17/18
Release water	401.5	8.01	853.0	134.5
MFT-U water	145.2	13.1	-	86.0
MFT-L water	148.0	6.29	-	15.6
CT-U water	151.0	-	665.0	98.4
CT-L water	166.0	-	524.0	69.1

The concentrations of sulfate in B1, B2 and B4 were much higher than those in

B3 due to the high dose of gypsum in CT. The SO_4^{2-} concentrations in B1 and B2 were lower than that in B4, possibly because of the mixing effects of CT water and MFT pore water and the microbial-mediated sulfate reduction process.

It appeared that the size effect had some influence on the SO_4^{2-} concentrations in the columns. In release water, the SO_4^{2-} concentration was 401.5 mg/L in B1/2 whereas this in C1-17/18 was only 134.5 mg/L. Similar to that in the release water, the SO_4^{2-} concentrations in the other fractions in B1/2 are much lower than those in C1-17/18.

4.3.3 Alkalinity Analysis

Both the carbonate and bicarbonate are important constitutions in the water samples from different fractions. According to the pH in all systems, HCO_3^- should be the predominant species of alkalinity. The alkalinities of water samples (in mg HCO_3^-/L) are shown in Table 4.6. For all barrels, the HCO_3^- concentrations in the release water were higher than those in other fractions. Seen in the Table 4.6, the concentration of HCO_3^- in the release water in B1/2 was 1141 mg/L, which was close to that in C1-17/18, and the same was in the other fractions. Therefore the size of columns showed no influence on the bicarbonate concentrations in the fractions.

Table 4.6 Alkalinities in the Fractions of Barrels and Static Columns

	Alkalinity(mg HCO_3^{2-}/L)			
	B1/2	B3	B4	C1-17/18
Release water	1141	1272	709	1340
MFT-U water	923	1000	-	1426
MFT-L water	828	1016	-	1324
CT-U water	893	-	654	992
CT-L water	852	-	706	1168

4.3.4 Sodium Ions and Potassium Ions

The concentrations of Na^+ and K^+ in the fractions are shown in Table 4.7. It can be seen that the concentrations of K^+ in different fractions were much lower than those of Na^+. Na^+ is one of the major cations in the fractions. The concentrations of Na^+ in each fraction were similar in all barrels and columns. Therefore, the difference in the make-up of B1/2, B3 and B4 had no influence on the Na^+ concentrations in different fractions. Whether the system was a barrel or column also had no influence on the Na^+ concentrations.

Table 4.7 Concentrations of Na^+ and K^+ in the Fractions of Barrels and Static Columns

	Na^+ (mg/L)				K^+ (mg/L)			
	B1/2	B3	B4	C1-17/18	B1/2	B3	B4	C1-17/18
Release water	1310	1080	1370	1205	18	15	17	16
MFT-U water	1135	1030	NA	1360	15	15	NA	19
MFT-L water	1120	993	NA	1135	14	14	NA	16
CT-U water	1155	NA	1320	1165	14	NA	15	14
CT-L water	1160	NA	1300	1240	15	NA	14	15

Note: NA – not applicable

4.3.5 Solids Properties

The particle size of solids in different layers of B1, B3 and B4 are shown in Figure 4.33 to 4.35. In these figures, the percentage of solid less than certain size increases with the increasing of particle size.

In Figure 4.33, the percentage of solids less than certain particle size in layer of

B1 varied greatly. There were 75.3% solids with particle size less than 20 μm in the upper layer of MFT, and the corresponding values in lower layer of MFT, upper layer of CT and lower layer of CT were 67.4%, 44.8% and 40.6 % respectively, i.e., the upper layer of MFT had the finest solids and the lower layer of CT had the coarsest solids in B1. However, in B3, the particle size distributions in both the upper layer and lower layer of MFT were almost same (approximately 75% solids with particle size less than 20 μm, Figure 4.34), indicating that MFT is very difficult to settle and densify, whereas the MFT-over-CT disposal system may facilitate the aggregation of fine particles in MFT.

Figure 4.35 gives the particle size distribution of both the upper layer and lower layer in B4. As we can see, the particle size distributions differ greatly. There were higher percentages of particles less than certain size in the upper layer of CT than those in lower layer of CT, due to the densification process.

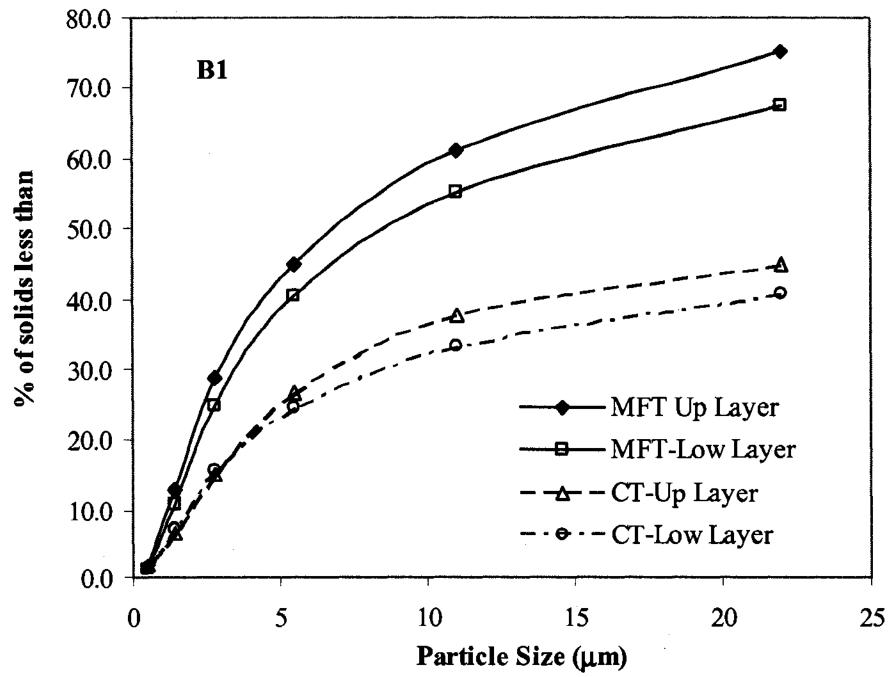


Figure 4.33 Distribution of particle size in different fractions of B1

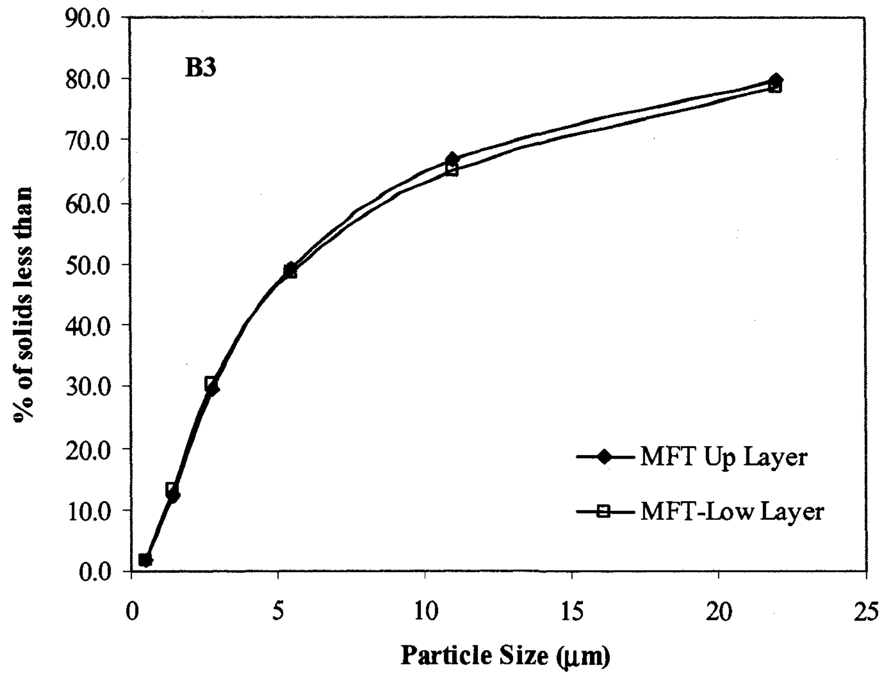


Figure 4.34 Distribution of particle size in different fractions of B3

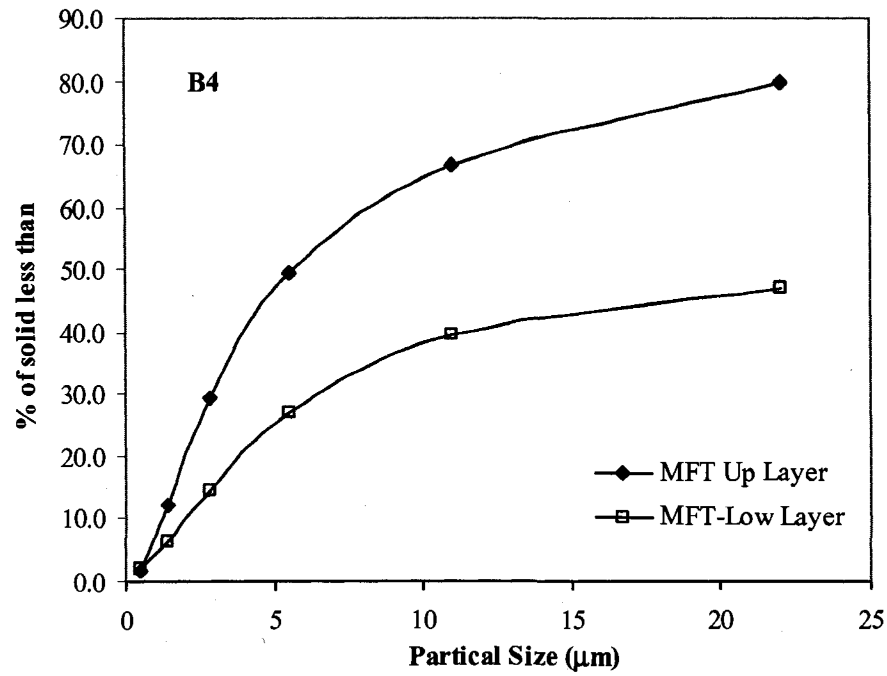


Figure 4.35 Distribution of particle size in different fractions of B4

Chapter 5

Conclusions and Recommendations

Based on the results and discussions in the previous sections, the following conclusions can be drawn:

- The obtained flowrates were 5 to 6 mL/h for low flowrate systems and 17 to 19 mL/h for high flowrate systems. Br^- tracer study was used to determine the hydraulic retention time for each system. In system 2, conductivity measurement was used to identify the hydraulic retention time. Due to the variances among all systems, the saturation times varied from 40 to 60 days for high flowrate systems, and from 100 to 123 days for the low flowrate systems.
- Table 5.1 shows the summary of cations and anions removal efficiencies for Systems 1 to 4. For System 1, there was no apparent removal Ca^{2+}. The removal efficiency of Mg^{2+}, Na^+, SO_4^{2-} and conductivity was 0%, 1.5%, 35% and 7% in the high flowrate system; 28%, 20%, 69% and 20% in the low flowrate system.

Table 5.1 Summary of Cations and Anions Removal Efficiency

System	Flowrate	Ca^{2+} (%)	Mg^{2+} (%)	Na^+ (%)	SO_4^{2-} (%)	Conductivity (%)
System 1	high flowrate	0	0	-1.5	-35	-7
	low flowrate	0	-28	-20	-69	-20
System 2	high flowrate	-68	-57	0	-50	-10
	low flowrate	-70	-60	0	-68	-10
System 3	high flowrate	-24	-14	5	-36	0
	low flowrate	-39	-26	8	-62	0
System 4	high flowrate	0	0	0	-57	0
	low flowrate	0	0	0	-49	-10

- For System 2, the high flowrate system achieved 68% Ca^{2+} removal efficiency, 57% Mg^{2+} removal efficiency, 50% SO_4^{2-} removal efficiency, and 10% conductivity removal efficiency; the low flowrate system achieved 70% Ca^{2+} removal efficiency, 60% Mg^{2+} removal efficiency, 68% SO_4^{2-} removal efficiency, and 10% conductivity removal efficiency. In both flowrate systems, feeding the amended CT water to the MFT layer promoted the release of Na^+, and more Na^+ was released in the low flowrate system. No significant conductivity change in the release water of the low flowrate system was observed.
- For System 3, Ca^{2+}, Mg^{2+}, and SO_4^{2-} removal efficiencies were 24%, 14% and 36%, respectively, in the high flowrate system; Ca^{2+}, Mg^{2+}, and SO_4^{2-} removal efficiencies were 39%, 26% and 62%, respectively. In the low flowrate system, Na^+ increased 5% and 8% for the high flowrate and low flowrate systems, respectively. The conductivity of the high flowrate system and the low flowrate system was almost equal to the conductivity of the feed water.
- No removal of Ca^{2+}, Mg^{2+} and Na^+ of WIP water (System 4) was observed in the high flowrate system or low flowrate system. A SO_4^{2-} removal efficiency of 57% and 49% was achieved in the high flowrate system and the low flowrate system, respectively. No conductivity reduction of the WIP water was observed in the high flowrate system. The conductivity removal efficiency of the low flowrate system was 10%.
- For all systems fed with CT water, the low flow rates seemed more favorable for achieving higher removal efficiencies.
- The pH of the release water in all systems was in the range of 7.2 to 8.8.
- MPN results indicated that in Systems 1 and 2, SRB outcompeted methanogens and resulted in a drastic decrease in the MPN of methanogens due to high SO_4^{2-}

concentrations. However, in System 3, addition of NaAc in the feed water supported the growth of both SRB and methanogens. MPN analyses also suggested microbial activity of both SRB and methanogens in columns with WIP feed water.

- It was found from the barrel and static column study that the size of the mesocosm had no apparent influence on the cation concentrations, but slight influence on SO_4^{2-} concentration. CT water penetrating through MFT could enhance the densification of fine particles in MFT.

Because of the time limitation of this study, the flow rates used in the experiments were 6 mL/h and 20 mL/h, and the incubation times were 140 days and 60 days, respectively. The lower the flow rate, the higher the removal efficiency. It would be useful to further study lower flow rates in order to investigate if there is a threshold value.

In this study, the flow rate of the feed water was controlled by a combination of valves and flow meter. In order to accurately control the flow rate, it is recommended to use a flow control pump to control the system flow.

Methanogenesis and sulfate reduction were important anaerobic biological processes in MFT deposition. However, MPN analysis can only estimate the number of the relevant microbial populations, but not the microbial activity. Therefore, it is also recommended to analyze the headspace gases in the dynamic columns to detect the methane and/or H_2S production, which could verify the occurrence of methanogenesis and/or sulfate reduction processes in the MFT.

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Appendix A Dynamic System Results

A1 Results of chemical analysis in DH-1 system (sample type: RelW)

Sample ID	Incub. Time (d)	pH	Cond	Br^+	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	SO_4^{2-}	CO_3^{2-} (wt ppm)	HCO_3^- (wt ppm)	Total Cations	Total Anions	Ratio Cat/Ani	ALK pH	S^{2-}
DH-1-1	1	8.04	4350	49	1180	29.2	15.3	23.7	840	94	0.0	1510	54.51	50.98	1.07	8.21	28.5
DH-1-3	2	8.33	4140	0	1070	16.5	12.2	17.5	800	61	0.0	1450	48.84	47.58	1.03	8.30	19.4
DH-1-5	5	7.98	4270	0	1110	15.4	13.4	19.5	810	23	0.0	1530	50.75	48.37	1.05	7.87	8.7
DH-1-6	6	7.66	4190	39	1120	16.4	15.2	23.1	800	40	0.0	1540	51.54	49.09	1.05	7.61	14.5
DH-1-7	7	7.61	4430	160	1120	16.3	16.0	23.9	800	127	0.0	1520	51.64	52.07	0.99	7.67	37.1
DH-1-8	8	7.64	4450	160	1090	15.7	15.3	23.1	800	119	0.0	1520	50.22	51.91	0.97	7.67	32.1
DH-1-9	9	7.58	4290	140	1080	15.6	15.0	22.7	800	88	0.0	1550	49.74	51.51	0.97	7.65	25.9
DH-1-10	10	7.57	4310	170	1090	15.5	15.2	22.7	800	127	0.0	1570	50.19	53.02	0.95	7.81	34.8
DH-1-11	11	7.57	4340	170	1090	15.7	15.2	22.8	800	113	0.0	1510	50.20	51.74	0.97	7.62	29.5
DH-1-12	12	7.59	4270	170	1170	16.9	16.4	24.6	780	98	0.0	1530	53.90	51.19	1.05	7.64	32.8
DH-1-13	13	7.73	4180	180	1160	16.9	16.6	25.4	800	98	0.0	1640	53.52	53.69	1.00	7.63	30.2
DH-1-14	14	7.66	4220	190	1150	16.8	16.7	25.6	780	94	0.0	1500	53.10	50.87	1.04	7.78	29.3
DH-1-15	15	7.68	4290	230	1190	17.9	17.5	26.7	790	117	0.0	1510	54.99	52.28	1.05	7.65	36.1
DH-1-16	16	7.64	4310	250	1170	17.1	17.1	26.3	800	142	0.0	1490	54.05	53.01	1.02	7.63	38.7
DH-1-17	17	7.71	4330	290	1180	17.1	17.3	26.5	790	151	0.0	1470	54.51	53.08	1.03	7.79	43.4
DH-1-18	18	7.66	4530	360	1190	17.1	17.7	27.3	790	173	0.0	1460	55.02	54.24	1.01	7.74	51.4
DH-1-19	19	7.69	4500	400	1200	17.4	18.0	27.8	800	193	0.0	1450	55.51	55.26	1.00	7.68	55.5
DH-1-20	20	7.78	4580	420	1230	17.7	18.2	27.8	790	200	0.0	1430	56.84	55.05	1.03	7.80	59.9
DH-1-21	21	7.73	4650	410	1220	17.7	18.1	27.8	730	175	0.0	1440	56.40	52.88	1.07	7.67	55.4
DH-1-22	22	7.59	4580	470	1220	18.2	18.6	28.6	790	197	0.0	1530	56.49	57.24	0.99	7.54	57.1
DH-1-23	23	7.63	4750	510	1220	17.8	18.8	29.0	770	220	0.0	1420	56.52	55.85	1.01	7.66	66.0
DH-1-24	24	7.54	4850	590	1220	17.8	19.2	29.7	780	241	0.0	1490	56.58	58.70	0.96	7.52	72.4
DH-1-25	25	7.51	4720	670	1300	19.0	20.6	32.0	770	294	0.0	1430	60.33	59.53	1.01	7.48	80.5
DH-1-26	26	7.66	4990	710	1310	19.0	20.5	32.2	770	273	0.0	1370	60.76	58.60	1.04	7.85	82.0
DH-1-27	27	7.52	5350	820	1330	19.5	21.7	33.9	830	288	0.0	1360	61.83	61.80	1.00	8.12	98.1

A1 Results of chemical analysis in DH-1 system (sample type: RelW) (cont'd)

Sample ID	Incub. Time (d)	pH	Cond	Br^+	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	SO_4^{2-}	CO_3^{2-} (wt ppm)	HCO_3^- (wt ppm)	Total Cations	Total Anions	Ratio Cat/Ani	ALK pH	S^{2-}
DH-1-28	28	7.49	5460	920	1400	20.5	23.5	36.8	830	315	0.0	1340	65.19	63.27	1.03	7.54	107.0
DH-1-29	29	7.49	5570	1000	1390	19.8	23.9	35.3	820	351	0.0	1300	64.70	64.07	1.01	7.64	117.0
DH-1-30	30	7.57	5640	1100	1380	20.0	24.7	37.7	820	379	88.5	1100	64.46	65.56	0.98	8.71	126.0
DH-1-31	31	7.52	5730	1200	1410	20.3	24.9	38.1	820	387	0.0	1290	65.80	67.12	0.98	7.60	129.0
DH-1-32	32	7.47	5850	1300	1410	20.4	25.8	39.4	810	426	0.0	1250	65.95	68.23	0.97	7.36	137.0
DH-1-33	33	7.56	5930	1300	1420	20.8	26.0	34.2	780	412	0.0	1240	66.15	66.93	0.99	7.86	141.0
DH-1-34	34	7.56	5980	1400	1430	20.7	26.1	38.7	800	444	0.0	1240	66.81	69.40	0.96	7.47	139.0
DH-1-35	35	7.52	5960	1500	1530	21.1	26.6	42.0	810	492	0.0	1200	71.38	71.26	1.00	7.22	157.0
DH-1-36	36	7.56	6030	1500	1510	20.8	26.8	42.2	790	509	0.0	1170	70.53	70.56	1.00	7.19	159.0
DH-1-37	37	7.57	6210	1600	1500	21.0	27.2	42.7	800	547	0.0	1160	70.16	72.70	0.97	7.14	162.0
DH-1-38	38	7.74	6120	1600	1520	20.6	26.6	42.1	770	559	0.0	1180	70.94	72.43	0.98	7.36	159.0
DH-1-39	39	7.54	6310	1800	1560	21.5	28.4	44.8	800	611	0.0	1110	72.98	75.68	0.96	7.11	176.0
DH-1-40	40	7.81	6430	1800	1620	22.9	31.0	49.2	800	617	0.0	1160	76.07	76.63	0.99	7.22	186.0
DH-1-41	41	7.71	6560	1800	1600	22.2	30.1	47.7	780	615	0.0	1140	75.03	75.70	0.99	7.12	186.0
DH-1-42	42	7.72	6740	1959	1620	21.1	28.8	45.0	817	662	0.0	1075	75.63	78.61	0.96	7.53	175.0
DH-1-43	43	7.84	6700	1930	1630	21.4	28.6	45.0	812	657	0.0	1070	76.05	77.93	0.98	7.13	172.0
DH-1-44	44	8.03	6700	1963	1630	21.2	28.0	43.0	809	668	0.0	1040	75.90	77.99	0.97	7.95	165.0
DH-1-45	45	8.03	6700	2023	1620	21.1	28.1	43.3	819	682	0.0	1060	75.48	79.63	0.95	7.13	161.0
DH-1-46	46	7.79	6720	2029	1630	21.0	28.2	44.4	808	678	0.0	1100	75.98	79.97	0.95	7.10	165.0
DH-1-47	47	7.84	6760	2051	1640	20.8	27.8	43.4	805	665	0.0	1070	76.32	79.39	0.96	7.11	162.0
DH-1-48	48	7.54	6830	2080	1630	20.7	27.5	43.5	809	679	0.0	1120	75.87	80.97	0.94	7.25	171.0
DH-1-49	49	7.82	6570	2000	1610	21.8	28.9	46.0	770	622	0.0	1070	75.27	76.88	0.98	7.17	191.0
DH-1-50	50	7.73	6600	2000	1620	21.3	28.3	44.9	770	605	0.0	1070	75.58	76.53	0.99	7.2	149.0
DH-1-51	51	7.89	6550	2000	1620	21.5	28.4	44.8	770	651	0.0	1060	75.59	77.32	0.98	7.23	149.0
DH-1-52	52	7.80	6590	2000	1630	22.1	29.1	46.6	780	618	0.0	1050	76.19	76.75	0.99	7.13	180.0

A1 Results of chemical analysis in DH-1 system (sample type: RelW) (cont'd)

Sample ID	Incub. Time (d)	pH	Cond	Br^+	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	SO_4^{2-}	CO_3^{2-} (wt ppm)	HCO_3^- (wt ppm)	Total Cations	Total Anions	Ratio Cat/Ani	ALK pH	S^{2-}
DH-1-53	53	7.70	6660	2100	1630	22.5	29.7	47.7	770	570	0.0	1100	76.31	77.52	0.98	7.17	179.0
DH-1-54	54	7.72	6610	2100	1620	22.8	29.9	47.8	770	625	0.0	1070	75.90	78.18	0.97	7.26	239.0
DH-1-55	55	7.65	6700	2100	1630	21.5	28.0	44.7	770	648	0.0	1090	75.99	78.98	0.96	7.16	243.0
DH-1-56	56	7.92	6660	2200	1640	22.0	28.1	39.3	790	603	0.0	1110	76.18	80.51	0.95	7.33	219.0
DH-1-57	57	7.90	6690	2200	1550	26.3	26.8	38.8	790	595	0.0	1100	72.24	80.18	0.90	7.10	204.0
DH-1-58	58	7.85	6690	2300	1705	23.6	25.6	39.9	790	626	0.0	1080	78.86	81.75	0.96	7.04	189.6
DH-1-59	59	7.72	6730	2200	1705	23.1	29.9	43.5	770	675	0.0	1110	79.39	81.45	0.97	7.09	228.0
DH-1-60	60	7.80	6810	2300	1706	23.1	29.9	34.5	790	689	0.0	1110	78.98	83.55	0.95	7.09	227.0

A2 Results of chemical analysis in DH-2 system (sample type: RelW)

Sample ID	Incub. Time (d)	pH	Cond	Br^+	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	SO_4^{2-}	CO_3^{2-} (wt ppm)	HCO_3^- (wt ppm)	Total Cations	Total Anions	Ratio Cat/Ani	ALK pH	S^{2-}
DH-2-2	2	7.91	4280	0	1060	16.2	17.6	24.7	800	117	0	1540	49.20	50.23	0.98	7.87	34
DH-2-3	3	7.88	4110	0	1150	17.0	16.6	24.7	800	67	0	1570	53.05	49.69	1.07	7.85	22
DH-2-4	4	7.83	4120	0	1110	16.3	15.6	23.1	800	75	0	1550	51.13	49.51	1.03	7.84	24
DH-2-5	5	7.76	4260	0	1070	15.8	15.8	23.4	790	139	0	1520	49.41	50.08	0.99	7.82	44
DH-2-6	6	7.76	4320	0	1120	16.5	16.6	24.7	750	183	0	1500	51.74	49.57	1.04	7.80	61
DH-2-7	7	7.90	4190	0	1180	17.7	18.0	27.3	790	220	0	1500	54.62	51.43	1.06	7.79	68
DH-2-8	8	7.80	4260	0	1180	17.6	18.6	28.3	780	253	0	1480	54.72	51.51	1.06	7.73	82
DH-2-9	9	7.76	4160	0	1230	18.1	19.3	29.5	780	269	0	1480	57.03	51.84	1.10	7.75	77
DH-2-10	10	7.78	4220	0	1220	18.1	19.3	29.5	780	294	0	1470	56.59	52.20	1.08	7.74	91
DH-2-11	11	7.97	4380	0	1240	18.5	19.9	30.4	790	317	0	1470	57.57	52.96	1.09	7.82	105
DH-2-12	12	7.83	4360	0	1230	18.4	19.8	30.3	780	340	0	1440	57.12	52.66	1.08	7.81	115
DH-2-13	13	7.83	4340	0	1240	18.5	20.0	30.6	780	363	0	1430	57.58	52.98	1.09	7.78	120
DH-2-14	14	7.80	4380	0	1220	18.2	19.8	30.3	780	387	0	1410	56.68	53.15	1.07	7.87	129
DH-2-15	15	7.75	4390	0	1220	18.2	20.3	31.0	780	415	0	1410	56.75	53.73	1.06	8.06	138
DH-2-16	16	7.69	4460	0	1240	18.6	21.6	32.9	770	495	0	1370	57.83	54.46	1.06	7.71	164
DH-2-17	17	7.69	4470	0	1240	18.6	22.2	33.5	770	529	0	1320	57.91	54.35	1.07	7.69	177
DH-2-18	18	7.68	4400	0	1240	18.8	22.2	33.6	770	504	0	1350	57.93	54.32	1.07	7.70	168
DH-2-19	19	7.63	4470	0	1250	19.0	22.7	34.3	770	518	0	1350	58.44	54.61	1.07	7.68	176
DH-2-20	20	7.49	4450	0	1260	19.2	23.6	35.7	760	548	0	1330	59.03	54.63	1.08	7.82	190
DH-2-21	21	7.44	4940	0	1230	19.7	26.7	39.1	830	657	0	1290	58.16	58.34	1.00	7.48	216
DH-2-22	22	7.46	4850	0	1230	20.0	28.7	41.5	810	708	0	1250	58.46	58.11	1.01	7.57	235
DH-2-23	23	7.40	4970	0	1240	20.5	31.4	45.2	810	778	0	1200	59.32	58.70	1.01	7.68	258
DH-2-24	24	7.66	4990	0	1250	21.0	34.6	48.5	810	836	0	1180	60.19	59.58	1.01	7.80	276
DH-2-25	25	7.52	4970	0	1260	21.3	37.4	39.7	780	850	0	1140	60.43	58.37	1.04	7.66	292
DH-2-26	26	7.42	4990	0	1240	21.0	37.4	51.5	790	824	0	1170	60.14	58.60	1.03	7.54	280

A2 Results of chemical analysis in DH-2 system (sample type: RelW) (cont'd)

Sample ID	Incub. Time (d)	pH	Cond	Br^+	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	SO_4^{2-}	CO_3^{2-} (wt ppm)	HCO_3^- (wt ppm)	Total Cations	Total Anions	Ratio Cat/Ani	ALK pH	S^{2-}
DH-2-27	27	7.42	4950	0	1240	21.0	36.3	50.4	810	830	0	1200	60.00	59.78	1.00	7.53	274
DH-2-28	28	7.39	5010	0	1260	21.5	38.7	50.6	800	870	0	1170	61.09	59.84	1.02	7.45	289
DH-2-29	29	7.54	5060	0	1210	20.3	37.0	51.4	810	922	0	1150	58.78	60.88	0.97	7.33	287
DH-2-30	30	7.57	5000	0	1270	21.7	41.6	57.2	800	954	0	1120	62.10	60.77	1.02	7.24	307
DH-2-31	31	7.67	5100	0	1200	20.5	40.2	54.6	790	975	0	1130	58.78	61.09	0.96	7.95	288
DH-2-32	32	7.67	5010	0	1240	21.4	43.2	58.4	790	1010	0	1130	60.98	61.82	0.99	7.04	300
DH-2-33	33	7.66	5030	0	1270	22.3	46.3	62.4	790	1030	0	1100	62.77	61.74	1.02	7.11	319
DH-2-34	34	7.54	5140	0	1260	22.2	46.7	62.6	790	998	0	1130	62.37	61.57	1.01	7.07	316
DH-2-35	35	7.74	5160	0	1250	22.3	49.7	65.5	780	1050	0	1090	62.34	61.72	1.01	6.99	326
DH-2-36	36	7.86	5200	0	1210	20.0	46.7	59.3	790	1080	0	1090	59.98	62.62	0.96	7.28	288
DH-2-37	37	7.98	5180	0	1240	21.2	50.5	60.7	790	1030	0	1090	61.70	61.58	1.00	7.40	299
DH-2-38	38	7.88	5140	0	1220	22.8	53.4	68.0	790	999	0	1140	61.48	61.75	1.00	7.41	307
DH-2-39	39	7.96	5140	0	1220	22.6	52.7	59.3	780	902	0	1170	60.98	59.94	1.02	7.49	294
DH-2-40	40	7.89	5070	0	1230	21.8	47.3	54.4	790	799	0	1260	60.70	59.56	1.02	7.62	256
DH-2-41	41	7.86	5030	0	1230	21.9	45.2	52.6	820	798	0	1250	60.44	60.22	1.00	7.38	249
DH-2-42	42	7.52	5020	0	1220	21.7	43.8	56.7	800	647	0	1360	60.08	58.31	1.03	7.67	233
DH-2-43	43	7.85	4870	0	1170	21.8	47.1	53.8	770	803	0	1210	58.04	58.26	1.00	7.49	261
DH-2-44	44	8.14	4910	0	1180	22.0	47.4	44.5	780	854	0	1160	58.04	58.78	0.99	7.37	264
DH-2-45	45	7.82	4900	0	1120	21.0	44.5	53.2	780	810	0	1160	55.60	57.86	0.96	7.42	252
DH-2-46	46	7.89	4880	0	1180	23.0	50.3	56.6	780	840	0	1200	58.92	59.14	1.00	7.45	275
DH-2-47	47	7.61	4940	0	1110	21.1	44.8	57.9	780	855	0	1190	55.43	59.29	0.93	7.38	248
DH-2-48	48	7.51	4950	0	1100	21.0	45.7	59.2	770	850	0	1260	55.13	60.05	0.92	7.97	351
DH-2-49	49	7.53	5040	0	1180	23.2	52.8	68.3	780	880	0	1140	59.71	58.99	1.01	7.42	399
DH-2-50	50	7.84	4990	0	1219	24.9	56.3	53.5	800	995	0	1140	61.01	61.95	0.98	7.61	334
DH-2-51	51	8.13	4960	0	1200	25.2	58.0	55.4	800	932	0	1130	60.42	60.48	1.00	7.31	311

A2 Results of chemical analysis in DH-2 system (sample type: RelW) (cont'd)

Sample ID	Incub. Time (d)	pH	Cond	Br^+	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	SO_4^{2-}	CO_3^{2-} (wt ppm)	HCO_3^- (wt ppm)	Total Cations	Total Anions	Ratio Cat/Ani	ALK pH	S^{2-}
DH-2-52	52	8.06	4970	0	1180	23.9	57.0	56.4	790	795	0	1220	59.49	58.82	1.01	7.68	291
DH-2-53	53	7.87	5020	0	1230	21.3	52.6	42.9	770	784	0	1210	60.55	57.86	1.05	7.70	260
DH-2-54	54	7.68	5030	0	1225	21.8	53.7	50.6	800	854	0	1110	60.82	58.52	1.04	7.17	318
DH-2-55	55	7.72	5060	0	1210	22.6	55.0	42.4	800	763	0	1100	59.89	56.46	1.06	7.21	270
DH-2-56	56	7.65	5080	0	1180	21.7	54.0	43.1	770	700	0	1260	58.52	56.93	1.03	7.87	274
DH-2-57	57	8.02	5130	0	1280	24.7	65.4	62.2	810	854	0	1190	64.85	60.17	1.08	7.28	328
DH-2-58	58	8.00	5100	0	1260	24.8	65.7	63.9	800	897	0	1110	64.09	59.42	1.08	7.00	338
DH-2-59	59	7.81	5130	0	1280	25.4	67.2	56.4	760	990	0	1130	64.72	60.56	1.07	7.20	360
DH-2-60	60	7.83	5190	0	1290	25.3	69.5	51.2	770	1240	0	1280	65.09	68.51	0.95	8.30	408

A3 Results of chemical analysis in DH-3 system (sample type: RelW)

Sample ID	Incub. Time (d)	pH	Cond	Br^+	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	SO_4^{2-}	CO_3^{2-} (wt ppm)	HCO_3^- (wt ppm)	Total Cations	Total Anions	Ratio Cat/Ani	ALK pH	S^{2-}
DH-3-3	3	7.92	6040	23	1036	16.5	15.8	23.6	810	93.6	0.0	1330	48.0	46.9	1.02	7.64	35.6
DH-3-4	4	7.78	6180	45	1070	16.5	16.5	24.8	790	181	0.0	1360	49.6	48.9	1.01	7.35	67.1
DH-3-5	5	7.84	6100	59	1057	16.4	16.7	25.2	790	233	0.0	1390	49.0	50.6	0.97	7.45	84.8
DH-3-6	6	7.77	6500	60	1070	16.5	17.0	25.5	800	235	0.0	1400	49.6	51.1	0.97	7.78	85.7
DH-3-7	7	7.78	6410	67	1058	16.3	16.9	25.5	790	247	0.0	1380	49.1	50.9	0.97	7.47	90.4
DH-3-8	8	7.85	6290	68	1081	16.7	17.0	25.7	800	256	0.0	1380	50.1	51.3	0.98	7.48	93.2
DH-3-9	9	7.74	6350	64	1070	16.5	17.3	26.5	770	239	0.0	1380	49.7	50.1	0.99	7.44	88.5
DH-3-10	10	7.75	6070	66	1080	16.3	16.9	25.6	800	235	0.0	1380	50.1	50.9	0.98	7.41	85.6
DH-3-11	11	7.78	5900	62	1070	16.4	16.7	25.3	800	222	0.0	1380	49.6	50.6	0.98	7.42	81.0
DH-3-12	12	7.78	5980	61	1060	16.3	16.7	25.2	790	221	0.0	1390	49.2	50.4	0.98	7.45	80.3
DH-3-13	13	7.75	5800	53	1050	16.0	15.7	24.1	800	156	0.0	1430	48.6	49.9	0.97	7.45	57.7
DH-3-14	14	7.77	5910	54	1051	16.1	15.8	24.1	810	162	0.0	1450	48.6	50.6	0.96	7.50	57.1
DH-3-15	15	7.54	5350	83	1150	17.2	17.2	26.9	790	246	0.0	1400	53.2	51.4	1.04	7.39	87.1
DH-3-16	16	7.64	5430	75	1150	17.1	16.6	25.8	810	244	0.0	1420	53.1	52.1	1.02	7.47	76.5
DH-3-17	17	7.64	5400	76	1130	16.9	16.6	25.7	810	254	0.0	1420	52.2	52.3	1.00	7.47	76.7
DH-3-19	19	7.56	5540	110	1160	17.3	16.8	26.0	790	306	0.0	1360	53.6	52.3	1.02	7.40	108.0
DH-3-20	20	7.55	5480	110	1150	17.4	16.9	26.1	790	305	0.0	1370	53.2	52.4	1.01	7.40	109.0
DH-3-21	21	7.60	5560	99	1150	17.0	16.6	25.6	790	270	0.0	1330	53.1	50.9	1.04	7.45	96.9
DH-3-22	22	7.61	5480	100	1150	17.2	16.6	25.5	800	271	0.0	1320	53.1	51.1	1.04	7.44	97.7
DH-3-23	23	7.96	4860	92	1150	17.6	17.0	26.7	750	298	0.0	1380	53.2	51.1	1.04	7.61	101.0
DH-3-24	24	7.94	4850	94	1165	17.9	17.0	26.6	760	293	0.0	1400	53.9	51.6	1.04	7.67	102.0
DH-3-25	25	7.89	4890	120	1180	18.0	17.5	27.2	750	300	0.0	1370	54.6	51.3	1.06	7.65	121.0
DH-3-26	26	7.86	4840	120	1170	17.8	17.4	27.0	760	303	0.0	1370	54.1	51.7	1.05	7.79	119.0
DH-3-27	27	7.72	4890	120	1160	17.3	17.2	26.7	760	305	0.0	1380	53.6	51.9	1.03	7.62	117.0
DH-3-28	28	7.89	4890	120	1180	17.3	17.1	26.9	760	312	37.8	1370	54.5	53.1	1.03	8.46	121.0
DH-3-29	29	7.70	5210	160	1150	17.0	17.2	26.5	700	400	0.0	1310	53.2	51.5	1.03	7.34	160.0

A3 Results of chemical analysis in DH-3 system (sample type: RelW) (cont'd)

Sample ID	Incub. Time (d)	pH	Cond	Br^+	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	SO_4^{2-}	CO_3^{2-} (wt ppm)	HCO_3^- (wt ppm)	Total Cations	Total Anions	Ratio Cat/Ani	ALK pH	S^{2-}
DH-3-30	30	7.70	5220	160	1150	16.6	17.1	26.4	700	400	0.0	1260	53.2	50.7	1.05	7.34	154.0
DH-3-31	31	7.72	5180	160	1150	16.7	17.1	26.5	720	382	0.0	1360	53.2	52.5	1.01	7.67	145.0
DH-3-32	32	7.70	5230	170	1130	16.6	17.0	26.3	720	390	0.0	1310	52.3	52.0	1.01	7.62	145.0
DH-3-33	33	7.88	5240	180	1130	16.5	17.0	26.3	720	413	0.0	1300	52.3	52.4	1.00	7.55	151.0
DH-3-34	34	7.89	5270	200	1170	16.8	17.8	27.1	720	431	0.0	1290	54.1	52.9	1.02	7.63	164.0
DH-3-35	35	7.88	5270	190	1130	16.5	17.3	26.4	710	432	0.0	1300	52.3	52.7	0.99	7.66	158.0
DH-3-36	36	7.94	5290	200	1110	16.1	16.9	25.9	720	444	0.0	1290	51.4	53.2	0.97	7.60	155.0
DH-3-37	37	7.92	5280	200	1130	16.6	17.4	26.6	730	444	0.0	1280	52.3	53.3	0.98	7.60	160.0
DH-3-38	38	8.27	5330	240	1210	17.6	20.2	31.8	740	566	0.0	1190	56.3	55.1	1.02	7.30	198.0
DH-3-39	39	8.32	5320	240	1190	17.2	19.9	31.1	740	564	0.0	1175	55.4	54.9	1.01	7.11	198.0
DH-3-40	40	8.17	5340	240	1230	17.5	20.0	31.2	750	528	0.0	1320	57.2	56.8	1.01	7.76	187.0
DH-3-41	41	8.18	5340	240	1240	17.5	19.9	31.0	740	534	0.0	1230	57.6	55.1	1.04	7.63	186.0
DH-3-42	42	8.15	5290	240	1230	17.5	19.5	30.4	750	527	0.0	1250	57.1	55.6	1.03	7.65	184.0
DH-3-43	43	8.13	5320	240	1220	17.3	19.1	29.7	740	524	0.0	1250	56.6	55.3	1.02	7.68	180.0
DH-3-44	44	7.88	5260	260	1220	18.9	19.2	27.1	790	494	0.0	1510	56.5	60.5	0.93	8.11	162.0
DH-3-45	45	7.92	5250	250	1190	17.1	18.6	28.1	770	500	0.0	1310	55.1	56.7	0.97	7.22	160.0
DH-3-46	46	7.95	5310	250	1140	16.4	17.9	27.4	770	545	0.0	1180	52.8	55.5	0.95	7.56	169.0
DH-3-47	47	7.94	5320	250	1150	16.2	17.7	27.0	760	538	88.8	1090	53.2	56.6	0.94	8.80	168.0
DH-3-48	48	7.70	5310	240	1170	16.8	18.1	28.0	760	653	0.0	1120	54.2	56.4	0.96	7.62	210.0
DH-3-49	49	7.70	5320	240	1170	17.0	18.4	28.5	770	665	0.0	1140	54.3	57.2	0.95	7.60	213.0
DH-3-50	50	8.63	5290	270	1200	19.0	20.3	31.3	760	520	0.0	1360	55.9	57.9	0.97	7.70	305.0
DH-3-51	51	8.47	5410	270	1200	19.0	20.4	31.3	770	399	0.0	1350	55.9	55.5	1.01	7.54	196.0
DH-3-52	52	8.50	5410	270	1240	18.8	20.2	30.7	770	384	0.0	1440	57.6	56.7	1.02	7.82	198.0
DH-3-53	53	8.49	5400	270	1260	18.6	19.7	29.7	780	441	0.0	1360	58.4	56.8	1.03	7.70	219.0
DH-3-54	54	8.48	5380	270	1270	19.0	20.4	30.9	770	444	0.0	1360	58.9	56.6	1.04	7.81	217.0
DH-3-55	55	8.01	5400	250	1290	18.0	19.1	29.4	760	636	0.0	1170	59.6	57.0	1.05	7.75	214.0

A3 Results of chemical analysis in DH-3 system (sample type: RelW) (cont'd)

Sample ID	Incub. Time (d)	pH	Cond	Br^+	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	SO_4^{2-}	CO_3^{2-} (wt ppm)	HCO_3^- (wt ppm)	Total Cations	Total Anions	Ratio Cat/Ani	ALK pH	S^{2-}
DH-3-56	56	8.01	5420	260	1270	17.9	19.1	29.3	760	641	0.0	1140	58.7	56.7	1.04	7.69	215.0
DH-3-57	57	8.42	5280	260	1265	17.5	17.8	26.5	760	301	0.0	1540	58.3	56.2	1.04	7.75	167.0
DH-3-58	58	8.40	5350	280	1220	15.8	16.3	23.4	770	341	0.0	1430	56.0	55.7	1.00	7.68	119.0
DH-3-59	59	8.47	5360	300	1240	18.8	19.3	26.0	830	495	0.0	1410	57.3	60.6	0.95	7.80	166.0
DH-3-60	60	8.37	5470	300	1270	18.7	19.6	25.7	820	600	0.0	1370	58.6	61.8	0.95	8.03	205.0

A4 Results of chemical analysis in DH-4 system (sample type: RelW)

Sample ID	Incub. Time (d)	pH	Cond	Br^+	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	SO_4^{2-}	CO_3^{2-} (wt ppm)	HCO_3^- (wt ppm)	Total Cations	Total Anions	Ratio Cat/Ani	ALK pH	S^{2-}
DH-4-3	3	8.04	5540	11	1100	16.7	15.2	23.0	830	19.9	0.0	1550	50.7	49.3	1.03	7.62	8.7
DH-4-4	4	7.74	5740	24	1090	16.6	15.6	24.0	830	35.3	0.0	1500	50.3	49.0	1.03	7.47	14.7
DH-4-5	5	7.76	5540	24	1110	16.8	15.5	23.9	830	40.1	0.0	1500	51.2	49.1	1.04	7.48	14.8
DH-4-6	6	7.72	5560	42	1110	16.7	15.6	24.1	820	57.6	0.0	1450	51.2	48.6	1.05	7.48	22.9
DH-4-7	7	7.73	5450	43	1100	16.7	15.5	24.0	830	58.0	0.0	1490	50.7	49.6	1.02	7.52	22.9
DH-4-8	8	7.60	5090	53	1110	16.7	15.2	23.3	830	63.4	0.0	1460	51.1	49.3	1.04	7.51	24.5
DH-4-9	9	7.60	5050	52	1110	16.5	15.6	24.0	830	64.2	0.0	1470	51.2	49.5	1.03	7.52	24.6
DH-4-10	10	7.76	5150	52	1100	16.3	15.1	23.2	830	62.0	0.0	1470	50.7	49.4	1.03	7.59	24.1
DH-4-11	11	7.62	5130	100	1080	16.4	14.5	22.5	820	102	0.0	1360	49.7	48.8	1.02	7.55	38.3
DH-4-12	12	7.61	5140	100	1090	16.3	14.5	22.4	820	104	0.0	1350	50.1	48.6	1.03	7.48	38.6
DH-4-13	13	7.61	5230	100	1090	16.6	14.5	22.4	820	102	0.0	1380	50.1	49.1	1.02	7.53	39.1
DH-4-14	14	7.74	5170	100	1090	15.9	14.3	22.1	810	102	0.0	1350	50.1	48.3	1.04	7.56	38.1
DH-4-15	15	7.73	5110	100	1090	15.9	14.4	22.1	820	104	0.0	1350	50.1	48.6	1.03	7.54	38.3
DH-4-16	16	7.93	4520	110	1070	16.3	14.5	22.5	790	91.3	0.0	1360	49.3	47.8	1.03	7.78	37.3
DH-4-17	17	7.99	4540	110	1130	16.8	14.7	22.7	800	91.7	0.0	1390	51.9	48.6	1.07	7.74	38.2
DH-4-18	18	8.08	4460	120	1090	16.6	14.4	22.3	790	94.1	0.0	1380	50.1	48.3	1.04	7.81	39.2
DH-4-19	19	8.07	4460	120	1090	16.5	14.4	22.2	790	95.1	0.0	1350	50.1	47.9	1.05	7.82	38.8
DH-4-20	20	7.95	4510	120	1130	17.3	14.7	22.5	800	95.0	0.0	1340	51.9	48.0	1.08	7.84	40.3
DH-4-21	21	8.09	4330	140	1110	16.3	14.1	21.7	800	92.6	0.0	1330	50.9	48.0	1.06	7.72	38.1
DH-4-22	22	7.82	4700	130	1060	15.5	13.5	20.7	760	88.0	0.0	1310	48.6	46.3	1.05	7.68	36.1
DH-4-23	23	7.78	4700	150	1060	15.3	13.2	20.1	780	96.4	0.0	1290	48.6	47.0	1.03	7.64	38.7
DH-4-24	24	7.76	4700	150	1050	14.9	13.3	20.6	780	97.6	0.0	1290	48.2	47.0	1.02	7.91	38.3
DH-4-25	25	7.75	4670	170	1060	14.8	13.0	20.3	770	97.5	0.0	1310	48.6	47.3	1.03	7.70	37.9
DH-4-26	26	7.76	4670	160	1060	15.0	13.0	20.1	780	96.2	0.0	1320	48.6	47.6	1.02	7.68	38.2
DH-4-27	27	7.68	4650	160	1060	15.0	12.8	19.9	770	97.2	0.0	1290	48.5	46.9	1.04	7.56	38.1

A4 Results of chemical analysis in DH-4 system (sample type: RelW) (cont'd)

Sample ID	Incub. Time (d)	pH	Cond	Br^+	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	SO_4^{2-}	CO_3^{2-} (wt ppm)	HCO_3^- (wt ppm)	Total Cations	Total Anions	Ratio Cat/Ani	ALK pH	S^{2-}
DH-4-28	28	7.67	4660	170	1060	15.0	13.1	20.2	780	97.8	0.0	1260	48.6	46.8	1.04	7.64	38.1
DH-4-29	29	7.87	4660	180	1020	14.2	12.3	18.9	780	98.4	0.0	1290	46.7	47.4	0.98	7.71	36.6
DH-4-30	30	7.89	4610	180	1040	14.5	12.5	19.4	780	97.0	0.0	1250	47.6	46.7	1.02	7.73	37.5
DH-4-31	31	7.82	4620	230	1070	14.3	12.3	19.3	820	118	0.0	1200	48.9	48.1	1.02	7.69	33.9
DH-4-32	32	7.79	4620	240	1060	14.1	12.0	18.7	830	118	0.0	1250	48.4	49.3	0.98	7.61	35.2
DH-4-33	33	7.83	4610	230	1030	13.8	11.8	18.3	840	107	0.0	1230	47.0	48.9	0.96	7.75	35.5
DH-4-34	34	7.75	4600	230	1060	13.8	12.0	18.9	830	108	0.0	1240	48.4	48.8	0.99	7.70	35.9
DH-4-35	35	7.78	4610	240	1050	13.9	11.9	18.6	830	91.5	0.0	1240	47.9	48.6	0.99	7.51	30.0
DH-4-36	36	7.75	4590	240	1050	14.0	12.0	18.8	830	91.4	0.0	1250	48.0	48.8	0.98	7.55	30.6
DH-4-37	37	7.77	4580	210	1000	13.6	12.2	19.3	740	88.3	0.0	1200	45.8	45.0	1.02	7.59	36.2
DH-4-38	38	7.89	4580	210	970	13.1	11.4	17.9	740	88.5	0.0	1210	44.4	45.1	0.98	7.68	34.6
DH-4-39	39	7.86	4480	210	970	13.2	11.5	18.1	730	93.9	0.0	1270	44.4	46.0	0.97	7.64	37.6
DH-4-40	40	7.87	4600	210	968	13.1	11.4	17.8	750	99.8	0.0	1250	44.3	46.3	0.96	7.68	37.8
DH-4-41	41	7.72	4590	220	990	13.6	11.6	18.1	750	84.3	0.0	1190	45.3	45.1	1.00	7.56	33.5
DH-4-42	42	7.71	4570	220	960	13.0	11.0	17.2	740	83.9	0.0	1210	43.8	45.2	0.97	7.60	32.2
DH-4-43	43	7.78	4610	260	990	13.6	11.3	17.4	770	84.6	0.0	1180	45.2	46.0	0.98	7.60	29.3
DH-4-44	44	7.78	4540	260	1000	13.9	11.6	17.8	770	84.1	0.0	1210	45.7	46.5	0.98	7.61	29.4
DH-4-45	45	7.89	4600	270	999	13.7	11.3	17.6	760	83.0	0.0	1120	45.6	44.9	1.02	7.59	28.8
DH-4-46	46	7.96	4620	280	1020	14.0	11.5	17.9	780	72.5	0.0	1220	46.6	47.0	0.99	7.74	25.0
DH-4-47	47	7.96	4500	280	998	13.7	11.2	17.2	780	73.0	0.0	1210	45.5	46.8	0.97	7.67	24.6
DH-4-48	48	7.84	4650	290	1010	13.9	11.4	17.7	770	99.2	0.0	1180	46.1	46.7	0.99	7.62	31.8
DH-4-49	49	7.83	4650	290	1010	13.6	11.1	17.2	770	96.7	0.0	1190	46.0	46.8	0.98	7.46	32.3
DH-4-50	50	7.88	4650	290	1000	13.5	11.1	17.2	760	99.9	0.0	1180	45.6	46.5	0.98	7.76	38.2
DH-4-51	51	7.88	4660	290	1000	13.2	10.7	16.4	780	104	0.0	1170	45.5	46.9	0.97	7.54	38.4
DH-4-52	52	7.96	4640	300	1030	13.6	11.5	18.4	790	108	0.0	1150	47.0	47.1	1.00	7.71	34.3

A4 Results of chemical analysis in DH-4 system (sample type: RelW) (cont'd)

Sample ID	Incub. Time (d)	pH	Cond	Br^+	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	SO_4^{2-}	CO_3^{2-} (wt ppm)	HCO_3^- (wt ppm)	Total Cations	Total Anions	Ratio Cat/Ani	ALK pH	S^{2-}
DH-4-53	53	7.96	4640	300	1060	13.9	11.7	18.6	790	108	0.0	1150	48.3	47.1	1.03	7.78	34.1
DH-4-54	54	7.96	4670	310	1040	13.4	11.2	17.8	780	93	0.0	1170	47.4	47.0	1.01	7.75	32.8
DH-4-55	55	7.87	4680	310	1030	12.9	11.1	17.7	790	125	0.0	1130	46.9	47.3	0.99	7.71	39.0
DH-4-56	56	7.86	4620	310	1040	12.9	11.2	18.0	790	129	0.0	1120	47.4	47.2	1.00	7.91	39.0
DH-4-57	57	7.93	4120	310	1050	13.2	11.3	18.0	800	145	0.0	1140	47.8	48.1	0.99	7.67	38.9
DH-4-58	72	7.86	4940	280	1080	13.2	11.4	18.0	780	145	23.1	1090	49.1	47.1	1.04	8.37	45.4
DH-4-59	59	7.88	4820	270	1070	13.0	11.3	18.1	790	138	0.0	1160	48.7	47.5	1.02	8.25	45.1
DH-4-60	60	7.90	4850	280	1050	12.7	11.0	17.4	780	128	0.0	1130	47.8	46.7	1.02	8.30	42.6

A5 Results of chemical analysis in DL-1 system (sample type: RelW)

Sample ID	Incub. Time (d)	pH	Cond	Br^+	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	SO_4^{2-}	CO_3^{2-} (wt ppm)	HCO_3^- (wt ppm)	Total Cations	Total Anions	Ratio Cat/Ani	ALK pH	S^{2-}
DL-1-8	8	7.83	4230	10	1140	15.8	14.5	22.3	800	53	0	1550	52.29	49.16	1.06	7.92	14.3
DL-1-9	9	7.93	4190	0	1090	15.1	13.9	20.9	810	28	0	1560	49.98	48.97	1.02	8.01	9.7
DL-1-10	10	7.79	4260	0	1090	15.1	13.7	20.8	800	15	0	1570	49.96	48.59	1.03	7.76	6.5
DL-1-11	11	7.89	4130	4	1120	15.6	13.9	21.1	810	12	0	1590	51.31	49.19	1.04	7.95	5.8
DL-1-12	12	7.74	4040	4	1050	14.5	13.1	19.8	810	10	0	1580	48.11	48.98	0.98	7.77	5.3
DL-1-13	13	7.91	4180	0	1060	14.5	13.0	19.5	800	11	0	1450	48.52	46.54	1.04	7.44	5.6
DL-1-14	14	7.91	4140	4	1050	14.1	12.8	19.3	800	8	0	1570	48.05	48.49	0.99	8.14	4.9
DL-1-15	15	7.72	4130	4	1110	15.7	14.1	21.5	800	6	0	1590	50.91	48.78	1.04	7.76	4.4
DL-1-16	16	7.74	4130	5	1120	16.1	14.5	22.2	800	5	0	1590	51.43	48.77	1.05	7.86	4.3
DL-1-17	17	7.91	4140	5	1080	16.3	13.2	20.2	800	5	0	1570	49.48	48.44	1.02	8.05	4.2
DL-1-18	18	8.07	3970	0	1120	16.3	14.6	22.2	790	6	0	1570	51.44	48.11	1.07	8.10	4.1
DL-1-19	19	7.88	3990	10	1120	18.3	16.0	24.4	800	5	0	1590	51.72	48.83	1.06	7.98	3.7
DL-1-20	20	7.71	4040	15	1125	17.1	15.6	23.5	810	10	0	1610	51.83	49.61	1.04	7.74	4.4
DL-1-21	21	7.73	3990	29	1130	17.5	15.8	24.0	800	15	0	1600	52.10	49.43	1.05	8.06	6.4
DL-1-22	22	7.75	4060	38	1140	17.5	15.6	23.7	800	24	0	1650	52.50	50.55	1.04	7.85	8.6
DL-1-23	23	7.78	4040	53	1160	16.9	15.1	23.1	800	33	0	1680	53.28	51.41	1.04	7.96	10.7
DL-1-24	24	7.85	4100	61	1160	17.6	15.8	24.1	790	36	0	1710	53.41	51.79	1.03	7.91	11.3
DL-1-25	25	7.90	4100	68	1140	16.8	15.0	23.1	790	41	0	1610	52.40	50.34	1.04	7.94	12.2
DL-1-26	26	7.80	4120	72	1160	17.3	15.6	23.7	790	38	0	1580	53.36	49.83	1.07	7.84	11.5
DL-1-27	27	7.63	3950	92	1170	17.4	15.6	23.9	790	47	0	1560	53.81	49.94	1.08	7.85	13.9
DL-1-28	28	7.59	4070	130	1190	17.4	16.1	24.5	790	70	0	1550	54.75	50.72	1.08	7.71	20.9
DL-1-29	29	7.63	4290	160	1180	17.2	16.3	24.7	770	91	0	1770	54.34	54.58	1.00	7.76	28.4
DL-1-30	30	7.66	4260	170	1200	17.7	16.5	25.3	780	95	0	1630	55.27	52.78	1.05	7.93	29.6
DL-1-31	31	7.73	4250	180	1190	17.6	16.4	24.9	790	97	0	1520	54.80	51.41	1.07	7.86	29.1
DL-1-32	32	7.79	4630	250	1220	17.9	17.3	26.7	850	152	0	1500	56.28	54.79	1.03	7.71	53.3

A5 Results of chemical analysis in DL-1 system (sample type: RelW) (cont'd)

Sample ID	Incub. Time (d)	pH	Cond	Br^+	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	SO_4^{2-}	CO_3^{2-} (wt ppm)	HCO_3^- (wt ppm)	Total Cations	Total Anions	Ratio Cat/Ani	ALK pH	S^{2-}
DL-1-33	33	7.83	4670	270	1240	18.9	17.7	27.4	860	168	0	1470	57.24	55.16	1.04	7.74	57.9
DL-1-34	34	7.72	4780	340	1230	18.2	18.5	28.5	830	206	0	1440	56.91	55.48	1.03	7.74	74.1
DL-1-35	35	7.81	4770	360	1250	18.1	18.6	28.8	840	216	0	1430	57.80	56.05	1.03	7.80	73.3
DL-1-36	36	7.96	4800	380	1250	18.8	18.4	28.4	850	217	0	1430	57.78	56.60	1.02	7.94	76.7
DL-1-37	37	7.78	4790	370	1220	17.6	18.0	27.7	830	199	0	1440	56.38	55.70	1.01	7.75	70.8
DL-1-38	38	7.76	4820	380	1260	18.5	18.4	28.6	850	199	0	1440	58.22	56.39	1.03	7.73	68.6
DL-1-39	39	7.74	4890	440	1280	18.9	19.5	30.5	850	234	0	1420	59.29	57.53	1.03	7.81	77.0
DL-1-40	40	7.89	4800	460	1300	17.8	18.5	29.1	850	239	0	1410	59.97	57.72	1.04	7.72	82.6
DL-1-41	41	7.78	4850	450	1290	17.7	18.4	28.7	850	234	0	1410	59.51	57.49	1.04	7.71	81.2
DL-1-42	42	7.52	4890	460	1280	17.6	18.1	28.3	860	241	0	1420	59.03	58.20	1.01	7.50	80.6
DL-1-43	43	7.62	4950	500	1310	17.5	18.4	28.8	850	250	0	1410	60.38	58.44	1.03	7.67	83.6
DL-1-44	44	7.59	4980	510	1260	16.2	17.2	26.7	850	245	0	1420	57.97	58.62	0.99	7.59	76.8
DL-1-45	45	7.69	4950	500	1260	17.0	18.1	28.4	810	235	0	1420	58.15	57.16	1.02	7.64	80.2
DL-1-46	46	7.69	5010	540	1290	17.9	19.3	30.5	840	248	0	1420	59.68	58.77	1.02	7.62	86.0
DL-1-47	47	7.64	5190	567	1300	17.1	18.6	29.3	876	265	0	1430	59.98	60.64	0.99	8.04	82.7
DL-1-48	48	7.78	5110	556	1310	17.2	18.4	28.7	878	249	0	1430	60.37	60.23	1.00	7.57	72.0
DL-1-49	49	7.83	5090	544	1310	17.3	18.0	28.3	870	237	0	1420	60.32	59.44	1.01	7.60	66.9
DL-1-50	50	7.99	5090	561	1290	17.5	18.2	28.5	884	246	0	1430	59.48	60.39	0.98	7.64	68.5
DL-1-51	51	7.84	5120	565	1280	16.8	17.5	27.2	869	245	0	1430	58.90	60.00	0.98	7.43	56.6
DL-1-52	52	7.84	5100	571	1290	17.6	18.5	28.8	880	231	0	1430	59.52	60.09	0.99	7.41	57.3
DL-1-53	53	7.89	5150	561	1290	17.7	18.2	28.4	878	243	0	1440	59.48	60.33	0.99	7.46	59.5
DL-1-54	54	7.77	4800	540	1220	17.2	17.8	27.9	840	225	0	1400	56.36	57.97	0.97	7.20	71.0
DL-1-55	55	7.80	4790	550	1250	17.7	18.5	29.0	830	240	0	1410	57.79	58.29	0.99	7.14	65.4
DL-1-56	56	8.13	4910	540	1240	17.6	18.4	28.8	810	215	0	1410	57.34	57.08	1.00	7.17	51.3
DL-1-57	57	7.92	4920	540	1190	16.7	17.2	26.7	830	223	0	1430	54.94	58.14	0.94	7.30	44.0

A5 Results of chemical analysis in DL-1 system (sample type: RelW) (cont'd)

Sample ID	Incub. Time (d)	pH	Cond	Br^+	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	SO_4^{2-}	CO_3^{2-} (wt ppm)	HCO_3^- (wt ppm)	Total Cations	Total Anions	Ratio Cat/Ani	ALK pH	S^{2-}
DL-1-58	58	7.85	4940	550	1170	16.3	17.0	26.4	830	222	0	1450	54.02	58.57	0.92	7.40	37.3
DL-1-59	59	7.77	4880	570	1180	14.1	14.8	23.0	830	223	0	1460	54.05	59.00	0.92	7.40	38.4
DL-1-60	60	7.56	4960	600	1210	16.9	18.0	28.1	820	281	0	1380	55.95	58.98	0.95	7.59	52.5
DL-1-61	61	7.90	5020	650	1380	18.3	20.3	33.3	860	330	0	1340	63.83	61.19	1.04	7.28	115.0
DL-1-62	62	7.78	5000	650	1380	18.2	19.9	32.5	860	332	0	1340	63.75	61.23	1.04	7.32	115.0
DL-1-63	63	7.73	4990	660	1390	18.2	19.7	32.2	850	330	0	1340	64.15	61.04	1.05	7.36	113.0
DL-1-64	64	8.03	5010	670	1380	18.3	19.6	31.9	860	327	0	1350	63.70	61.54	1.03	7.35	114.0
DL-1-65	65	7.85	5040	660	1380	18.3	19.4	17.5	850	325	0	1340	62.96	60.93	1.03	7.70	114.0
DL-1-66	66	7.75	5050	670	1410	18.7	19.7	31.9	850	312	0	1360	65.02	61.11	1.06	7.24	110.0
DL-1-67	67	7.78	5120	680	1390	18.4	19.2	30.9	860	314	0	1360	64.05	61.56	1.04	7.26	107.0
DL-1-68	68	7.88	5180	680	1380	18.7	19.3	31.0	860	325	0	1326	63.64	61.23	1.04	7.14	106.0
DL-1-69	69	7.88	5160	680	1380	19.1	19.4	30.9	860	330	0	1390	63.65	62.39	1.02	7.51	109.0
DL-1-70	70	7.63	5140	680	1370	18.7	19.1	30.5	860	305	0	1400	63.16	62.03	1.02	7.68	101.0
DL-1-71	71	7.75	5170	670	1370	18.5	19.0	30.4	850	296	0	1400	63.14	61.44	1.03	7.26	96.2
DL-1-72	72	7.47	5170	650	1370	18.6	18.9	30.0	820	294	0	1450	63.12	61.12	1.03	7.21	94.4
DL-1-73	73	7.53	5160	670	1350	18.6	18.9	30.1	850	298	0	1390	62.25	61.31	1.02	7.26	97.4
DL-1-74	74	7.53	5220	680	1390	18.6	19.0	30.1	850	304	0	1390	64.00	61.56	1.04	7.27	97.1
DL-1-75	75	7.78	5070	680	1390	18.4	19.0	30.3	850	260	0	1430	64.00	61.30	1.04	7.34	88.5
DL-1-76	76	7.97	5050	690	1390	18.4	19.2	30.7	860	245	0	1430	64.04	61.40	1.04	7.13	85.4
DL-1-77	77	7.80	5100	690	1380	18.3	19.0	30.3	860	295	0	1380	63.57	61.62	1.03	7.94	95.9
DL-1-78	78	7.86	5080	700	1370	18.4	19.0	30.2	860	295	0	1360	63.13	61.42	1.03	7.05	96.4
DL-1-79	79	7.73	5060	690	1360	18.3	18.9	30.3	840	275	0	1390	62.69	60.80	1.03	7.20	90.7
DL-1-80	80	7.64	5190	710	1370	18.4	19.1	30.5	860	285	0	1390	63.15	61.82	1.02	7.20	93.8
DL-1-81	81	7.56	5130	700	1380	18.5	19.0	30.3	850	295	0	1370	63.57	61.30	1.04	7.30	97.6
DL-1-82	82	7.61	5310	700	1250	17.0	17.4	27.5	850	194	0	1620	57.61	63.29	0.91	7.23	57.1

A5 Results of chemical analysis in DL-1 system (sample type: RelW) (cont'd)

Sample ID	Incub. Time (d)	pH	Cond	Br^+	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	SO_4^{2-}	CO_3^{2-} (wt ppm)	HCO_3^- (wt ppm)	Total Cations	Total Anions	Ratio Cat/Ani	ALK pH	S^{2-}
DL-1-83	83	8.07	5330	710	1280	17.7	18.0	26.9	850	206	0	1400	58.95	60.06	0.98	7.15	54.4
DL-1-84	84	8.20	5220	708	1290	18.2	18.1	26.0	846	205	0	1440	59.36	60.56	0.98	7.61	56.1
DL-1-85	85	7.86	5370	730	1290	18.0	18.2	28.0	860	179	0	1450	59.47	60.85	0.98	7.23	55.0
DL-1-86	86	7.83	5310	730	1240	17.0	17.4	27.1	850	194	0	1410	57.15	60.23	0.95	7.17	58.0
DL-1-87	87	7.51	5380	740	1235	15.5	16.3	25.4	840	193	0	1430	56.72	60.38	0.94	7.14	40.7
DL-1-88	88	7.49	5400	760	1240	16.6	17.7	27.9	850	193	0	1450	57.21	61.23	0.93	7.25	127.0
DL-1-89	89	7.53	5370	690	1280	16.0	17.4	27.3	780	201	0	1530	58.88	59.87	0.98	7.32	420.0
DL-1-90	90	7.59	5420	710	1280	17.1	18.3	28.7	800	199	0	1560	59.05	61.13	0.97	7.24	347.0
DL-1-91	91	7.54	5400	730	1250	16.8	17.6	27.5	810	202	0	1550	57.62	61.56	0.94	7.29	433.0
DL-1-92	92	7.47	5430	740	1220	16.5	17.2	26.8	810	208	0	1530	56.24	61.48	0.91	7.22	586.0
DL-1-93	93	7.51	5440	750	1210	16.5	17.3	26.9	810	218	0	1520	55.82	61.65	0.91	7.26	548.0
DL-1-94	94	7.64	5440	780	1230	16.8	17.9	28.4	830	226	0	1520	56.82	62.76	0.91	7.24	351.0
DL-1-95	95	7.39	5500	780	1240	16.2	17.0	26.5	830	225	0	1530	57.07	62.90	0.91	7.41	762.0
DL-1-96	96	7.63	5640	780	1350	18.3	20.5	33.2	820	186	0	1530	62.53	61.81	1.01	7.32	191.0
DL-1-97	97	7.68	5620	780	1330	18.1	20.0	31.8	820	166	0	1610	61.55	62.70	0.98	7.24	200.0
DL-1-98	98	8.37	5540	770	1310	18.0	19.3	24.1	810	170	0	1410	60.23	59.10	1.02	7.64	187.0
DL-1-99	99	8.40	5450	750	1340	18.7	19.0	16.8	790	249	0	1340	61.16	58.78	1.04	7.58	160.0
DL-1-100	100	7.98	5570	750	1310	18.0	18.2	27.6	780	142	0	1590	60.31	60.37	1.00	7.87	49.6
DL-1-101	101	7.90	5620	760	1340	18.0	18.8	28.4	790	140	0	1560	61.71	60.24	1.02	7.82	48.7
DL-1-102	102	8.03	5640	770	1370	18.4	19.3	29.2	800	128	0	1590	63.11	60.89	1.04	7.71	43.9
DL-1-103	103	7.85	5600	770	1190	16.5	17.8	26.7	790	140	0	1550	54.98	60.21	0.91	7.65	38.3
DL-1-104	104	7.98	5630	790	1220	17.2	18.7	28.4	800	133	0	1560	56.46	60.75	0.93	7.50	44.9
DL-1-105	105	7.95	5650	800	1230	17.3	19.0	29.3	800	157	0	1560	56.97	61.38	0.93	7.59	43.2
DL-1-106	106	7.90	5670	810	1230	17.2	18.8	28.8	800	191	0	1520	56.93	61.56	0.92	7.45	47.6
DL-1-107	107	7.78	5690	820	1250	17.3	18.8	29.2	760	209	0	1490	57.82	60.44	0.96	7.34	58.2

A5 Results of chemical analysis in DL-1 system (sample type: RelW) (cont'd)

Sample ID	Incub. Time (d)	pH	Cond	Br^+	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	SO_4^{2-}	CO_3^{2-} (wt ppm)	HCO_3^- (wt ppm)	Total Cations	Total Anions	Ratio Cat/Ani	ALK pH	S^{2-}
DL-1-108	108	7.78	5710	830	1260	17.3	19.6	30.7	770	220	0	1510	58.39	61.40	0.95	7.28	63.1
DL-1-109	109	7.69	5740	830	1260	17.7	19.9	31.2	760	248	0	1440	58.45	60.56	0.97	7.40	111.0
DL-1-110	110	8.07	5230	830	1240	17.4	19.1	29.3	760	221	0	1480	57.42	60.65	0.95	7.40	156.0
DL-1-111	111	7.98	5750	840	1210	17.2	18.6	26.7	760	146	0	1500	55.93	59.54	0.94	7.42	162.0
DL-1-112	112	7.86	5860	850	1170	16.2	17.9	27.5	760	97	0	1550	54.15	59.46	0.91	7.84	58.9
DL-1-113	113	7.64	5880	770	1210	16.4	17.8	27.6	720	140	0	1570	55.89	58.56	0.95	7.61	330.0
DL-1-114	114	7.68	5860	810	1250	17.7	19.3	30.3	750	267	0	1440	57.93	60.42	0.96	7.15	106.0
DL-1-115	115	7.54	5860	810	1240	17.0	18.3	28.5	750	216	0	1460	57.30	59.69	0.96	7.23	278.0
DL-1-116	116	7.49	5860	820	1250	17.8	19.6	30.8	750	184	0	1540	57.98	60.46	0.96	7.27	302.0
DL-1-117	117	8.06	5600	820	1280	17.3	19.1	23.8	750	151	111	1440	58.88	61.83	0.95	8.54	173.0
DL-1-118	118	7.89	5590	820	1220	15.7	17.4	22.9	750	149	0	1520	56.04	59.40	0.94	7.56	41.2
DL-1-119	119	7.66	5640	820	1280	16.7	19.1	30.2	750	213	0	1510	59.18	60.57	0.98	7.53	74.0
DL-1-120	120	8.22	5690	870	1280	17.1	19.5	23.7	750	254	0	1510	58.90	62.05	0.95	7.63	66.4
DL-1-121	121	7.91	5670	840	1300	17.5	19.5	29.4	730	245	0	1500	60.07	60.76	0.99	7.73	94.9
DL-1-122	122	8.21	5670	860	1360	18.0	20.3	26.3	750	244	0	1510	62.60	61.71	1.01	7.62	113.0
DL-1-123	123	8.15	5670	860	1320	17.9	20.5	28.8	750	239	0	1540	61.00	62.10	0.98	7.91	221.0

A6 Results of chemical analysis in DL-2 system (sample type: RelW)

Sample ID	Incub. Time (d)	pH	Cond	Br^+	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	SO_4^{2-}	CO_3^{2-} (wt ppm)	HCO_3^- (wt ppm)	Total Cations	Total Anions	Ratio Cat/Ani	ALK pH	S^{2-}
DL-2-5	5	8.10	4020	0.01	1110	16.3	14.2	21.5	800	32.1	0	1540	50.94	48.45	1.05	8.05	10.10
DL-2-7	7	7.92	3960	0.01	1140	16.3	14.6	22.1	790	22.6	0	1550	52.30	48.13	1.09	7.82	8.96
DL-2-8	8	7.93	3930	0.01	1130	16.7	14.9	22.7	780	9.7	0	1580	51.94	48.08	1.08	7.85	5.40
DL-2-9	9	8.10	4030	0.01	1120	16.4	14.8	22.7	800	7.0	0	1580	51.48	48.58	1.06	8.15	4.83
DL-2-10	10	7.92	4070	0.01	1160	16.9	15.2	23.3	800	5.2	0	1580	53.30	48.55	1.10	7.91	4.24
DL-2-11	11	7.90	3990	0.01	1130	16.3	14.8	22.6	800	4.6	0	1590	51.91	48.70	1.07	7.78	4.04
DL-2-12	12	7.90	4070	0.01	1140	16.5	14.9	22.7	800	3.9	0	1580	52.36	48.52	1.08	7.95	3.95
DL-2-13	13	7.93	3990	0.01	1140	16.4	14.9	22.7	800	3.5	0	1580	52.36	48.51	1.08	7.87	3.85
DL-2-14	14	7.83	4040	0.01	1130	16.2	14.7	22.5	800	3.3	0	1620	51.90	49.16	1.06	7.84	3.76
DL-2-15	15	7.92	4040	0.01	1140	16.3	14.8	22.6	800	3.2	0	1590	52.35	48.67	1.08	7.93	3.69
DL-2-16	16	7.90	4080	0.01	1130	16.1	14.5	22.2	800	2.1	0	1560	51.86	48.15	1.08	8.06	3.58
DL-2-17	17	7.85	3990	0.01	1145	17.0	15.3	23.4	800	1.9	0	1580	52.66	48.48	1.09	8.13	3.53
DL-2-18	18	7.88	4080	0.01	1140	16.5	14.8	22.6	800	2.1	0	1580	52.35	48.48	1.08	8.11	3.58
DL-2-19	19	8.03	4210	0.01	1090	15.7	14.6	13.3	850	2.7	0	1580	49.68	49.90	1.00	8.01	5.67
DL-2-20	20	8.10	4300	0.01	1100	15.7	14.6	21.5	870	2.1	0	1580	50.52	50.45	1.00	7.91	5.09
DL-2-21	21	8.06	4300	0.01	1100	20.0	14.3	22.1	870	2.4	0	1520	50.64	49.48	1.02	8.12	4.13
DL-2-22	22	8.28	4140	0.01	1140	17.0	15.3	23.7	880	2.8	0	1600	52.46	51.08	1.03	7.83	3.86
DL-2-23	23	7.96	4320	0.01	1100	16.0	15.0	23.1	870	4.1	0	1620	50.64	51.15	0.99	7.75	4.50
DL-2-24	24	7.78	4320	0.01	1180	17.6	16.1	24.9	870	1.9	0	1600	54.34	50.78	1.07	7.63	3.60
DL-2-25	25	7.88	4290	0.01	1120	16.5	15.2	23.7	850	2.9	0	1600	51.57	50.23	1.03	7.77	3.83
DL-2-26	26	7.84	4300	0.01	1120	16.3	15.1	23.4	870	4.7	0	1590	51.54	50.67	1.02	7.71	4.41
DL-2-27	27	7.83	4310	1.70	1180	16.8	15.2	23.6	850	14.9	0	1590	54.18	50.34	1.08	7.76	6.01
DL-2-28	28	7.69	4350	0.01	1100	15.6	14.3	21.9	850	14.1	0	1590	50.51	50.30	1.00	7.69	6.81
DL-2-29	29	7.66	4410	0.01	1110	15.8	14.6	22.3	850	20.3	0	1600	51.00	50.60	1.01	7.63	8.92
DL-2-30	30	7.74	4370	0.01	1120	15.9	14.7	22.5	850	29.8	0	1590	51.45	50.63	1.02	7.75	11.60
DL-2-31	31	7.73	4420	0.01	1130	15.8	14.8	22.6	850	41.0	0	1600	51.90	51.03	1.02	7.62	15.50

A6 Results of chemical analysis in DL-2 system (sample type: RelW) (cont'd)

Sample ID	Incub. Time (d)	pH	Cond	Br^{+}	Na^{+}	K^{+}	Mg^{2+}	Ca^{2+}	Cl^{-}	SO_4^{2-}	CO_3^{2-} (wt ppm)	HCO_3^{-} (wt ppm)	Total Cations	Total Anions	Ratio Cat/Ani	ALK pH	S^{2-}
DL-2-32	32	7.71	4340	0.01	1090	15.1	14.2	21.6	860	51.2	0	1590	50.04	51.36	0.97	7.62	17.60
DL-2-33	33	7.69	4480	0.01	1110	13.7	13.2	20.0	840	64.9	0	1590	50.71	51.08	0.99	7.64	20.30
DL-2-34	34	7.69	4500	0.01	1110	15.6	15.4	23.6	887	119.0	0	1590	51.12	53.53	0.96	7.67	31.80
DL-2-35	35	7.66	4480	0.01	1160	16.7	16.3	25.1	897	105.0	0	1590	53.48	53.52	1.00	7.80	36.50
DL-2-36	36	7.67	4470	0.01	1130	16.3	15.8	24.3	884	116.0	0	1590	52.08	53.38	0.98	7.79	39.60
DL-2-37	37	7.62	4510	0.01	1150	16.4	16.2	25.0	894	140.0	0	1590	53.02	54.17	0.98	7.77	46.90
DL-2-38	38	7.51	4550	0.01	1180	17.0	16.8	25.7	882	166.0	0	1580	54.43	54.21	1.00	7.70	56.90
DL-2-39	39	7.52	4560	0.01	1170	16.8	16.6	25.4	900	165.0	0	1600	53.95	55.02	0.98	7.73	55.80
DL-2-40	40	7.61	4560	0.01	1160	15.8	15.2	23.6	884	169.0	0	1580	53.29	54.32	0.98	7.72	53.40
DL-2-41	41	7.75	4480	0.01	1150	16.6	16.5	25.4	900	226.0	0	1590	53.07	56.13	0.95	7.77	65.30
DL-2-42	42	7.73	4440	0.01	1170	17.0	16.8	25.8	860	184.0	0	1520	54.00	52.98	1.02	7.75	64.10
DL-2-43	43	7.85	4550	0.01	1140	16.7	16.5	25.4	860	195.0	0	1600	52.64	54.52	0.97	7.89	65.90
DL-2-44	44	7.94	4560	0.01	1190	17.0	17.1	26.3	880	211.0	0	1600	54.92	55.55	0.99	7.87	71.20
DL-2-45	45	7.80	4540	0.00	1150	16.7	16.2	25.1	880	220.0	0	1610	53.03	55.77	0.95	7.68	70.70
DL-2-46	46	7.84	4570	0.00	1150	16.5	16.4	25.2	880	223.0	0	1610	53.05	55.83	0.95	7.76	71.00
DL-2-47	47	7.82	4580	0.00	1190	15.8	15.7	24.2	870	234.0	0	1620	54.66	55.94	0.98	7.97	71.40
DL-2-48	48	7.95	4660	0.00	1190	16.4	16.6	26.0	880	257.0	0	1610	54.84	56.54	0.97	7.74	80.50
DL-2-49	49	8.09	4680	0.00	1200	16.4	16.6	26.0	880	267.0	0	1630	55.28	57.07	0.97	8.29	79.70
DL-2-50	50	7.95	4720	0.00	1210	15.6	16.7	25.8	870	298.0	0	1620	55.69	57.27	0.97	7.70	86.50
DL-2-51	51	7.73	4720	0.00	1160	15.6	17.1	26.3	870	306.0	0	1610	53.57	57.28	0.94	7.59	91.80
DL-2-52	52	7.77	4760	0.00	1180	15.7	17.9	27.5	870	320.0	0	1600	54.57	57.40	0.95	7.72	97.40
DL-2-53	53	7.63	4800	0.00	1180	16.1	18.6	28.4	870	335.0	0	1620	54.69	58.04	0.94	7.36	100.00
DL-2-54	54	7.58	4830	0.00	1190	16.1	19.2	29.3	870	350.0	0	1610	55.22	58.19	0.95	7.37	107.00
DL-2-55	55	7.66	4870	0.00	1320	18.6	22.5	34.9	840	451.0	0	1600	61.49	59.29	1.04	7.35	149.00
DL-2-56	56	7.80	4870	0.00	1360	18.7	22.9	19.9	830	472.0	0	1550	62.51	58.62	1.07	7.78	156.00
DL-2-57	57	7.80	4890	0.00	1340	18.8	24.0	36.5	830	492.0	0	1580	62.57	59.53	1.05	7.36	162.00

A6 Results of chemical analysis in DL-2 system (sample type: RelW) (cont'd)

Sample ID	Incub. Time (d)	pH	Cond	Br^+	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	SO_4^{2-}	CO_3^{2-} (wt ppm)	HCO_3^- (wt ppm)	Total Cations	Total Anions	Ratio Cat/Ani	ALK pH	S^{2-}
DL-2-58	58	7.64	4900	0.00	1320	18.9	25.2	37.8	830	520.0	0	1540	61.87	59.46	1.04	7.37	169.00
DL-2-59	59	7.64	4960	0.00	1330	19.4	26.4	39.3	830	545.0	0	1540	62.49	59.98	1.04	7.59	182.00
DL-2-60	60	7.56	4980	0.00	1360	19.5	27.5	40.7	830	590.0	0	1510	63.96	60.43	1.06	7.39	194.00
DL-2-61	61	7.58	5040	0.00	1320	19.7	28.9	42.4	800	605.0	0	1520	62.42	60.06	1.04	7.35	201.00
DL-2-62	62	7.83	4940	0.00	1330	19.7	29.3	38.1	850	600.0	0	1470	62.68	60.54	1.04	7.23	200.00
DL-2-63	63	8.03	4930	0.00	1340	19.9	30.1	36.5	850	595.0	0	1480	63.10	60.60	1.04	7.16	199.00
DL-2-64	64	7.75	4890	0.00	1330	20.2	31.0	39.4	850	625.0	0	1530	62.90	62.05	1.01	7.17	205.00
DL-2-65	65	7.92	4900	0.00	1350	20.5	31.8	34.7	860	635.0	0	1480	63.61	61.72	1.03	7.36	208.00
DL-2-66	66	7.81	4940	0.00	1320	20.2	32.7	35.6	850	640.0	0	1490	62.41	61.70	1.01	7.26	214.00
DL-2-67	67	7.56	5070	0.00	1370	21.1	36.3	46.2	850	695.0	0	1460	65.44	62.36	1.05	7.44	230.00
DL-2-68	68	7.90	5070	0.00	1360	21.3	37.5	41.8	850	680.0	0	1510	64.89	62.86	1.03	7.22	225.00
DL-2-69	69	8.19	5140	0.00	1320	19.3	33.4	34.5	850	442.0	0	1590	62.39	59.22	1.05	7.93	187.00
DL-2-70	70	7.85	5270	0.00	1310	19.8	34.9	35.6	850	457.0	0	1640	62.15	60.35	1.03	7.32	146.00
DL-2-71	71	8.07	5190	0.00	1350	20.1	35.4	36.9	850	435.0	0	1640	64.01	59.89	1.07	7.43	200.00
DL-2-72	72	7.98	5200	0.00	1340	19.6	35.0	37.8	840	556.0	0	1540	63.57	60.49	1.05	7.64	165.00
DL-2-73	73	8.10	5230	0.00	1360	20.4	36.0	41.5	840	432.0	0	1620	64.73	59.22	1.09	7.37	272.00
DL-2-74	74	7.61	5310	0.00	1330	19.4	36.0	45.0	830	548.0	0	1720	63.57	62.99	1.01	7.47	141.00
DL-2-75	75	7.68	5300	0.00	1330	18.1	34.6	39.6	820	647.0	0	1650	63.15	63.63	0.99	7.34	141.00
DL-2-76	76	8.03	5250	0.00	1320	18.4	36.8	40.0	820	549.0	0	1690	62.93	62.24	1.01	7.47	225.00
DL-2-77	77	7.69	5300	0.00	1320	18.5	38.0	47.6	820	585.0	0	1790	63.41	64.63	0.98	7.94	695.00
DL-2-78	78	7.75	5350	0.00	1330	18.7	38.7	47.8	830	563.0	0	1800	63.92	64.62	0.99	7.95	766.00
DL-2-79	79	7.71	5340	0.00	1330	19.2	39.7	48.7	830	540.0	0	1780	64.06	63.81	1.00	8.02	874.00
DL-2-80	80	7.81	5320	0.00	1315	20.0	42.5	52.2	810	528.0	0	1810	63.84	63.49	1.01	7.99	706.00
DL-2-81	81	8.07	5240	0.00	1335	19.7	41.0	47.8	830	612.0	0	1610	64.36	62.52	1.03	7.36	245.00
DL-2-82	82	7.46	5420	0.00	1320	18.3	40.8	48.3	800	567.0	0	1800	63.68	63.86	1.00	8.11	1020.00
DL-2-83	83	7.71	5540	0.00	1330	22.2	50.1	51.0	780	560.0	0	1760	65.12	62.49	1.04	7.55	207.00

A6 Results of chemical analysis in DL-2 system (sample type: RelW) (cont'd)

Sample ID	Incub. Time (d)	pH	Cond	Br^+	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	SO_4^{2-}	CO_3^{2-} (wt ppm)	HCO_3^- (wt ppm)	Total Cations	Total Anions	Ratio Cat/Ani	ALK pH	S^{2-}
DL-2-84	84	7.76	5610	0.00	1330	22.3	50.6	50.1	780	506.0	0	1810	65.12	62.19	1.05	7.72	195.00
DL-2-85	85	7.66	5610	0.00	1320	22.0	48.6	46.9	790	565.0	0	1830	64.35	64.03	1.01	7.98	212.00
DL-2-86	86	8.03	5380	0.00	1340	23.2	45.7	48.4	780	567.0	0	1590	65.08	59.85	1.09	7.46	427.00
DL-2-87	87	8.13	5290	0.00	1320	21.5	43.2	47.9	780	528.0	0	1630	63.94	59.69	1.07	7.66	437.00
DL-2-88	88	7.52	5580	0.00	1320	21.9	47.8	54.5	740	510.0	0	1870	64.66	62.13	1.04	7.95	186.00
DL-2-89	89	7.51	5600	0.00	1340	22.2	50.9	57.7	770	535.0	0	1770	65.96	61.85	1.07	8.43	398.00
DL-2-90	90	7.66	5600	0.00	1210	20.4	50.4	46.0	750	389.0	0	1830	59.63	59.23	1.01	7.93	271.00
DL-2-91	91	7.61	5630	0.00	1200	20.4	49.4	48.2	770	421.0	0	1820	59.22	60.30	0.98	7.79	364.00
DL-2-92	92	7.68	5620	0.00	1250	19.2	44.9	41.7	760	393.0	0	1840	60.67	59.76	1.02	7.88	199.00
DL-2-93	93	8.13	5530	0.00	1270	22.2	50.0	40.9	760	545.0	0	1580	62.00	58.67	1.06	7.26	387.00
DL-2-94	94	8.15	5450	0.00	1210	21.2	45.5	36.0	760	520.0	0	1630	58.74	58.96	1.00	7.58	275.00
DL-2-95	95	7.96	5560	0.00	1230	20.6	44.4	32.7	760	458.0	0	1720	59.34	59.15	1.00	7.56	287.00
DL-2-96	96	7.69	5620	0.00	1260	19.2	42.0	42.2	760	347.0	0	1810	60.88	58.31	1.04	7.72	521.00
DL-2-97	97	7.98	5690	0.00	1210	20.0	44.9	40.3	740	268.0	0	1890	58.88	57.41	1.03	8.13	411.00
DL-2-98	98	7.96	5710	0.00	1180	19.9	45.0	38.5	750	286.0	0	1860	57.49	57.58	1.00	8.15	570.00
DL-2-99	99	7.76	5740	0.00	1230	21.1	48.7	45.8	750	305.0	0	1860	60.37	57.97	1.04	8.26	767.00
DL-2-100	100	7.71	5750	0.00	1220	20.7	47.3	48.1	750	344.0	0	1840	59.92	58.46	1.03	8.14	1090.00
DL-2-101	101	7.73	5830	0.00	1220	21.1	50.8	46.1	740	362.0	0	1820	60.12	58.22	1.03	8.15	697.00
DL-2-102	102	7.59	5850	0.00	1220	21.5	53.5	56.9	740	414.0	0	1770	60.90	58.49	1.04	8.15	841.00
DL-2-103	103	7.52	5900	0.00	1220	21.6	56.6	63.9	740	450.0	0	1790	61.51	59.57	1.03	8.20	1150.00
DL-2-104	104	7.79	5600	0.00	1290	22.3	62.9	56.3	750	493.0	0	1850	64.72	61.73	1.05	7.87	1030.00
DL-2-105	105	7.79	5650	0.00	1320	22.7	64.1	54.8	740	520.0	0	1810	66.06	61.35	1.08	7.80	934.00
DL-2-106	106	7.89	5630	0.00	1310	22.7	64.6	48.1	730	528.0	0	1820	65.33	61.40	1.06	7.83	764.00
DL-2-107	107	7.84	5650	0.00	1300	22.2	63.5	53.0	740	536.0	0	1770	65.03	61.03	1.07	7.85	862.00
DL-2-108	108	7.81	5690	0.00	1320	23.0	65.1	56.6	730	520.0	0	1810	66.24	61.07	1.08	7.89	676.00
DL-2-109	109	7.78	5680	0.00	1290	21.7	59.3	56.9	740	505.0	0	1860	64.43	61.86	1.04	7.72	1010.00
DL-2-110	110	7.83	5610	0.00	1320	23.0	61.8	48.3	740	545.0	0	1820	65.55	62.04	1.06	7.83	678.00

A7 Results of chemical analysis in DL-3 system (sample type: RelW)

Sample ID	Incub. Time (d)	pH	Cond	Br^+	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	SO_4^{2-}	CO_3^{2-} (wt ppm)	HCO_3^- (wt ppm)	Total Cations	Total Anions	Ratio Cat/Ani	ALK pH	S^{2-}
DL-3-3	3	8.07	5720	5	1021	15.4	14.2	21.0	830	41.1	0.0	1510	47.0	49.1	0.96	7.64	15.80
DL-3-4	4	8.06	5900	9	1021	15.7	13.9	20.6	820	36.9	0.0	1510	47.0	48.7	0.96	7.70	15.30
DL-3-5	5	7.78	5910	1	1027	15.1	14.1	21.3	830	14.3	0.0	1550	47.3	49.1	0.96	7.48	7.37
DL-3-6	6	7.79	5630	1	1030	15.4	14.2	21.5	830	14.3	0.0	1590	47.4	49.8	0.95	7.57	7.42
DL-3-7	7	7.80	5630	1	1030	15.1	14.1	21.3	820	14.2	0.0	1520	47.4	48.3	0.98	7.53	7.55
DL-3-8	8	7.79	5830	1	1035	15.1	14.1	21.3	830	15.4	0.0	1550	47.6	49.1	0.97	7.57	7.60
DL-3-9	9	7.78	5780	1	1045	14.9	14.1	21.2	830	14.4	0.0	1550	48.1	49.1	0.98	7.58	7.67
DL-3-10	10	7.78	5600	1	1045	15.0	14.1	21.3	840	17.3	0.0	1520	48.1	49.0	0.98	7.47	7.68
DL-3-11	11	7.90	5510	1	1060	14.9	14.1	21.2	830	13.8	0.0	1550	48.7	49.1	0.99	7.60	7.47
DL-3-12	12	7.90	5610	1	1090	16.1	15.4	23.9	830	14.2	0.0	1530	50.3	48.8	1.03	7.57	7.59
DL-3-13	13	7.79	5490	6	1100	16.1	15.3	23.7	830	5.0	0.0	1560	50.7	49.1	1.03	7.57	6.71
DL-3-14	14	7.77	5410	5	1120	16.3	15.2	23.4	830	11.9	0.0	1560	51.6	49.3	1.05	7.50	6.83
DL-3-15	15	7.65	5090	5	1110	16.1	14.8	22.6	830	13.7	0.0	1580	51.0	49.6	1.03	7.48	6.91
DL-3-16	16	7.77	5060	5	1100	16.4	14.7	22.5	830	11.3	0.0	1550	50.6	49.1	1.03	7.59	6.62
DL-3-17	17	7.77	5111	6	1110	16.2	14.7	22.4	830	9.8	0.0	1560	51.0	49.2	1.04	7.60	6.43
DL-3-19	19	7.82	5300	6	1130	16.5	14.7	22.5	830	8.2	0.0	1560	51.9	49.2	1.05	7.69	6.25
DL-3-20	20	7.82	5280	6	1110	16.2	14.6	22.2	840	10.5	0.0	1550	51.0	49.4	1.03	8.02	6.14
DL-3-21	21	7.83	5140	6	1120	16.3	14.7	22.4	840	9.8	0.0	1620	51.5	50.5	1.02	7.70	6.11
DL-3-22	22	7.84	5160	6	1110	16.1	14.7	22.3	850	6.9	0.0	1570	51.0	49.9	1.02	7.70	6.12
DL-3-23	23	8.04	4630	5	1100	15.8	15.6	24.5	780	8.7	0.0	1630	50.8	48.9	1.04	7.75	5.50
DL-3-24	24	8.06	4740	6	1090	15.9	15.3	23.9	780	8.6	0.0	1600	50.3	48.5	1.04	7.78	5.54
DL-3-25	25	8.05	4640	9	1100	16.3	15.6	24.3	780	7.6	0.0	1590	50.8	48.3	1.05	7.68	5.10
DL-3-26	26	8.03	4490	9	1120	16.5	15.4	23.8	790	5.0	0.0	1630	51.6	49.2	1.05	7.75	5.16
DL-3-27	27	8.01	4580	9	1115	16.8	15.4	23.7	790	5.2	0.0	1590	51.4	48.5	1.06	7.80	5.19
DL-3-28	28	7.99	4500	13	1120	16.5	15.3	23.6	800	5.3	0.0	1590	51.6	48.9	1.06	7.74	5.27
DL-3-29	29	7.86	4780	14	1040	14.8	13.2	19.7	800	6.4	0.0	1650	47.7	49.9	0.96	7.69	5.56

A7 Results of chemical analysis in DL-3 system (sample type: RelW) (cont'd)

Sample ID	Incub. Time (d)	pH	Cond	Br^+	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	SO_4^{2-}	CO_3^{2-} (wt ppm)	HCO_3^- (wt ppm)	Total Cations	Total Anions	Ratio Cat/Ani	ALK pH	S^{2-}
DL-3-30	30	7.87	4820	15	1060	14.8	13.1	19.4	800	6.7	0.0	1590	48.5	48.9	0.99	7.76	5.20
DL-3-31	31	7.86	4790	15	1030	14.6	12.9	19.1	800	6.3	0.0	1590	47.2	48.9	0.96	7.73	5.09
DL-3-32	32	7.85	4820	16	1090	15.5	14.1	21.1	810	6.4	0.0	1580	50.0	49.1	1.02	7.76	5.38
DL-3-33	33	7.89	4780	15	1090	15.7	14.7	22.4	810	6.5	0.0	1590	50.1	49.2	1.02	7.68	5.41
DL-3-34	34	7.93	4800	16	1070	15.3	14.0	21.2	810	6.7	0.0	1620	49.1	49.7	0.99	7.72	5.30
DL-3-35	35	7.91	4790	16	1070	14.8	13.4	20.0	810	6.7	0.0	1580	49.0	49.1	1.00	7.77	5.25
DL-3-36	36	7.95	4800	17	1060	15.1	13.9	20.4	810	7.0	0.0	1580	48.7	49.1	0.99	7.71	5.62
DL-3-37	37	7.96	4780	17	1060	14.9	13.5	20.2	820	6.6	0.0	1590	48.6	49.5	0.98	7.74	5.12
DL-3-38	38	7.78	4840	48	1130	15.3	14.4	22.2	820	28.3	0.0	1620	51.8	50.8	1.02	7.71	10.00
DL-3-39	39	7.78	4810	46	1110	15.1	14.3	21.9	820	22.4	0.0	1620	50.9	50.7	1.00	8.37	9.72
DL-3-40	40	7.83	4780	47	1100	15.2	14.4	22.0	820	26.7	0.0	1600	50.5	50.5	1.00	7.66	11.00
DL-3-41	41	7.78	4790	48	1120	15.4	14.6	22.5	820	25.7	0.0	1580	51.4	50.1	1.03	7.70	11.20
DL-3-42	42	7.85	4790	47	1090	13.4	12.5	18.8	820	26.5	0.0	1580	49.7	50.1	0.99	7.73	10.50
DL-3-43	43	7.86	4770	47	1100	15.4	14.6	22.4	820	25.5	0.0	1590	50.6	50.3	1.01	7.75	11.40
DL-3-44	44	7.85	4800	50	1110	15.3	14.9	23.0	850	34.7	0.0	1590	51.0	51.4	0.99	7.65	11.90
DL-3-45	45	7.89	4800	51	1100	15.1	14.2	21.8	860	27.3	0.0	1580	50.5	51.3	0.98	7.67	11.50
DL-3-46	46	7.94	4810	49	1080	13.9	12.8	19.5	870	29.3	0.0	1580	49.4	51.6	0.96	7.69	11.00
DL-3-47	47	7.88	4800	49	1060	14.4	13.3	20.3	860	26.1	0.0	1590	48.6	51.4	0.94	7.74	10.80
DL-3-48	48	7.96	4790	49	1060	14.9	13.5	20.6	860	27.4	0.0	1590	48.6	51.5	0.94	7.78	10.80
DL-3-49	49	7.96	4770	49	1080	15.0	13.7	21.0	850	26.0	0.0	1640	49.5	52.0	0.95	7.81	10.40
DL-3-50	50	7.93	4890	50	1110	14.6	12.9	19.3	870	22.6	0.0	1620	50.7	52.2	0.97	7.77	10.30
DL-3-51	51	7.94	4860	49	1090	15.9	14.1	21.4	860	19.3	0.0	1600	50.0	51.5	0.97	7.79	9.87
DL-3-52	52	7.88	4870	51	1090	15.7	14.0	21.3	860	17.6	0.0	1590	50.0	51.3	0.98	7.78	8.10
DL-3-53	53	7.86	4880	73	1080	15.6	13.9	21.3	850	21.1	0.0	1600	49.6	51.5	0.96	7.72	9.75
DL-3-54	54	7.84	4890	74	1080	15.5	13.9	21.1	850	20.2	0.0	1600	49.6	51.5	0.96	7.77	9.77
DL-3-55	55	7.83	4930	77	1080	15.1	14.2	22.2	840	41.9	0.0	1580	49.6	51.4	0.97	7.74	17.30

A7 Results of chemical analysis in DL-3 system (sample type: RelW) (cont'd)

Sample ID	Incub. Time (d)	pH	Cond	Br^{+}	Na^{+}	K^{+}	Mg^{2+}	Ca^{2+}	Cl^{-}	SO_4^{2-}	CO_3^{2-} (wt ppm)	HCO_3^{-} (wt ppm)	Total Cations	Total Anions	Ratio Cat/Ani	ALK pH	S^{2-}
DL-3-56	56	7.77	4900	79	1040	14.9	13.6	20.8	850	44.2	0.0	1570	47.8	51.6	0.93	7.72	16.80
DL-3-57	57	7.82	4920	81	1050	15.1	13.8	21.0	860	51.5	0.0	1580	48.2	52.2	0.92	7.70	17.60
DL-3-58	58	7.80	4870	84	1040	15.0	13.7	20.9	840	50.4	0.0	1600	47.8	52.0	0.92	7.65	17.70
DL-3-59	59	7.79	4960	89	1140	15.1	13.6	20.3	900	48.2	0.0	1580	52.1	53.4	0.98	7.72	20.80
DL-3-60	60	7.83	4930	86	1130	14.8	13.4	20.0	890	49.6	0.0	1570	51.6	52.9	0.98	7.89	17.60
DL-3-61	61	7.83	4950	95	1140	14.7	13.4	20.1	890	50.5	0.0	1570	52.1	53.0	0.98	7.76	18.60
DL-3-62	62	7.93	4920	91	1120	14.1	12.7	18.9	880	52.5	0.0	1590	51.1	53.1	0.96	7.87	17.90
DL-3-63	63	7.93	4910	94	1120	13.2	12.1	18.0	890	60.8	0.0	1570	50.9	53.2	0.96	7.83	18.80
DL-3-64	64	7.87	4920	97	1140	15.0	14.3	22.4	870	65.0	0.0	1610	52.3	53.5	0.98	7.75	21.20
DL-3-65	65	7.24	5190	88	1140	16.1	15.8	23.4	830	51.8	29.7	1545	52.5	51.9	1.01	8.42	22.90
DL-3-66	66	7.76	5150	88	1150	15.6	14.9	22.8	820	49.4	26.7	1510	52.8	50.9	1.04	8.39	21.30
DL-3-67	67	7.76	5070	87	1160	15.5	14.8	22.7	830	54.8	26.4	1500	53.2	51.1	1.04	8.39	23.30
DL-3-68	68	7.79	5120	88	1140	15.4	14.7	22.6	840	57.8	38.4	1480	52.3	51.5	1.02	8.45	22.90
DL-3-69	69	7.72	5270	100	1180	15.9	15.1	23.3	845	46.8	16.5	1570	54.1	52.3	1.03	8.36	20.30
DL-3-70	70	7.71	5210	100	1170	15.6	14.9	22.9	825	44.8	21.0	1550	53.7	51.5	1.04	8.38	20.10
DL-3-71	71	7.67	5250	100	1130	15.3	14.7	22.6	810	57.4	38.1	1510	51.9	51.3	1.01	8.45	22.20
DL-3-72	72	7.53	4970	120	1100	16.3	14.8	22.9	830	68.4	0.0	1540	50.6	51.6	0.98	8.18	25.00
DL-3-73	73	7.61	5060	120	1110	15.1	14.5	22.5	820	85.8	0.0	1520	51.0	51.3	0.99	8.28	30.50
DL-3-74	74	7.64	5050	120	1090	14.7	14.0	21.9	830	89.3	0.6	1550	50.0	52.2	0.96	8.33	29.90
DL-3-75	75	7.68	4920	120	1080	14.8	14.1	22.0	820	99	0.0	1540	49.6	51.9	0.96	8.20	33.60
DL-3-76	76	7.97	5090	160	1110	15.3	14.6	22.6	830	140	0.0	1550	51.0	53.7	0.95	7.91	31.30
DL-3-77	77	7.98	5160	170	1120	15.3	14.6	22.6	830	144	0.0	1550	51.4	53.9	0.95	8.16	23.90
DL-3-78	78	8.04	5100	170	1100	14.8	14.3	22.2	830	139	209	1120	50.5	53.7	0.94	9.13	32.20
DL-3-79	79	7.88	5130	180	1120	14.8	14.0	22.0	845	136	0.0	1660	51.3	56.1	0.92	7.96	34.00
DL-3-80	80	7.89	4540	170	1090	15.2	15.1	23.6	860	86.7	0.0	1620	50.2	54.7	0.92	8.30	30.20
DL-3-81	81	7.90	4790	170	1100	15.1	15.0	23.4	870	86.1	0.0	1630	50.6	55.1	0.92	8.33	28.30

A7 Results of chemical analysis in DL-3 system (sample type: RelW) (cont'd)

Sample ID	Incub. Time (d)	pH	Cond	Br^+	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	SO_4^{2-}	CO_3^{2-} (wt ppm)	HCO_3^- (wt ppm)	Total Cations	Total Anions	Ratio Cat/Ani	ALK pH	S^{2-}
DL-3-82	82	7.73	4560	170	1090	14.9	14.7	22.7	870	133	0.0	1550	50.1	54.8	0.91	8.33	44.50
DL-3-83	83	7.75	4930	170	1080	15.2	15.0	23.2	880	130	16.5	1530	49.8	55.3	0.90	8.36	45.30
DL-3-84	84	7.73	5010	170	1080	15.1	14.8	23.0	880	131	20.4	1530	49.7	55.4	0.90	8.36	44.60
DL-3-85	85	7.75	4890	160	1080	15.1	14.8	22.8	840	122	35.1	1500	49.7	54.0	0.92	8.44	39.50
DL-3-86	86	7.79	4730	170	1110	15.9	14.7	22.8	850	115	0.0	1660	51.0	55.7	0.92	8.06	39.60
DL-3-87	87	7.73	4780	180	1100	15.4	14.9	23.1	840	147	0.0	1560	50.6	54.5	0.93	8.02	50.30
DL-3-88	88	7.70	4780	180	1110	15.1	14.7	22.7	830	146	0.0	1550	51.0	54.1	0.94	8.02	49.40
DL-3-89	89	7.72	4800	180	1115	15.2	14.9	22.8	830	205	0.0	1490	51.2	54.3	0.94	8.11	67.00
DL-3-90	90	7.67	4780	180	1115	15.2	14.9	22.8	830	197	0.0	1480	51.2	54.0	0.95	7.98	67.00
DL-3-91	91	7.93	4840	200	1120	15.3	14.8	22.7	830	210	0.0	1545	51.5	55.6	0.93	8.05	71.30
DL-3-92	92	7.95	4820	200	1130	15.6	15.1	23.1	830	190	0.0	1580	51.9	55.7	0.93	8.07	63.70
DL-3-93	93	7.99	4830	200	1130	15.4	15.0	23.4	800	190	0.0	1610	51.9	55.4	0.94	7.86	63.70
DL-3-94	94	7.95	4870	200	1140	15.4	14.9	23.0	800	220	0.0	1600	52.4	55.8	0.94	7.85	75.80
DL-3-95	95	7.82	4930	200	1130	15.8	14.9	22.9	800	210	0.0	1540	51.9	54.7	0.95	7.88	70.90
DL-3-96	96	7.89	4980	200	1140	15.0	16.8	22.3	810	195	0.0	1550	52.5	54.8	0.96	8.03	64.40
DL-3-97	97	7.72	4970	200	1150	16.2	15.1	23.2	790	254	0.0	1430	52.8	53.5	0.99	8.14	98.90
DL-3-98	98	7.67	4980	200	1120	16.0	14.9	23.0	800	263	0.0	1430	51.5	54.0	0.95	8.08	98.50
DL-3-99	99	7.68	4990	200	1140	16.2	15.2	23.4	810	275	0.0	1430	52.4	54.5	0.96	8.14	98.80
DL-3-100	100	7.73	4980	210	1150	15.8	16.0	24.8	810	265	0.0	1500	53.0	55.6	0.95	8.03	86.50
DL-3-101	101	7.74	4970	210	1170	15.8	15.7	24.3	800	245	0.0	1510	53.8	55.0	0.98	8.07	86.90
DL-3-102	102	7.74	4890	250	1160	15.7	15.0	23.2	750	230	0.0	1570	53.2	54.8	0.97	8.14	74.40
DL-3-103	103	7.78	4940	200	1180	15.2	14.9	23.0	770	220	0.0	1580	54.1	54.7	0.99	8.16	73.00
DL-3-104	104	8.16	5090	200	1190	16.3	16.2	23.5	770	359	0.0	1400	54.7	54.6	1.00	7.97	176.00
DL-3-105	105	8.17	5100	250	1210	16.1	16.7	25.3	760	426	0.0	1410	55.7	56.5	0.99	7.96	141.00
DL-3-106	106	8.29	5060	250	1230	16.2	16.5	23.6	770	447	0.0	1410	56.4	57.2	0.99	7.90	147.00
DL-3-107	107	8.32	5030	250	1260	16.4	16.4	22.3	770	449	0.0	1410	57.7	57.3	1.01	7.93	134.00

A7 Results of chemical analysis in DL-3 system (sample type: RelW) (cont'd)

Sample ID	Incub. Time (d)	pH	Cond	Br^+	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	SO_4^{2-}	CO_3^{2-} (wt ppm)	HCO_3^- (wt ppm)	Total Cations	Total Anions	Ratio Cat/Ani	ALK pH	S^{2-}
DL-3-108	108	8.08	5070	260	1250	16.5	16.3	24.2	770	387	0.0	1410	57.3	56.1	1.02	7.97	189.00
DL-3-109	109	8.44	5080	260	1250	16.4	16.1	18.7	770	432	0.0	1390	57.0	56.7	1.01	7.89	386.00
DL-3-110	110	8.16	5090	260	1230	16.5	16.1	24.2	780	485	0.0	1400	56.5	58.3	0.97	7.95	193.00
DL-3-111	111	8.22	5090	260	1240	16.4	16.1	23.3	780	466	0.0	1370	56.8	57.4	0.99	7.88	149.00
DL-3-112	112	8.17	5070	260	1260	16.2	16.0	23.6	790	410	0.0	1440	57.7	57.7	1.00	7.99	211.00
DL-3-113	113	8.13	5140	260	1290	16.0	15.9	23.5	780	373	0.0	1460	59.0	56.9	1.04	8.09	172.00
DL-3-114	114	8.21	5010	210	1310	15.8	15.6	22.7	830	351	0.0	1470	59.8	57.4	1.04	8.13	141.00
DL-3-116	116	8.36	5090	270	1290	16.2	16.1	12.2	820	154	43.2	1570	58.5	56.9	1.03	8.48	161.00
DL-3-117	117	8.67	5240	290	1310	16.3	16.4	9.8	820	269	143.0	1350	59.2	59.2	1.00	8.90	309.00
DL-3-118	118	8.79	5170	280	1310	16.7	16.3	9.3	790	346	85.5	1420	59.2	59.1	1.00	8.75	235.00
DL-3-119	119	8.43	5300	290	1300	16.6	16.5	13.8	810	340	88.2	1430	59.0	59.9	0.99	8.70	115.00
DL-3-120	120	8.60	5220	290	1300	16.4	16.2	9.8	810	220	142.0	1360	58.8	58.1	1.01	8.90	224.00
DL-3-121	121	8.59	5170	280	1320	16.3	17.0	14.3	800	161	83.1	1450	59.9	55.9	1.07	8.71	194.00
DL-3-122	122	8.59	5210	290	1280	16.3	16.7	12.9	800	161	77.4	1460	58.1	56.0	1.04	8.69	262.00
DL-3-123	123	8.59	5010	380	1280	16.0	16.5	16.1	860	342	0.0	1490	58.2	60.5	0.96	7.89	131.00
DL-3-124	124	8.56	5130	370	1260	16.2	16.4	15.9	860	343	0.0	1560	57.4	61.6	0.93	8.19	136.00
DL-3-125	125	8.64	5070	370	1250	16.3	16.3	15.5	870	279	0.0	1490	56.9	59.4	0.96	8.06	146.00
DL-3-126	126	8.54	5140	370	1240	15.9	15.8	15.2	860	231	0.0	1450	56.4	57.4	0.98	7.96	84.30
DL-3-127	127	8.40	5100	370	1230	15.4	15.0	13.9	860	318	0.0	1480	55.8	59.7	0.93	7.86	92.90
DL-3-128	128	8.36	5220	370	1260	16.0	15.6	14.4	860	392	0.0	1480	57.2	61.3	0.93	7.93	108.00
DL-3-129	129	8.25	5090	370	1260	16.1	15.9	16.9	860	464	0.0	1460	57.4	62.5	0.92	8.08	142.00
DL-3-130	130	8.23	5170	360	1300	16.4	16.1	17.1	850	448	0.0	1450	59.1	61.5	0.96	7.84	174.00
DL-3-131	131	8.06	5190	370	1290	16.8	17.0	22.4	850	410	0.0	1450	59.1	60.9	0.97	7.89	148.00
DL-3-132	132	8.04	5180	370	1320	16.8	16.9	22.1	850	425	0.0	1450	60.3	61.2	0.99	7.84	149.00
DL-3-133	133	8.01	5200	380	1310	16.6	16.6	21.8	880	446	0.0	1450	59.9	62.6	0.96	7.86	149.00
DL-3-134	134	8.37	5620	370	1320	20.1	17.0	25.5	860	299	0.0	1530	60.6	60.2	1.01	7.97	178.00

A7 Results of chemical analysis in DL-3 system (sample type: RelW) (cont'd)

Sample ID	Incub. Time (d)	pH	Cond	Br^+	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	SO_4^{2-}	CO_3^{2-} (wt ppm)	HCO_3^- (wt ppm)	Total Cations	Total Anions	Ratio Cat/Ani	ALK pH	S^{2-}
DL-3-135	135	8.41	5630	380	1330	17.4	17.2	25.6	860	325	0.0	1560	61.0	61.3	0.99	8.17	186.00
DL-3-136	136	8.57	5440	380	1320	17.2	16.7	21.5	850	183	0.0	1560	60.3	58.1	1.04	7.82	269.00
DL-3-137	137	8.50	5410	380	1320	17.5	16.8	21.5	840	194	0.0	1550	60.3	57.9	1.04	8.08	268.00
DL-3-138	138	8.59	5400	380	1290	16.0	17.7	23.8	850	182	0.0	1550	59.2	57.9	1.02	7.76	210.00
DL-3-139	139	8.12	5380	380	1320	16.1	17.5	23.3	850	496	0.0	1430	60.4	62.5	0.97	7.93	168.00
DL-3-140	140	8.12	5410	390	1310	16.0	17.3	23.0	850	462	0.0	1430	60.0	61.9	0.97	7.98	170.00

A8 Results of chemical analysis in DL-4 system (sample type: RelW)

Sample ID	Incub. Time (d)	pH	Cond	Br^+	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	SO_4^{2-}	CO_3^{2-} (wt ppm)	HCO_3^- (wt ppm)	Total Cations	Total Anions	Ratio Cat/Ani	ALK pH	S^{2-}
DL-4-3	3	7.95	5480	9	1100	16.4	14.5	21.7	840	32.5	0.0	1470	50.5	48.5	1.04	7.65	13.2
DL-4-4	4	7.83	5340	93	1070	15.9	14.0	21.4	810	139.0	0.0	1300	49.2	48.2	1.02	7.52	51.7
DL-4-5	5	7.81	5320	94	1070	16.0	13.9	21.3	810	140.0	0.0	1280	49.2	47.9	1.03	7.50	52.1
DL-4-6	6	7.93	5400	90	1090	16.3	14.1	21.6	820	138.0	0.0	1300	50.1	48.4	1.03	7.60	49.5
DL-4-7	7	7.93	5320	87	1080	16.0	14.1	21.5	820	135.0	0.0	1280	49.6	48.0	1.03	7.53	49.6
DL-4-8	8	7.91	4980	86	1080	15.9	14.0	21.2	810	129.0	0.0	1300	49.6	47.9	1.04	7.65	48.0
DL-4-9	9	7.89	4980	86	1080	16.0	14.0	21.2	820	130.0	0.0	1300	49.6	48.2	1.03	7.64	48.4
DL-4-10	10	7.94	4970	82	1090	16.1	14.0	21.1	830	125.0	0.0	1310	50.0	48.5	1.03	7.65	45.0
DL-4-11	11	7.94	5000	76	1080	16.1	13.9	21.0	830	106.0	0.0	1340	49.6	48.5	1.02	7.68	39.0
DL-4-12	12	7.94	4990	77	1070	16.0	13.9	21.0	830	105.0	0.0	1340	49.1	48.5	1.01	7.70	39.1
DL-4-13	13	7.95	5020	76	1100	16.1	13.9	21.0	830	105.0	0.0	1350	50.4	48.6	1.04	7.71	39.3
DL-4-14	14	7.84	4990	67	1110	16.0	13.9	21.0	830	69.4	0.0	1460	50.9	49.6	1.03	7.66	26.9
DL-4-15	15	7.84	5000	68	1100	15.9	13.8	20.9	830	69.7	0.0	1410	50.4	48.8	1.03	7.69	26.4
DL-4-16	16	8.12	4510	62	1110	16.6	14.2	21.5	800	58.0	0.0	1480	50.9	48.8	1.04	7.73	24.5
DL-4-17	17	8.12	4510	62	1110	16.3	14.1	21.5	800	57.1	0.0	1510	50.9	49.3	1.03	7.72	24.4
DL-4-18	18	8.12	4540	61	1120	16.7	14.1	21.4	800	47.8	0.0	1530	51.4	49.4	1.04	7.67	20.9
DL-4-19	19	8.15	4380	61	1110	16.5	14.8	22.9	800	47.5	0.0	1540	51.1	49.5	1.03	7.84	21.0
DL-4-20	20	8.16	4520	61	1100	16.0	14.3	22.0	800	47.6	0.0	1550	50.5	49.7	1.02	7.71	20.4
DL-4-21	21	8.09	4470	60	1110	16.2	14.3	21.9	810	43.1	0.0	1510	51.0	49.2	1.04	7.94	18.4
DL-4-22	22	8.08	4720	61	1070	15.7	13.5	20.3	800	41.8	0.0	1450	49.1	47.9	1.02	7.90	17.8
DL-4-23	23	8.14	4720	60	1040	14.7	13.2	20.1	810	38.0	0.0	1460	47.7	48.3	0.99	8.02	15.7
DL-4-24	24	8.14	4700	60	1060	15.5	13.6	20.7	800	38.3	0.0	1450	48.7	47.9	1.02	7.82	16.6
DL-4-25	25	7.99	4690	68	1040	14.9	13.4	20.4	860	22.2	0.0	1460	47.7	49.5	0.96	7.88	11.1
DL-4-26	26	7.98	4680	69	1020	14.4	12.6	19.1	800	22.5	0.0	1460	46.7	47.8	0.98	7.80	10.6
DL-4-27	27	8.00	4690	70	1030	14.6	12.9	19.5	820	22.5	0.0	1510	47.2	49.2	0.96	7.81	10.7
DL-4-28	28	8.00	4730	70	1040	14.8	12.9	19.4	830	23.0	0.0	1460	47.6	48.7	0.98	7.88	10.8

A8 Results of chemical analysis in DL-4 system (sample type: RelW) (cont'd)

Sample ID	Incub. Time (d)	pH	Cond	Br^+	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	SO_4^{2-}	CO_3^{2-} (wt ppm)	HCO_3^- (wt ppm)	Total Cations	Total Anions	Ratio Cat/Ani	ALK pH	S^{2-}
DL-4-29	29	8.04	4710	70	1040	14.9	13.0	19.7	820	22.2	0.0	1460	47.7	48.4	0.99	7.88	10.7
DL-4-30	30	8.06	4680	70	1030	14.8	12.9	19.6	810	22.3	0.0	1460	47.2	48.1	0.98	7.85	10.8
DL-4-31	31	8.06	4640	82	1090	15.1	13.4	20.5	870	24.6	0.0	1570	49.9	51.8	0.96	7.85	10.4
DL-4-32	32	8.14	4660	79	1090	15.0	13.3	20.4	870	25.5	0.0	1450	49.9	49.8	1.00	8.01	10.5
DL-4-33	33	8.17	4650	77	1060	14.3	12.5	19.0	870	23.1	0.0	1470	48.4	50.0	0.97	7.83	9.6
DL-4-34	34	8.14	4660	77	1100	15.0	13.2	20.2	870	22.2	0.0	1460	50.3	49.9	1.01	7.87	10.0
DL-4-35	35	8.13	4650	79	1080	15.1	13.2	20.2	870	18.1	0.0	1470	49.5	50.0	0.99	7.76	8.5
DL-4-36	36	8.09	4700	77	1090	15.1	13.2	20.2	860	18.3	0.0	1490	49.9	50.0	1.00	7.79	8.6
DL-4-37	37	8.05	4370	79	1040	14.6	13.0	20.0	790	16.1	0.0	1440	47.7	47.2	1.01	7.85	8.3
DL-4-38	38	8.03	4620	77	1010	13.7	12.3	18.8	790	16.6	0.0	1450	46.2	47.3	0.98	7.77	8.0
DL-4-39	39	8.11	4620	77	1020	14.3	12.6	19.3	790	15.9	0.0	1470	46.7	47.6	0.98	7.90	8.5
DL-4-40	40	8.05	4580	77	1020	14.2	12.6	19.1	800	15.2	0.0	1450	46.7	47.6	0.98	7.86	8.1
DL-4-41	41	8.13	4680	79	1010	14.1	12.4	18.8	800	14.5	0.0	1440	46.2	47.4	0.98	8.32	8.0
DL-4-42	42	8.18	4610	78	1040	14.7	12.8	19.5	800	13.6	0.0	1460	47.6	47.7	1.00	7.89	8.6
DL-4-43	43	8.12	4400	92	1060	15.1	13.0	19.6	880	19.1	0.0	1465	48.5	50.4	0.96	8.02	8.6
DL-4-44	44	8.11	4680	90	1080	14.9	12.9	19.3	880	17.8	0.0	1450	49.4	50.1	0.99	7.98	8.4
DL-4-45	45	8.06	4680	94	1075	14.4	12.6	19.2	880	12.8	0.0	1440	49.1	49.8	0.99	7.93	7.1
DL-4-46	46	8.00	4690	100	1065	13.8	11.9	17.8	870	10.4	0.0	1460	48.5	49.9	0.97	7.87	6.6
DL-4-47	47	8.03	4670	88	1040	14.4	12.4	18.6	870	13.8	0.0	1440	47.5	49.5	0.96	8.00	6.4
DL-4-48	48	8.06	4560	110	1045	14.7	12.7	19.0	880	13.0	0.0	1440	47.8	50.0	0.96	7.91	7.2
DL-4-49	49	8.04	4720	110	1045	14.6	12.5	18.9	880	13.5	0.0	1450	47.8	50.2	0.95	7.89	7.2
DL-4-50	50	8.07	4690	110	1055	15.0	12.7	19.2	890	13.1	0.0	1420	48.3	50.0	0.97	7.84	7.0
DL-4-51	51	8.09	4660	110	1040	14.7	12.4	18.6	900	13.7	0.0	1450	47.6	50.8	0.94	7.95	6.9
DL-4-52	52	8.17	4670	110	1070	14.9	13.0	20.1	890	11.6	0.0	1430	49.0	50.1	0.98	8.03	7.2
DL-4-53	53	8.12	4670	110	1090	15.2	13.2	20.5	900	11.5	0.0	1430	49.9	50.4	0.99	8.30	7.1
DL-4-54	54	8.15	4700	110	1080	14.9	13.1	20.3	910	11.2	0.0	1420	49.4	50.5	0.98	8.00	7.0

A8 Results of chemical analysis in DL-4 system (sample type: RelW) (cont'd)

Sample ID	Incub. Time (d)	pH	Cond	Br^+	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	SO_4^{2-}	CO_3^{2-} (wt ppm)	HCO_3^- (wt ppm)	Total Cations	Total Anions	Ratio Cat/Ani	ALK pH	S^{2-}
DL-4-55	55	8.14	4700	110	1080	14.9	13.1	20.2	920	11.4	51.0	1330	49.4	51.0	0.97	8.57	7.1
DL-4-56	56	8.12	4710	110	1060	13.0	11.4	17.6	910	11.4	32.7	1190	48.3	47.8	1.01	8.61	6.7
DL-4-57	57	8.01	4690	120	1090	14.9	13.2	20.5	900	8.8	53.7	1290	49.9	50.0	1.00	8.57	5.8
DL-4-58	76	7.90	4830	120	1100	14.6	13.3	20.5	885	10.8	29.4	1360	50.3	49.9	1.01	8.41	6.3
DL-4-59	59	7.89	4930	120	1090	14.5	13.1	20.2	890	5.0	24.0	1380	49.9	50.1	1.00	8.39	6.1
DL-4-60	60	7.95	4970	120	1080	14.6	13.2	20.4	890	5.0	25.2	1390	49.5	50.3	0.98	8.39	6.5
DL-4-61	61	7.95	4950	120	1090	14.8	13.4	20.6	865	11.2	34.5	1360	49.9	49.5	1.01	8.44	6.5
DL-4-62	62	7.91	4990	130	1070	14.3	12.8	19.7	870	10.5	18.0	1390	48.9	49.7	0.98	8.37	6.8
DL-4-63	63	7.90	4900	130	1080	14.5	13.0	19.9	875	6.5	36.9	1320	49.4	49.3	1.00	8.44	6.8
DL-4-64	64	7.99	4940	130	1090	14.5	13.0	20.1	880	8.5	42.3	1290	49.9	49.1	1.01	8.55	6.7
DL-4-65	65	7.95	4790	140	1050	13.7	12.3	18.9	920	8.8	30.6	1330	48.0	50.7	0.95	8.39	6.9
DL-4-66	66	7.88	4800	140	1060	14.5	12.4	19.4	920	10.9	0.0	1410	48.5	51.0	0.95	8.34	6.9
DL-4-67	67	8.00	4750	150	1040	13.6	12.0	18.6	920	10.7	11.4	1380	47.5	51.0	0.93	8.35	6.9
DL-4-68	68	7.95	4580	150	1080	14.1	12.6	19.5	920	12.0	26.1	1350	49.3	51.0	0.97	8.30	6.9
DL-4-69	69	8.04	4810	150	1085	14.0	12.4	19.3	910	10.0	31.2	1330	49.5	50.6	0.98	8.39	6.8
DL-4-70	70	8.05	4790	150	1080	14.0	12.3	19.1	910	4.5	37.8	1330	49.3	50.7	0.97	8.47	6.7
DL-4-71	71	7.86	4760	150	1075	14.2	12.5	19.4	900	4.0	45.0	1310	49.1	50.3	0.98	8.51	5.9
DL-4-72	72	7.82	4750	150	1070	14.4	12.6	19.6	910	8.6	37.5	1330	48.9	50.7	0.96	8.46	5.8
DL-4-73	73	7.88	4620	160	1060	14.0	12.4	19.2	820	14.7	45.0	1250	48.4	47.4	1.02	8.50	8.5
DL-4-74	74	7.84	4610	160	1055	14.0	12.5	19.5	830	16.5	33.9	1300	48.2	48.2	1.00	8.42	8.4
DL-4-75	75	7.76	434	170	1060	14.2	12.8	20.0	860	22.3	30.0	1300	48.5	49.1	0.99	8.43	8.4
DL-4-76	76	7.83	4630	170	1055	14.0	12.6	19.7	830	19.0	38.1	1270	48.3	48.0	1.01	8.47	9.0
DL-4-77	77	7.84	4510	170	1050	14.0	12.6	19.6	830	16.3	0.0	1360	48.0	48.1	1.00	8.21	9.1
DL-4-78	78	7.86	4450	170	1065	14.1	12.5	19.5	840	16.8	0.0	1350	48.7	48.3	1.01	8.18	9.0
DL-4-79	79	7.97	4360	170	1040	13.9	12.1	18.6	860	19.1	0.0	1390	47.5	49.5	0.96	8.18	9.6
DL-4-80	80	8.00	4380	180	1035	13.8	11.9	18.3	870	19.8	0.0	1350	47.3	49.3	0.96	8.05	9.2

A8 Results of chemical analysis in DL-4 system (sample type: RelW) (cont'd)

Sample ID	Incub. Time (d)	pH	Cond	Br^+	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	SO_4^{2-}	CO_3^{2-} (wt ppm)	HCO_3^- (wt ppm)	Total Cations	Total Anions	Ratio Cat/Ani	ALK pH	S^{2-}
DL-4-81	81	8.05	4390	180	1060	14.2	12.5	19.5	870	19.3	0.0	1360	48.5	49.5	0.98	8.07	9.3
DL-4-82	82	8.06	4390	180	1050	14.0	12.3	19.0	870	18.3	0.0	1350	48.0	49.3	0.97	8.16	9.0
DL-4-83	83	7.99	4390	180	1040	13.9	11.9	18.4	860	17.1	0.0	1360	47.5	49.1	0.97	7.99	9.0
DL-4-84	84	7.95	4370	180	1050	13.7	11.8	18.1	860	15.5	0.0	1410	47.9	49.9	0.96	8.00	7.6
DL-4-85	85	7.97	4370	180	1040	13.6	11.6	17.8	860	12.4	0.0	1350	47.4	48.9	0.97	8.13	7.5
DL-4-86	86	7.98	4460	190	1050	14.4	12.2	19.0	830	17.3	0.0	1350	48.0	48.2	0.99	8.23	9.1
DL-4-87	87	7.88	4480	190	1080	14.4	12.3	19.0	830	14.6	0.0	1340	49.3	48.0	1.03	8.20	9.1
DL-4-88	88	7.81	4450	200	1080	14.7	12.1	18.6	830	29.5	0.0	1310	49.3	48.0	1.03	8.19	13.6
DL-4-89	89	7.82	4460	200	1080	14.6	12.1	18.7	820	28.3	0.0	1310	49.3	47.7	1.03	8.18	13.6
DL-4-90	90	8.05	4380	210	1080	14.8	12.0	18.6	820	29.5	0.0	1290	49.3	47.5	1.04	8.16	14.5
DL-4-91	91	8.01	4440	210	1080	14.8	12.0	18.5	830	31.1	0.0	1300	49.3	48.0	1.03	8.24	14.6
DL-4-92	92	8.01	4420	210	1090	15.1	12.0	18.5	820	30.6	0.0	1310	49.7	47.8	1.04	8.24	14.7
DL-4-93	93	8.06	4390	200	1080	14.6	11.9	18.3	810	30.0	0.0	1300	49.2	47.3	1.04	8.30	14.7
DL-4-94	94	8.03	4440	200	1060	14.9	12.1	18.6	820	28.9	0.0	1300	48.4	47.5	1.02	8.22	15.1
DL-4-95	95	7.98	4450	210	1060	14.4	11.4	17.3	840	33.8	0.0	1300	48.3	48.3	1.00	8.33	16.8
DL-4-96	96	8.02	4450	210	1040	14.3	11.7	17.8	850	32.9	0.0	1310	47.4	48.7	0.97	8.33	15.7
DL-4-97	97	8.02	4440	210	1070	14.4	11.6	17.7	850	29.9	0.0	1310	48.7	48.7	1.00	8.31	15.0
DL-4-98	98	8.04	4490	210	1050	14.5	11.8	18.0	840	29.8	0.0	1300	47.9	48.2	0.99	8.31	14.9
DL-4-99	99	8.05	4480	220	1050	14.2	11.5	17.6	840	22.7	0.0	1310	47.9	48.4	0.99	8.31	11.5
DL-4-100	100	7.91	4450	220	1040	14.4	12.1	18.7	840	23.5	0.0	1300	47.5	48.2	0.99	8.26	11.6
DL-4-101	101	7.94	4450	230	1060	14.9	12.1	18.6	840	27.9	0.0	1300	48.4	48.4	1.00	8.20	13.5
DL-4-102	102	7.89	4420	220	1030	14.6	11.7	17.9	830	25.1	0.0	1310	47.0	48.1	0.98	8.25	13.4
DL-4-103	103	7.85	4400	220	1050	13.5	11.2	17.0	830	27.9	0.0	1280	47.8	47.7	1.00	8.27	13.9
DL-4-104	104	7.84	4450	220	1060	13.8	11.3	17.3	820	34.7	0.0	1290	48.2	47.7	1.01	8.29	14.0
DL-4-105	105	7.82	4450	220	1080	14.0	11.2	17.0	830	31.7	0.0	1300	49.1	48.1	1.02	8.31	14.0
DL-4-106	106	7.82	4450	230	1070	15.2	11.8	18.1	830	30.8	0.0	1290	48.8	48.0	1.02	8.30	15.0

A8 Results of chemical analysis in DL-4 system (sample type: RelW) (cont'd)

Sample ID	Incub. Time (d)	pH	Cond	Br^{+}	Na^{+}	K^{+}	Mg^{2+}	Ca^{2+}	Cl^{-}	SO_4^{2-}	CO_3^{2-} (wt ppm)	HCO_3^{-} (wt ppm)	Total Cations	Total Anions	Ratio Cat/Ani	ALK pH	S^{2-}
DL-4-107	107	7.89	4480	230	1090	14.9	12.2	18.6	830	29.5	0.0	1290	49.7	48.0	1.04	8.31	15.1
DL-4-108	108	8.12	4570	230	1060	15.2	11.8	18.2	850	34.9	0.0	1290	48.4	48.7	0.99	8.27	17.6
DL-4-109	109	8.13	4560	230	1070	15.2	11.8	18.3	840	31.9	0.0	1300	48.8	48.5	1.01	8.28	15.2
DL-4-110	110	7.67	4550	290	1070	13.7	11.7	18.2	840	137.0	0.0	1120	48.8	48.5	1.01	8.08	50.4
DL-4-111	111	7.71	4530	290	1060	13.4	11.6	18.1	830	134.0	0.0	1120	48.3	48.2	1.00	8.12	49.7
DL-4-112	112	7.67	4540	280	1080	13.7	11.6	18.0	830	134.0	0.0	1090	49.2	47.5	1.03	8.14	50.4
DL-4-113	113	7.65	4600	290	1090	13.8	11.9	18.6	830	138.0	0.0	1140	49.7	48.6	1.02	8.12	50.8
DL-4-114	114	7.83	4530	290	1070	13.7	11.8	18.4	830	123.0	0.0	1170	48.8	48.7	1.00	8.14	46.4
DL-4-115	115	7.82	4440	290	1100	13.8	11.8	18.5	830	126.0	0.0	1140	50.1	48.3	1.04	8.16	46.8
DL-4-116	116	7.83	4510	370	1100	14.1	11.7	18.2	890	177.0	0.0	1130	50.1	51.9	0.96	7.99	49.5
DL-4-117	117	7.80	4470	370	1100	13.7	11.5	17.8	890	175.0	0.0	1130	50.0	51.9	0.96	8.05	48.0
DL-4-118	118	7.84	4440	370	1110	13.7	11.9	18.8	890	196.0	0.0	1100	50.5	51.8	0.98	8.01	53.8
DL-4-119	119	7.81	4360	370	1100	14.0	11.9	18.8	890	195.0	0.0	1100	50.1	51.8	0.97	8.12	54.5
DL-4-120	120	7.78	4450	370	1110	13.6	11.7	18.4	900	194.0	0.0	1100	50.5	52.1	0.97	8.03	53.9
DL-4-121	121	7.80	4480	370	1120	14.0	11.8	18.4	890	192.0	0.0	1100	51.0	51.7	0.99	7.99	54.9
DL-4-122	122	7.91	4470	370	1110	14.4	12.0	18.7	890	194.0	0.0	1120	50.6	52.1	0.97	7.99	56.0
DL-4-123	123	7.88	4510	370	1100	14.1	11.8	18.4	900	193.0	0.0	1110	50.1	52.2	0.96	8.07	55.6
DL-4-124	124	7.87	4490	380	1110	14.2	11.9	18.5	900	197.0	0.0	1110	50.5	52.4	0.96	8.00	55.5
DL-4-125	125	7.95	4430	380	1100	14.1	11.4	17.7	890	132.0	0.0	1140	50.0	51.3	0.98	7.85	36.5
DL-4-126	126	7.91	4400	380	1110	14.3	11.3	17.4	890	133.0	0.0	1140	50.4	51.3	0.98	7.92	37.2
DL-4-127	127	7.85	4680	380	1130	13.0	11.4	18.1	890	160.0	0.0	1120	51.3	51.5	1.00	7.95	44.1
DL-4-128	128	7.83	4690	390	1120	12.9	11.4	18.1	890	162.0	0.0	1120	50.9	51.7	0.98	7.94	43.1
DL-4-129	129	7.83	4700	380	1135	13.3	11.5	18.2	890	182.0	0.0	1100	51.6	51.6	1.00	7.95	49.2
DL-4-130	130	7.81	4750	390	1129	13.4	11.4	18.1	900	179.0	0.0	1100	51.3	52.0	0.99	7.89	49.2
DL-4-131	131	7.77	4630	390	1150	13.5	11.5	18.3	900	181.0	0.0	1100	52.2	52.0	1.00	7.90	49.4
DL-4-132	132	7.91	4640	390	1135	13.4	11.5	18.1	900	184.0	0.0	1090	51.6	51.9	0.99	8.20	50.5

A8 Results of chemical analysis in DL-4 system (sample type: RelW) (cont'd)

Sample ID	Incub. Time (d)	pH	Cond	Br^+	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	SO_4^{2-}	CO_3^{2-} (wt ppm)	HCO_3^- (wt ppm)	Total Cations	Total Anions	Ratio Cat/Ani	ALK pH	S^{2-}
DL-4-133	133	7.91	4670	390	1120	12.9	11.3	17.9	900	186.0	0.0	1090	50.9	52.0	0.98	7.91	49.2
DL-4-134	134	7.85	4620	390	1110	12.5	11.1	17.7	900	183.0	0.0	1100	50.4	52.1	0.97	8.12	47.6
DL-4-135	135	7.76	4660	390	1130	12.8	11.3	17.9	890	183.0	0.0	1090	51.3	51.6	0.99	7.99	48.2
DL-4-136	136	7.87	4410	360	1077	13.5	11.5	18.3	870	168.0	0.0	1100	49.0	50.5	0.97	7.97	48.6
DL-4-137	137	7.89	4400	360	1081	13.1	11.3	17.8	890	173.0	0.0	1100	49.2	51.2	0.96	7.97	48.8
DL-4-138	138	7.85	4410	360	1075	12.9	11.2	17.5	890	165.0	0.0	1110	48.9	51.2	0.95	7.97	48.5
DL-4-139	139	7.93	4410	360	1090	12.8	10.9	16.9	880	149.0	0.0	1120	49.5	50.8	0.97	8.08	42.7
DL-4-140	140	7.95	4390	360	1081	12.7	10.9	16.8	840	152.0	0.0	1120	49.1	49.7	0.99	7.98	42.4

A9 Results of baseline chemical analysis for dynamic system

Sampling Date	Sample ID	Sample Type	Incub. Time (d)	pH	Cond	Br^+	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	SO_4^{2-}	CO_3^{2-} (wt ppm)	HCO_3^- (wt ppm)	Total Cations	Total Anions	Ratio Cat/Ani	ALK pH	S^{2-}
17-Jun-04	CT RW from Site	PW	0	7.63	4500	0.0	1140	26.1	28.1	113	690	1060	0.0	727	58.23	53.44	1.09	7.45	351.0
26-Jul-04	D2-BASE-1	water	0	7.69	5250	3.8	1070	24.9	106	157	700	1620	0.0	859	63.84	67.60	0.94	7.72	482.0
26-Jul-04	D2-BASE-2	water	0	7.76	5770	1.4	1080	25.0	162	212	680	2160	0.0	785	71.70	77.04	0.93	7.58	709.0
28-Jul-04	JPang-WIP-0704	water	0	7.92	2970	0.0	893	12.3	7.3	14.3	720	307	0.0	863	40.47	40.83	0.99	7.92	97.4
19-Aug-04	CT WATER BASE-1	water	0	8.25	7360	2500	1730	27.0	26.4	31.1	750	1060	0.0	584	79.66	83.65	0.95	7.78	355.0
19-Aug-04	CT WATER BASE-2-1	water	0	8.40	5260	18.0	1180	27.8	115	58	760	1660	0.0	436	64.50	63.36	1.02	7.84	546.0
19-Aug-04	CT WATER BASE-2-2	water	0	7.93	5930	0.0	1160	26.9	172	155	749	2229	0.0	540	73.21	76.39	0.96	7.48	753.0
03-Feb-05	D3-BASE	water	0	8.07	6430	320	1240	26.5	26.0	61.7	720	995	0.0	784	59.84	57.86	1.03	7.43	346.0
03-Feb-05	D4-BASE	water	0	8.07	5270	330	1090	15.0	8.1	13.7	760	321	0.0	843	49.14	46.04	1.07	7.47	114.0
23-Mar-05	D3-Base-60	water	59	8.07	5700	340	1230	25.0	23.8	42.0	820	1035	0.0	842	58.20	62.71	0.93	7.74	332.0
31-Mar-05	D4-Base-60	water	59	8.38	4890	300	1100	14.7	8.2	13.7	770	296	35.7	869	49.57	47.04	1.05	8.53	111.0

A10 Results of baseline MFT chemical analysis

Sampling Date	Sample ID	Sample Type	Incub. Time (d)	pH	Cond	Br^+	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	SO_4^{2-}	CO_3^{2-} (wt ppm)	HCO_3^- (wt ppm)	Total Cations	Total Anions	Ratio Cat/Ani	ALK pH	S^{2-}
12-Jul-04	MFT Mixed	Slurry	0	7.48	4110	0.0	1040	16.3	13.7	20.7	800	18	0	1610	47.81	49.29	0.97	7.95	6.27
19-Aug-04	MFT BASE 2	Slurry	0	7.59	4110	0.0	1110	17.5	15.1	23.1	868	30.7	0	1560	51.12	50.66	1.01	7.90	9.71
19-Aug-04	MFT BASE 4	Slurry	0	7.67	4160	0.0	1090	17.5	14.8	22.8	868	17.7	0	1570	50.21	50.56	0.99	8.05	6.15

A11 Results of chemical analysis in pore water of D3 & D4 systems

Sample ID	Sample Type	pH	Cond	Br^+	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	SO_4^{2-}	CO_3^{2-} (wt ppm)	HCO_3^- (wt ppm)	Total Cations	Total Anions	Ratio Cat/Ani	Alkalinity expressed as HCO_3^-	ALK pH	S^{2-}
DL-3-R	RawW	8.05	5600	420	1120	24.5	24.6	39.6	930	1220	0.0	752	53.4	69.2	0.77	616	8.0	329.0
DL-4-R	RawW	8.57	4440	390	1000	14.3	7.8	12.4	920	386	0.0	853	45.1	52.8	0.85	699	8.2	108.0
DH-3-Top	Rel W	7.91	4510	210	1200	17.9	22.0	41.4	740	590	0.0	1230	56.5	55.9	1.01	1008	7.6	205.0
DH-3-U	PoreW	8.36	4300	220	1130	14.5	13.7	16.3	820	51.0	0.0	1480	51.5	51.2	1.01	1213	7.4	50.5
DH-3-M-U	PoreW	8.62	4070	260	1050	14.7	10.9	11.4	760	58.1	0.0	1330	47.5	47.7	1.00	1090	7.6	68.3
DH-3-M-L	PoreW	8.63	3920	290	1050	15.3	10.9	11.7	720	80.3	0.0	1200	47.5	45.3	1.05	984	7.6	124.0
DH-3-L	PoreW	8.73	4280	300	1050	16.8	13.5	16.9	750	205	0.0	1360	48.1	51.4	0.93	1115	7.5	230.0
DL-3-Top	Rel W	7.68	5680	380	1150	15.7	20.5	36.4	720	920	0.0	950	53.9	59.8	0.90	779	8.2	299.0
DL-3-U	PoreW	8.43	5570	500	1140	11.3	14.4	13.9	870	239	0.0	1410	51.7	58.9	0.88	1156	8.1	201.0
DL-3- M-U	PoreW	8.22	5530	500	1120	11.3	15.6	14.9	830	295	0.0	1330	51.0	57.6	0.89	1090	7.7	121.0
DL-3- M-L	PoreW	8.16	5260	480	1060	12.2	14.6	14.6	800	226	0.0	1250	48.3	53.7	0.90	1025	7.6	201.0
DL-3-L	PoreW	8.19	5430	490	1110	14.2	16.6	18.2	810	443	0.0	1170	50.9	57.4	0.89	959	7.8	140.0
DH-4-Top	Rel W	8.04	3970	260	955	12.9	11.3	17.9	760	204	0.0	1040	43.7	46.0	0.95	852	7.6	69.7
DH-4-U	PoreW	8.36	3880	290	950	13.3	8.3	9.7	810	13.5	0.0	1060	42.8	44.1	0.97	869	7.7	8.7
DH-4-M-U	PoreW	8.47	3790	300	963	12.2	7.4	8.9	800	13.7	0.0	998	43.2	42.9	1.01	818	7.6	9.7
DH-4-M-L	PoreW	8.42	3850	300	990	13.2	7.4	9.2	780	11.5	0.0	1070	44.5	43.5	1.02	877	7.7	8.1
DH-4-L	PoreW	8.51	3760	300	975	13.0	6.8	8.4	790	12.1	0.0	1000	43.7	42.6	1.02	820	7.7	8.1
DL-4-Top	Rel W	7.84	4560	390	950	11.8	10.2	15.5	830	71.4	0.0	1170	43.2	48.9	0.88	959	8.3	31.1
DL-4-U	PoreW	8.13	4620	430	922	11.7	10.2	12.9	810	9.0	0.0	1130	41.9	46.9	0.89	926	8.2	9.4
DL-4- M-U	PoreW	8.28	4610	460	906	10.5	8.8	11.3	810	13.9	0.0	1120	41.0	47.2	0.87	918	8.3	11.2
DL-4- M-L	PoreW	8.23	4480	430	900	11.7	9.0	11.3	800	BDL	8.4	1060	40.7	#VALUE!	#VALUE!	883	8.3	9.1
DL-4-L	PoreW	8.26	4550	460	920	11.6	8.4	10.8	810	14.2	0.0	1070	41.5	46.4	0.90	877	8.3	9.7

A12 Results of chemical analysis in Jars

System	Sample ID	Sample Type	Incub. Time (d)	pH	Cond	Br^+	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	SO_4^{2-}	CO_3^{2-} (wt ppm)	HCO_3^- (wt ppm)	Total Cations	Total Anions	Ratio Cat/Ani	Alkalinity expressed as HCO_3^-	ALK pH	S^{2-}
Jar 1	Jar D1-1	PoreW	128	8.37	8340	3000	2300	19.7	25.4	31.0	1100	703	0.0	1580	104.2	109.0	0.96	1295	7.5	285
Jar 1	Jar D1-2	PoreW	128	8.21	8200	3000	2270	18.9	24.5	32.1	1100	673	0.0	1550	102.8	107.9	0.95	1270	7.8	241
Jar 2	Jar D2-1	PoreW	128	8.19	6150	8.9	1530	20.0	42.5	41.4	1000	797	0.0	1750	72.6	73.6	0.99	1434	8.0	277
Jar 2	Jar D2-2	PoreW	128	7.92	6260	0.1	1590	20.3	47.2	45.8	1000	887	0.0	1640	75.9	73.5	1.03	1344	7.6	494
Jar 3	Jar D3-1	PoreW	128	8.03	7390	700	1900	20.1	29.8	37.2	1000	590	0.0	2090	87.5	83.5	1.05	1713	7.5	533
Jar 3	Jar D3-2	PoreW	128	7.90	6140	500	1560	17.9	22.5	32.9	1000	582	0.0	1750	71.8	75.2	0.95	1434	7.8	198
Jar 4	Jar D4-1	PoreW	128	8.14	5880	810	1500	17.0	19.0	28.0	1100	370	0.0	1590	68.6	74.9	0.92	1303	8.3	131
Jar 4	Jar D4-2	PoreW	128	7.83	5100	430	1250	15.4	14.6	21.5	1100	9.9	0.0	1090	57.0	54.4	1.05	893	7.8	7.1

A13 MPN data of DH & DL systems

System	Sample ID	t (d)	Methanogen MPN/ g DRY WT	SRB MPN/g DRY WT
DH-1	DH-1-U	60	4.52E+01	8.94E+04
	DH-1-M-U	60		5.04E+05
	DH-1-M-L	60		9.41E+04
	DH-1-L	60	1.81E+01	9.05E+04
DH-2	DH-2-U	60	4.59E+01	4.26E+04
	DH-2-M-U	60		1.99E+05
	DH-2-M-L	60		9.41E+04
	DH-2-L	60	9.36E+01	5.06E+05
DH-3	DH-3-U	60	5.11E+04	9.30E+04
	DH-3-M-U	60	5.49E+04	5.10E+04
	DH-3-M-L	60	4.74E+04	2.00E+04
	DH-3-L	60	5.04E+04	4.90E+04
DH-4	DH-4-U	60	5.46E+04	2.09E+05
	DH-4-M-U	60	2.10E+05	9.55E+04
	DH-4-M-L	60	4.34E+04	5.10E+05
	DH-4-L	60	5.30E+04	9.82E+04
DL-1	DL-1-U	140	BDL	2.04E+04
	DL-1-M-U	140		9.55E+03
	DL-1-M-L	140		2.13E+04
	DL-1-L	140	1.89E+01	1.80E+04
DL-2	DL-2-U	140	BDL	5.15E+04
	DL-2-M-U	140		9.57E+03
	DL-2-M-L	140		8.56E+03
	DL-2-L	140	7.55E+00	2.01E+04
DL-3	DL-3-U	140	5.11E+04	4.91E+04
	DL-3-M-U	140	1.97E+04	4.47E+05
	DL-3-M-L	140	4.61E+05	4.61E+03
	DL-3-L	140	5.32E+04	8.81E+03
DL-4	DL-4-U	140	8.05E+04	4.13E+04
	DL-4-M-U	140	4.17E+04	4.39E+04
	DH-L-M-L	140	4.78E+04	7.21E+04
	DL-4-L	140	1.80E+05	4.64E+04

A14 MPN data of Jars

System	Sample ID	t (d)	Methanogen MPN/ g DRY WT	SRB MPN/g DRY WT
1	JAR D1-1	140	1.83E+05	4.96E+05
	JAR D1-2	140	9.57E+04	9.23E+04
2	JAR D2-1	140	3.35E+05	2.24E+05
	JAR D2-2	140	9.75E+04	5.08E+05
3	JAR D3-1	140	5.02E+05	5.35E+05
	JAR D3-2	140	8.89E+04	1.97E+05
4	JAR D4-1	140	2.07E+05	2.10E+05
	JAR D4-2	140	2.07E+05	9.42E+04

A15 Results of S^{2-} analysis in dynamic system (MFT)

ID	S^{2-}	ID	S^{2-}	ID	S^{2-}
DL-1-U	BDL	DH-3-U	BDL	DH-4-U	BDL
DL-1-M-U	BDL	DH-3-M-U	BDL	DH-4-M-U	BDL
DL-1-M-L	BDL	DH-3-M-L	BDL	DH-4-M-L	BDL
DL-1-L	BDL	DH-3-L	BDL	DH-4-L	BDL
DL-2-U	BDL	DL-3-U	BDL	DL-4-U	BDL
DL-2-M-U	BDL	DL-3-M-U	BDL	DL-4-M-U	BDL
DL-2-M-L	BDL	DL-3-M-L	BDL	DL-4-M-L	BDL
DL-2-L	BDL	DL-3-L	BDL	DL-4-L	BDL

A16 Results of S^{2-} analysis in D-3 system

ID	Day	S^{2-}	ID	Day	S^{2-}
DH-3-3	3	BDL	DL-3-3	3	BDL
DH-3-7	7	BDL	DL-3-7	7	BDL
DH-3-14	14	BDL	DL-3-14	14	BDL
DH-3-21	21	BDL	DL-3-21	21	BDL
DH-3-28	28	BDL	DL-3-28	28	BDL
DH-3-35	35	BDL	DL-3-35	35	BDL
DH-3-42	42	0.8	DL-3-42	42	BDL
DH-3-49	49	1.0	DL-3-49	49	BDL
DH-3-56	56	2.0	DL-3-56	56	BDL
DH-3-60	60	BDL	DL-3-63	63	BDL
			DL-3-70	70	BDL
			DL-3-77	77	BDL
			DL-3-84	84	BDL
			DL-3-91	91	BDL
			DL-3-98	98	BDL
			DL-3-105	105	BDL
			DL-3-112	112	1.0
			DL-3-119	119	0.5
			DL-3-126	126	BDL
			DL-3-133	133	BDL
			DL-3-140	140	BDL

A17 Results of S^{2-} analysis in D-4 system

ID	Day	S^{2-}	ID	Day	S^{2-}
DH-4-3	3	BDL	DL-4-3	3	BDL
DH-4-7	7	BDL	DL-4-7	7	BDL
DH-4-14	14	BDL	DL-4-14	14	BDL
DH-4-21	21	BDL	DL-4-21	21	BDL
DH-4-28	28	BDL	DL-4-28	28	BDL
DH-4-35	35	1.0	DL-4-35	35	BDL
DH-4-42	42	2.0	DL-4-42	42	BDL
DH-4-49	49	2.5	DL-4-49	49	BDL
DH-4-56	56	3.0	DL-4-56	56	BDL
DH-4-60	60	3.0	DL-4-63	63	BDL
			DL-4-70	70	BDL
			DL-4-77	77	BDL
			DL-4-84	84	BDL
			DL-4-91	91	BDL
			DL-4-98	98	BDL
			DL-4-105	105	BDL
			DL-4-112	112	4.5
			DL-4-119	119	BDL
			DL-4-126	126	2.5
			DL-4-133	133	BDL
			DL-4-140	140	BDL

A18 Results of S^{2-} analysis in Jars

ID	S^{2-}
JarD1-1	BDL
JarD1-2	BDL
JarD2-1	BDL
JarD2-2	BDL
JarD3-1	BDL
JarD3-2	BDL
JarD4-1	5.5
JarD4-2	0.3

A19 Results of Redox potential analysis in dynamic system

ID	Eh (mV)		ID	Eh (mV)	
	1 hr	2 hr		1 hr	2 hr
DH-1-U	-141.1	-153.3	DH-3-U	-140.0	-155.0
DH-1-M-U	-174.4	-178.8	DH-3-M-U	55.0	9.0
DH-1-M-L	-150.4	-161.0	DH-3-M-L	-130.0	-165.0
DH-1-L	-147.7	-166.9	DH-3-L	-200.0	-204.0
DL-1-U	-153.0	-165.0	DL-3-U	-165.0	-178.0
DL-1-M-U	-142.0	-153.0	DL-3-M-U	-190.0	-200.0
DL-1-M-L	-172.0	-178.0	DL-3-M-L	-194.0	-201.0
DL-1-L	-154.0	-164.0	DL-3-L	-196.0	-199.0
DH-2-U	-181.0	-182.8	DH-4-U	17.2	-9.0
DH-2-M-U	-178.8	-182.6	DH-4-M-U	46.0	13.0
DH-2-M-L	-194.1	-198.0	DH-4-M-L	24.0	-13.0
DH-2-L	-180.7	-183.8	DH-4-L	21.1	0.0
DL-2-U	-193.0	-195.0	DL-4-U	65.0	47.0
DL-2-M-U	-183.0	-189.0	DL-4-M-U	-53.0	-78.0
DL-2-M-L	-187.0	-189.0	DL-4-M-L	39.0	15.0
DL-2-L	-198.0	-199.0	DL-4-L	-125.0	-150.0

A20 Results of Redox potential analysis in Jars

ID	Eh (mV)	
	1 hr	2 hr
D1-1	-178	-190
D1-2	-175	-184
D2-1	-198	-206
D2-2	-208	-211
D3-1	-201	-208
D3-2	-180	-186
D4-1	-188	-194
D4-2	-91	-102

A21 Solids content of D3 & D4 systems

Sample ID	Solids (g/100g)	Bitumen (g/100g)	22 µm	11 µm	5.5 µm	2.8 µm	1.4 µm	0.5 µm
Base	38.8	3.35	73.8	59.0	42.9	28.3	14.2	2.5
DH-3-U								
DH-3-M-U								
DH-3-M-L								
DH-3-L	42.3	3.63	76.7	62.3	46.2	30.4	14.6	2.4
DL-3--U	42.0	3.65	74.0	60.2	44.3	28.5	13.4	2.2
DL-3--M-U	42.8	3.20	75.7	62.9	45.8	27.1	11.6	1.9
DL-3--M-L	43.1	3.44	73.4	59.6	43.8	27.6	12.6	2.0
DL-3--L	43.3	3.67	74.7	60.7	45.1	29.3	13.9	2.3
DH-4-U	42.0	3.65	74.0	60.2	44.3	28.5	13.4	2.2
DH-4-M-U	42.8	3.20	75.7	62.9	45.8	27.1	11.6	1.9
DH-4-M-L	43.1	3.44	73.4	59.6	43.8	27.6	12.6	2.0
DH-4-L	43.3	3.67	74.7	60.7	45.1	29.3	13.9	2.3
DL-4--U	44.8	3.58	74.6	61.2	44.8	27.2	11.7	1.7
DL-4--M-U	43.4	3.58	74.4	60.9	44.9	28.3	12.7	1.8
DL-4--M-L	45.1	3.67	77.9	64.4	47.8	29.5	12.7	1.8
DL-4--L	45.0	3.55	77.1	64.0	47.2	28.1	11.6	1.7

A22 Solids content of Jars

Sample ID	Solids (g/100g)	Bitumen (g/100g)	22 µm	11 µm	5.5 µm	2.8 µm	1.4 µm	0.5 µm
D1-Jar Base	38.0	3.32	78.7	63.1	45.9	30.0	14.6	2.4
D2-Jar Base	38.0	3.27	74.0	59.8	43.6	27.7	12.9	1.9
D3&D4 Jar Base	38.8	3.35	73.8	59.0	42.9	28.3	14.2	2.5
Jar D1-1	39.4	3.1	74.8	61.4	45.4	28.2	12.2	1.8
Jar D1-2	38.5	3.3	76.4	62.2	45.9	29.1	13.0	1.9
Jar D2-1	38.1	3.3	77.8	63.4	46.7	29.1	12.7	1.8
Jar D2-2	38.2	3.3	75.7	61.9	45.5	27.8	12.0	1.7
Jar D3-1	37.5	3.2	75.4	61.0	44.8	28.3	13.0	2.1
Jar D3-2	37.8	3.1	78.1	65.1	47.5	27.2	11.4	2.3
Jar D4-1	39.0	3.4	77.7	63.3	46.7	29.2	13.0	2.1
Jar D4-2	38.9	3.3	77.3	63.6	47.1	29.0	12.4	1.7

A23 Volume of CT water flow through D1 column (high flowrate)

No.	Day	V (ml)	Sum-V (ml)
DH-1-1	1	0	0
DH-1-2	2	0	0
DH-1-3	3	60	60
DH-1-4	4	0	60
DH-1-5	5	240	300
DH-1-6	6	600	900
DH-1-7	7	440	1340
DH-1-8	8	360	1700
DH-1-9	9	455	2155
DH-1-10	10	380	2535
DH-1-11	11	420	2955
DH-1-12	12	330	3285
DH-1-13	13	460	3745
DH-1-14	14	465	4210
DH-1-15	15	270	4480
DH-1-16	16	395	4875
DH-1-17	17	410	5285
DH-1-18	18	480	5765
DH-1-19	19	480	6245
DH-1-20	20	170	6415
DH-1-21	21	350	6765
DH-1-22	22	410	7175
DH-1-23	23	330	7505
DH-1-24	24	520	8025
DH-1-25	25	510	8535
DH-1-26	26	200	8735
DH-1-27	27	520	9255
DH-1-28	28	520	9775
DH-1-29	29	440	10215
DH-1-30	30	300	10515
DH-1-31	31	350	10865
DH-1-32	32	490	11355
DH-1-33	33	200	11555
DH-1-34	34	430	11985
DH-1-35	35	500	12485
DH-1-36	36	480	12965

A23 Volume of CT water flow through D1 column (high flowrate) (cont'd)

No.	Day	V (ml)	Sum-V (ml)
DH-1-37	37	410	13375
DH-1-38	38	500	13875
DH-1-39	39	500	14375
DH-1-40	40	300	14675
DH-1-41	41	420	15095
DH-1-42	42	460	15555
DH-1-43	43	450	16005
DH-1-44	44	460	16465
DH-1-45	45	450	16915
DH-1-46	46	500	17415
DH-1-47	47	450	17865
DH-1-48	48	340	18205
DH-1-49	49	500	18705
DH-1-50	50	460	19165
DH-1-51	51	500	19665
DH-1-52	52	450	20115
DH-1-53	53	440	20555
DH-1-54	54	510	21065
DH-1-55	55	300	21365
DH-1-56	56	480	21845
DH-1-57	57	420	22265
DH-1-58	58	400	22665
DH-1-59	59	450	23115
DH-1-60	60	700	23815
Flowrate	*1440 hrs*	*23815 ml*	*16.54 ml/h*

A24 Volume of CT water flow through D2 column (high flowrate)

No.	Day	V (ml)	Sum-V (ml)
DH-2-1	1	0	0
DH-2-2	2	355	355
DH-2-3	3	355	710
DH-2-4	4	400	1110
DH-2-5	5	570	1680
DH-2-6	6	300	1980
DH-2-7	7	420	2400
DH-2-8	8	460	2860
DH-2-9	9	430	3290
DH-2-10	10	400	3690
DH-2-11	11	475	4165
DH-2-12	12	470	4635
DH-2-13	13	285	4920
DH-2-14	14	320	5240
DH-2-15	15	375	5615
DH-2-16	16	310	5925
DH-2-17	17	175	6100
DH-2-18	18	300	6400
DH-2-19	19	510	6910
DH-2-20	20	300	7210
DH-2-21	21	500	7710
DH-2-22	22	575	8285
DH-2-23	23	520	8805
DH-2-24	24	480	9285
DH-2-25	25	505	9790
DH-2-26	26	510	10300
DH-2-27	27	380	10680
DH-2-28	28	430	11110
DH-2-29	29	500	11610
DH-2-30	30	500	12110
DH-2-31	31	480	12590
DH-2-32	32	420	13010
DH-2-33	33	480	13490
DH-2-34	34	460	13950
DH-2-35	35	450	14400
DH-2-36	36	370	14770

A24 Volume of CT water flow through D2 column (high flowrate) (cont'd)

No.	Day	V (ml)	Sum-V (ml)
DH-2-37	37	250	15020
DH-2-38	38	270	15290
DH-2-39	39	250	15540
DH-2-40	40	225	15765
DH-2-41	41	130	15895
DH-2-42	42	90	15985
DH-2-43	43	500	16485
DH-2-44	44	550	17035
DH-2-45	45	360	17395
DH-2-46	46	580	17975
DH-2-47	47	425	18400
DH-2-48	48	650	19050
DH-2-49	49	410	19460
DH-2-50	50	500	19960
DH-2-51	51	460	20420
DH-2-52	52	440	20860
DH-2-53	53	450	21310
DH-2-54	54	700	22010
DH-2-55	55	350	22360
DH-2-56	56	310	22670
DH-2-57	57	300	22970
DH-2-58	58	425	23395
DH-2-59	59	520	23915
DH-2-60	60	400	24315
Flowrate	*1440 hrs*	*24315*	*16.89 ml/h*

A25 Volume of CT water flow through D3 column (high flowrate)

No.	Day	V (ml)	Sum-V (ml)
DH-3-1	1	0	0
DH-3-2	2	0	0
DH-3-3	3	480	480
DH-3-4	4	480	960
DH-3-5	5	480	1440
DH-3-6	6	480	1920
DH-3-7	7	480	2400
DH-3-8	8	480	2880
DH-3-9	9	480	3360
DH-3-10	10	480	3840
DH-3-11	11	480	4320
DH-3-12	12	480	4800
DH-3-13	13	450	5250
DH-3-14	14	420	5670
DH-3-15	15	480	6150
DH-3-16	16	480	6630
DH-3-17	17	480	7110
DH-3-18	18	480	7590
DH-3-19	19	480	8070
DH-3-20	20	480	8550
DH-3-21	21	480	9030
DH-3-22	22	480	9510
DH-3-23	23	480	9990
DH-3-24	24	480	10470
DH-3-25	25	480	10950
DH-3-26	26	480	11430
DH-3-27	27	480	11910
DH-3-28	28	480	12390
DH-3-29	29	480	12870
DH-3-30	30	480	13350
DH-3-31	31	480	13830
DH-3-32	32	480	14310
DH-3-33	33	480	14790
DH-3-34	34	480	15270
DH-3-35	35	480	15750
DH-3-36	36	450	16200

A25 Volume of CT water flow through D3 column (high flowrate) (cont'd)

No.	Day	V (ml)	Sum-V (ml)
DH-3-37	37	480	16680
DH-3-38	38	480	17160
DH-3-39	39	480	17640
DH-3-40	40	480	18120
DH-3-41	41	480	18600
DH-3-42	42	400	19000
DH-3-43	43	350	19350
DH-3-44	44	480	19830
DH-3-45	45	480	20310
DH-3-46	46	480	20790
DH-3-47	47	450	21240
DH-3-48	48	400	21640
DH-3-49	49	350	21990
DH-3-50	50	480	22470
DH-3-51	51	480	22950
DH-3-52	52	480	23430
DH-3-53	53	480	23910
DH-3-54	54	480	24390
DH-3-55	55	400	24790
DH-3-56	56	350	25140
DH-3-57	57	500	25640
DH-3-58	58	450	26090
DH-3-59	59	400	26490
DH-3-60	60	450	26940
Flowrate	*1440 hrs*	*26940*	*18.71 ml/h*

A26 Volume of CT water flow through D4 column (high flowrate)

No.	Day	V (ml)	Sum-V (ml)
DH-4-1	1	0	0
DH-4-2	2	0	0
DH-4-3	3	300	300
DH-4-4	4	480	780
DH-4-5	5	480	1260
DH-4-6	6	480	1740
DH-4-7	7	480	2220
DH-4-8	8	480	2700
DH-4-9	9	480	3180
DH-4-10	10	480	3660
DH-4-11	11	480	4140
DH-4-12	12	480	4620
DH-4-13	13	480	5100
DH-4-14	14	480	5580
DH-4-15	15	480	6060
DH-4-16	16	480	6540
DH-4-17	17	480	7020
DH-4-18	18	480	7500
DH-4-19	19	480	7980
DH-4-20	20	480	8460
DH-4-21	21	480	8940
DH-4-22	22	480	9420
DH-4-23	23	480	9900
DH-4-24	24	480	10380
DH-4-25	25	480	10860
DH-4-26	26	480	11340
DH-4-27	27	480	11820
DH-4-28	28	480	12300
DH-4-29	29	480	12780
DH-4-30	30	480	13260
DH-4-31	31	480	13740
DH-4-32	32	480	14220
DH-4-33	33	480	14700
DH-4-34	34	480	15180
DH-4-35	35	480	15660
DH-4-36	36	480	16140

A26 Volume of CT water flow through D4 column (high flowrate) (cont'd)

No.	Day	V (ml)	Sum-V (ml)
DH-4-37	37	480	16620
DH-4-38	38	480	17100
DH-4-39	39	480	17580
DH-4-40	40	480	18060
DH-4-41	41	480	18540
DH-4-42	42	480	19020
DH-4-43	43	480	19500
DH-4-44	44	480	19980
DH-4-45	45	480	20460
DH-4-46	46	480	20940
DH-4-47	47	480	21420
DH-4-48	48	480	21900
DH-4-49	49	480	22380
DH-4-50	50	480	22860
DH-4-51	51	480	23340
DH-4-52	52	490	23830
DH-4-53	53	500	24330
DH-4-54	54	500	24830
DH-4-55	55	550	25380
DH-4-56	56	450	25830
DH-4-57	57	500	26330
DH-4-58	58	550	26880
DH-4-59	59	500	27380
DH-4-60	60	550	27930
Flowrate	*1440 hrs*	*27930*	*19.40 ml/h*

A27 Volume of CT water flow through D1 column (low flowrate)

No.	Day	V (ml)	Sum-V (ml)
DL-1-1	1	0	0
DL-1-2	2	0	0
DL-1-3	3	0	0
DL-1-4	4	0	0
DL-1-5	5	0	0
DL-1-6	6	0	0
DL-1-7	7	0	0
DL-1-8	8	150	150
DL-1-9	9	100	250
DL-1-10	10	165	415
DL-1-11	11	180	595
DL-1-12	12	125	720
DL-1-13	13	110	830
DL-1-14	14	100	930
DL-1-15	15	150	1080
DL-1-16	16	135	1215
DL-1-17	17	65	1280
DL-1-18	18	110	1390
DL-1-19	19	130	1520
DL-1-20	20	175	1695
DL-1-21	21	190	1885
DL-1-22	22	150	2035
DL-1-23	23	150	2185
DL-1-24	24	130	2315
DL-1-25	25	100	2415
DL-1-26	26	145	2560
DL-1-27	27	150	2710
DL-1-28	28	145	2855
DL-1-29	29	140	2995
DL-1-30	30	140	3135
DL-1-31	31	120	3255
DL-1-32	32	165	3420
DL-1-33	33	80	3500
DL-1-34	34	150	3650
DL-1-35	35	125	3775
DL-1-36	36	135	3910

A27 Volume of CT water flow through D1 column (low flowrate) (cont'd)

No.	Day	V (ml)	Sum-V (ml)
DL-1-37	37	160	4070
DL-1-38	38	90	4160
DL-1-39	39	110	4270
DL-1-40	40	140	4410
DL-1-41	41	150	4560
DL-1-42	42	100	4660
DL-1-43	43	150	4810
DL-1-44	44	140	4950
DL-1-45	45	90	5040
DL-1-46	46	130	5170
DL-1-47	47	145	5315
DL-1-48	48	80	5395
DL-1-49	49	80	5475
DL-1-50	50	70	5545
DL-1-51	51	175	5720
DL-1-52	52	150	5870
DL-1-53	53	100	5970
DL-1-54	54	100	6070
DL-1-55	55	170	6240
DL-1-56	56	150	6390
DL-1-57	57	100	6490
DL-1-58	58	140	6630
DL-1-59	59	200	6830
DL-1-60	60	150	6980
DL-1-61	61	150	7130
DL-1-62	62	150	7280
DL-1-63	63	140	7420
DL-1-64	64	140	7560
DL-1-65	65	200	7760
DL-1-66	66	100	7860
DL-1-67	67	130	7990
DL-1-68	68	150	8140
DL-1-69	69	130	8270
DL-1-70	70	160	8430
DL-1-71	71	140	8570
DL-1-72	72	180	8750

A27 Volume of CT water flow through D1 column (low flowrate) (cont'd)

No.	Day	V (ml)	Sum-V (ml)
DL-1-73	73	110	8860
DL-1-74	74	130	8990
DL-1-75	75	130	9120
DL-1-76	76	160	9280
DL-1-77	77	160	9440
DL-1-78	78	150	9590
DL-1-79	79	170	9760
DL-1-80	80	150	9910
DL-1-81	81	100	10010
DL-1-82	82	140	10150
DL-1-83	83	130	10280
DL-1-84	84	60	10340
DL-1-85	85	90	10430
DL-1-86	86	170	10600
DL-1-87	87	140	10740
DL-1-88	88	135	10875
DL-1-89	89	140	11015
DL-1-90	90	140	11155
DL-1-91	91	150	11305
DL-1-92	92	100	11405
DL-1-93	93	140	11545
DL-1-94	94	145	11690
DL-1-95	95	150	11840
DL-1-96	96	120	11960
DL-1-97	97	80	12040
DL-1-98	98	60	12100
DL-1-99	99	40	12140
DL-1-100	100	75	12215
DL-1-101	101	75	12290
DL-1-102	102	140	12430
DL-1-103	103	140	12570
DL-1-104	104	150	12720
DL-1-105	105	140	12860
DL-1-106	106	130	12990
DL-1-107	107	135	13125
DL-1-108	108	145	13270

A27 Volume of CT water flow through D1 column (low flowrate) (cont'd)

No.	Day	V (ml)	Sum-V (ml)
DL-1-109	109	135	13405
DL-1-110	110	140	13545
DL-1-111	111	140	13685
DL-1-112	112	140	13825
DL-1-113	113	100	13925
DL-1-114	114	140	14065
DL-1-115	115	135	14200
DL-1-116	116	150	14350
DL-1-117	117	130	14480
DL-1-118	118	140	14620
DL-1-119	119	140	14760
DL-1-120	120	140	14900
DL-1-121	121	140	15040
DL-1-122	122	140	15180
DL-1-123	123	140	15320
DL-1-124	124	140	15460
DL-1-125	125	100	15560
DL-1-126	126	140	15700
DL-1-127	127	140	15840
DL-1-128	128	140	15980
DL-1-129	129	140	16120
DL-1-130	130	140	16260
DL-1-131	131	140	16400
DL-1-132	132	140	16540
DL-1-133	133	140	16680
DL-1-134	134	140	16820
DL-1-135	135	140	16960
DL-1-136	136	140	17100
DL-1-137	137	140	17240
DL-1-138	138	140	17380
DL-1-139	139	140	17520
DL-1-140	140	140	17660
Flowrate	*3360 hrs*	*17660 ml*	*5.26 ml/h*

A28 Volume of CT water flow through D2 column (low flowrate)

No.	Day	V (ml)	Sum-V (ml)
DL-2-1	1	0	0
DL-2-2	2	0	0
DL-2-3	3	0	0
DL-2-4	4	0	0
DL-2-5	5	130	130
DL-2-6	6	0	130
DL-2-7	7	190	320
DL-2-8	8	190	510
DL-2-9	9	150	660
DL-2-10	10	160	820
DL-2-11	11	160	980
DL-2-12	12	150	1130
DL-2-13	13	155	1285
DL-2-14	14	160	1445
DL-2-15	15	150	1595
DL-2-16	16	150	1745
DL-2-17	17	160	1905
DL-2-18	18	115	2020
DL-2-19	19	100	2120
DL-2-20	20	90	2210
DL-2-21	21	70	2280
DL-2-22	22	160	2440
DL-2-23	23	190	2630
DL-2-24	24	180	2810
DL-2-25	25	120	2930
DL-2-26	26	150	3080
DL-2-27	27	150	3230
DL-2-28	28	150	3380
DL-2-29	29	150	3530
DL-2-30	30	120	3650
DL-2-31	31	150	3800
DL-2-32	32	90	3890
DL-2-33	33	140	4030
DL-2-34	34	150	4180
DL-2-35	35	130	4310
DL-2-36	36	115	4425

A28 Volume of CT water flow through D2 column (low flowrate) (cont'd)

No.	Day	V (ml)	Sum-V (ml)
DL-2-37	37	150	4575
DL-2-38	38	200	4775
DL-2-39	39	150	4925
DL-2-40	40	100	5025
DL-2-41	41	155	5180
DL-2-42	42	140	5320
DL-2-43	43	130	5450
DL-2-44	44	130	5580
DL-2-45	45	90	5670
DL-2-46	46	145	5815
DL-2-47	47	110	5925
DL-2-48	48	145	6070
DL-2-49	49	140	6210
DL-2-50	50	150	6360
DL-2-51	51	140	6500
DL-2-52	52	200	6700
DL-2-53	53	100	6800
DL-2-54	54	130	6930
DL-2-55	55	140	7070
DL-2-56	56	135	7205
DL-2-57	57	170	7375
DL-2-58	58	150	7525
DL-2-59	59	180	7705
DL-2-60	60	110	7815
DL-2-61	61	130	7945
DL-2-62	62	130	8075
DL-2-63	63	160	8235
DL-2-64	64	150	8385
DL-2-65	65	140	8525
DL-2-66	66	170	8695
DL-2-67	67	150	8845
DL-2-68	68	100	8945
DL-2-69	69	120	9065
DL-2-70	70	100	9165
DL-2-71	71	80	9245
DL-2-72	72	60	9305

A28 Volume of CT water flow through D2 column (low flowrate) (cont'd)

No.	Day	V (ml)	Sum-V (ml)
DL-2-73	73	90	9395
DL-2-74	74	90	9485
DL-2-75	75	80	9565
DL-2-76	76	60	9625
DL-2-77	77	95	9720
DL-2-78	78	90	9810
DL-2-79	79	60	9870
DL-2-80	80	70	9940
DL-2-81	81	60	10000
DL-2-82	82	145	10145
DL-2-83	83	140	10285
DL-2-84	84	140	10425
DL-2-85	85	120	10545
DL-2-86	86	40	10585
DL-2-87	87	40	10625
DL-2-88	88	120	10745
DL-2-89	89	140	10885
DL-2-90	90	140	11025
DL-2-91	91	150	11175
DL-2-92	92	140	11315
DL-2-93	93	90	11405
DL-2-94	94	60	11465
DL-2-95	95	150	11615
DL-2-96	96	140	11755
DL-2-97	97	140	11895
DL-2-98	98	140	12035
DL-2-99	99	140	12175
DL-2-100	100	150	12325
DL-2-101	101	140	12465
DL-2-102	102	135	12600
DL-2-103	103	150	12750
DL-2-104	104	130	12880
DL-2-105	105	140	13020
DL-2-106	106	140	13160
DL-2-107	107	140	13300
DL-2-108	108	140	13440

A28 Volume of CT water flow through D2 column (low flowrate) (cont'd)

No.	Day	V (ml)	Sum-V (ml)
DL-2-109	109	110	13550
DL-2-110	110	100	13650
DL-2-111	111	70	13720
DL-2-112	112	70	13790
DL-2-113	113	60	13850
DL-2-114	114	60	13910
DL-2-115	115	60	13970
DL-2-116	116	60	14030
DL-2-117	117	60	14090
DL-2-118	118	60	14150
DL-2-119	119	60	14210
DL-2-120	120	60	14270
DL-2-121	121	60	14330
DL-2-122	122	50	14380
DL-2-123	123	50	14430
DL-2-124	124	60	14490
DL-2-125	125	50	14540
DL-2-126	126	50	14590
DL-2-127	127	50	14640
DL-2-128	128	100	14740
DL-2-129	129	60	14800
DL-2-130	130	60	14860
DL-2-131	131	60	14920
DL-2-132	132	80	15000
DL-2-133	133	90	15090
DL-2-134	134	90	15180
DL-2-135	135	90	15270
DL-2-136	136	80	15350
DL-2-137	137	90	15440
DL-2-138	138	140	15580
DL-2-139	139	140	15720
DL-2-140	140	140	15860
Flowrate	*3360 hrs*	*15860*	*4.72 ml/h*

A29 Volume of CT water flow through D3 column (low flowrate)

No.	Day	V (ml)	Sum-V (ml)
DL-3-1	1	0	0
DL-3-2	2	0	0
DL-3-3	3	140	140
DL-3-4	4	100	240
DL-3-5	5	140	380
DL-3-6	6	140	520
DL-3-7	7	140	660
DL-3-8	8	140	800
DL-3-9	9	140	940
DL-3-10	10	140	1080
DL-3-11	11	140	1220
DL-3-12	12	140	1360
DL-3-13	13	140	1500
DL-3-14	14	140	1640
DL-3-15	15	140	1780
DL-3-16	16	140	1920
DL-3-17	17	140	2060
DL-3-18	18	140	2200
DL-3-19	19	140	2340
DL-3-20	20	140	2480
DL-3-21	21	140	2620
DL-3-22	22	140	2760
DL-3-23	23	140	2900
DL-3-24	24	140	3040
DL-3-25	25	140	3180
DL-3-26	26	140	3320
DL-3-27	27	140	3460
DL-3-28	28	140	3600
DL-3-29	29	140	3740
DL-3-30	30	140	3880
DL-3-31	31	140	4020
DL-3-32	32	140	4160
DL-3-33	33	140	4300
DL-3-34	34	140	4440
DL-3-35	35	140	4580
DL-3-36	36	150	4730

A29 Volume of CT water flow through D3 column (low flowrate) (cont'd)

No.	Day	V (ml)	Sum-V (ml)
DL-3-37	37	150	4880
DL-3-38	38	150	5030
DL-3-39	39	140	5170
DL-3-40	40	150	5320
DL-3-41	41	150	5470
DL-3-42	42	150	5620
DL-3-43	43	145	5765
DL-3-44	44	165	5930
DL-3-45	45	150	6080
DL-3-46	46	140	6220
DL-3-47	47	145	6365
DL-3-48	48	145	6510
DL-3-49	49	140	6650
DL-3-50	50	140	6790
DL-3-51	51	135	6925
DL-3-52	52	145	7070
DL-3-53	53	150	7220
DL-3-54	54	160	7380
DL-3-55	55	150	7530
DL-3-56	56	145	7675
DL-3-57	57	150	7825
DL-3-58	58	150	7975
DL-3-59	59	165	8140
DL-3-60	60	145	8285
DL-3-61	61	150	8435
DL-3-62	62	160	8595
DL-3-63	63	150	8745
DL-3-64	64	145	8890
DL-3-65	65	155	9045
DL-3-66	66	140	9185
DL-3-67	67	135	9320
DL-3-68	68	140	9460
DL-3-69	69	150	9610
DL-3-70	70	160	9770
DL-3-71	71	145	9915
DL-3-72	72	150	10065

A29 Volume of CT water flow through D3 column (low flowrate) (cont'd)

No.	Day	V (ml)	Sum-V (ml)
DL-3-73	73	145	10210
DL-3-74	74	140	10350
DL-3-75	75	100	10450
DL-3-76	76	145	10595
DL-3-77	77	160	10755
DL-3-78	78	150	10905
DL-3-79	79	150	11055
DL-3-80	80	155	11210
DL-3-81	81	160	11370
DL-3-82	82	145	11515
DL-3-83	83	150	11665
DL-3-84	84	150	11815
DL-3-85	85	145	11960
DL-3-86	86	150	12110
DL-3-87	87	150	12260
DL-3-88	88	150	12410
DL-3-89	89	155	12565
DL-3-90	90	150	12715
DL-3-91	91	160	12875
DL-3-92	92	155	13030
DL-3-93	93	160	13190
DL-3-94	94	160	13350
DL-3-95	95	150	13500
DL-3-96	96	160	13660
DL-3-97	97	150	13810
DL-3-98	98	165	13975
DL-3-99	99	155	14130
DL-3-100	100	150	14280
DL-3-101	101	160	14440
DL-3-102	102	145	14585
DL-3-103	103	150	14735
DL-3-104	104	185	14920
DL-3-105	105	160	15080
DL-3-106	106	160	15240
DL-3-107	107	165	15405
DL-3-108	108	165	15570

A29 Volume of CT water flow through D3 column (low flowrate) (cont'd)

No.	Day	V (ml)	Sum-V (ml)
DL-3-109	109	165	15735
DL-3-110	110	150	15885
DL-3-111	111	145	16030
DL-3-112	112	150	16180
DL-3-113	113	150	16330
DL-3-114	114	165	16495
DL-3-115	115	160	16655
DL-3-116	116	150	16805
DL-3-117	117	170	16975
DL-3-118	118	175	17150
DL-3-119	119	165	17315
DL-3-120	120	160	17475
DL-3-121	121	165	17640
DL-3-122	122	155	17795
DL-3-123	123	150	17945
DL-3-124	124	150	18095
DL-3-125	125	160	18255
DL-3-126	126	165	18420
DL-3-127	127	155	18575
DL-3-128	128	150	18725
DL-3-129	129	145	18870
DL-3-130	130	150	19020
DL-3-131	131	160	19180
DL-3-132	132	150	19330
DL-3-133	133	155	19485
DL-3-134	134	150	19635
DL-3-135	135	150	19785
DL-3-136	136	150	19935
DL-3-137	137	155	20090
DL-3-138	138	140	20230
DL-3-139	139	140	20370
DL-3-140	140	145	20515
Flowrate	*3360 hrs*	*20515*	*6.11 ml/h*

A30 Volume of CT water flow through D4 column (low flowrate)

No.	Day	V (ml)	Sum-V (ml)
DL-4-1	1	0	0
DL-4-2	2	0	0
DL-4-3	3	140	140
DL-4-4	4	140	280
DL-4-5	5	140	420
DL-4-6	6	140	560
DL-4-7	7	140	700
DL-4-8	8	140	840
DL-4-9	9	140	980
DL-4-10	10	140	1120
DL-4-11	11	140	1260
DL-4-12	12	140	1400
DL-4-13	13	140	1540
DL-4-14	14	140	1680
DL-4-15	15	140	1820
DL-4-16	16	140	1960
DL-4-17	17	140	2100
DL-4-18	18	140	2240
DL-4-19	19	140	2380
DL-4-20	20	140	2520
DL-4-21	21	140	2660
DL-4-22	22	140	2800
DL-4-23	23	140	2940
DL-4-24	24	140	3080
DL-4-25	25	140	3220
DL-4-26	26	140	3360
DL-4-27	27	140	3500
DL-4-28	28	140	3640
DL-4-29	29	150	3790
DL-4-30	30	160	3950
DL-4-31	31	145	4095
DL-4-32	32	140	4235
DL-4-33	33	150	4385
DL-4-34	34	145	4530
DL-4-35	35	150	4680
DL-4-36	36	150	4830

A30 Volume of CT water flow through D4 column (low flowrate) (cont'd)

No.	Day	V (ml)	Sum-V (ml)
DL-4-37	37	150	4980
DL-4-38	38	155	5135
DL-4-39	39	140	5275
DL-4-40	40	160	5435
DL-4-41	41	150	5585
DL-4-42	42	145	5730
DL-4-43	43	150	5880
DL-4-44	44	150	6030
DL-4-45	45	150	6180
DL-4-46	46	140	6320
DL-4-47	47	165	6485
DL-4-48	48	160	6645
DL-4-49	49	150	6795
DL-4-50	50	165	6960
DL-4-51	51	150	7110
DL-4-52	52	155	7265
DL-4-53	53	150	7415
DL-4-54	54	145	7560
DL-4-55	55	155	7715
DL-4-56	56	150	7865
DL-4-57	57	170	8035
DL-4-58	58	165	8200
DL-4-59	59	145	8345
DL-4-60	60	165	8510
DL-4-61	61	160	8670
DL-4-62	62	150	8820
DL-4-63	63	165	8985
DL-4-64	64	140	9125
DL-4-65	65	150	9275
DL-4-66	66	145	9420
DL-4-67	67	140	9560
DL-4-68	68	150	9710
DL-4-69	69	140	9850
DL-4-70	70	145	9995
DL-4-71	71	150	10145
DL-4-72	72	160	10305

A30 Volume of CT water flow through D4 column (low flowrate) (cont'd)

No.	Day	V (ml)	Sum-V (ml)
DL-4-73	73	145	10450
DL-4-74	74	160	10610
DL-4-75	75	165	10775
DL-4-76	76	160	10935
DL-4-77	77	160	11095
DL-4-78	78	160	11255
DL-4-79	79	150	11405
DL-4-80	80	145	11550
DL-4-81	81	150	11700
DL-4-82	82	160	11860
DL-4-83	83	150	12010
DL-4-84	84	150	12160
DL-4-85	85	160	12320
DL-4-86	86	160	12480
DL-4-87	87	165	12645
DL-4-88	88	160	12805
DL-4-89	89	165	12970
DL-4-90	90	150	13120
DL-4-91	91	165	13285
DL-4-92	92	145	13430
DL-4-93	93	160	13590
DL-4-94	94	165	13755
DL-4-95	95	150	13905
DL-4-96	96	145	14050
DL-4-97	97	150	14200
DL-4-98	98	155	14355
DL-4-99	99	160	14515
DL-4-100	100	155	14670
DL-4-101	101	165	14835
DL-4-102	102	160	14995
DL-4-103	103	150	15145
DL-4-104	104	160	15305
DL-4-105	105	160	15465
DL-4-106	106	155	15620
DL-4-107	107	150	15770
DL-4-108	108	155	15925

A30 Volume of CT water flow through D4 column (low flowrate) (cont'd)

No.	Day	V (ml)	Sum-V (ml)
DL-4-109	109	150	16075
DL-4-110	110	145	16220
DL-4-111	111	140	16360
DL-4-112	112	150	16510
DL-4-113	113	160	16670
DL-4-114	114	155	16825
DL-4-115	115	160	16985
DL-4-116	116	145	17130
DL-4-117	117	165	17295
DL-4-118	118	150	17445
DL-4-119	119	155	17600
DL-4-120	120	150	17750
DL-4-121	121	165	17915
DL-4-122	122	150	18065
DL-4-123	123	145	18210
DL-4-124	124	145	18355
DL-4-125	125	155	18510
DL-4-126	126	150	18660
DL-4-127	127	160	18820
DL-4-128	128	145	18965
DL-4-129	129	155	19120
DL-4-130	130	150	19270
DL-4-131	131	160	19430
DL-4-132	132	145	19575
DL-4-133	133	150	19725
DL-4-134	134	140	19865
DL-4-135	135	150	20015
DL-4-136	136	140	20155
DL-4-137	137	155	20310
DL-4-138	138	150	20460
DL-4-139	139	140	20600
DL-4-140	140	140	20740
Flowrate	*3360 hrs*	*20740*	*6.17 ml/h*

A31 Change of MFT height in DH system

No	t_{incu} (d)	H (cm)	No	t_{incu} (d)	H (cm)	No	t_{incu} (d)	H (cm)	No	t_{incu} (d)	H (cm)
DH-1-1	1	-0.4	DH-2-1	1	0.5	DH-3-1	1	-0.1	DH-4-1	1	0.0
DH-1-2	2	-0.4	DH-2-2	2	0.5	DH-3-2	2	0.1	DH-4-2	2	0.2
DH-1-3	3	-0.5	DH-2-3	3	0.6	DH-3-3	3	0.6	DH-4-3	3	0.0
DH-1-4	4	0.0	DH-2-4	4	0.7	DH-3-4	4	0.6	DH-4-4	4	0.2
DH-1-5	5	0.8	DH-2-5	5	0.8	DH-3-5	5	0.6	DH-4-5	5	0.2
DH-1-6	6	0.0	DH-2-6	6	0.9	DH-3-6	6	0.6	DH-4-6	6	-0.6
DH-1-7	7	-0.3	DH-2-7	7	1.0	DH-3-7	7	0.5	DH-4-7	7	-1.1
DH-1-8	8	-0.1	DH-2-8	8	1.1	DH-3-8	8	0.1	DH-4-8	8	-1.3
DH-1-9	9	-0.3	DH-2-9	9	1.2	DH-3-9	9	-0.1	DH-4-9	9	-1.5
DH-1-10	10	-0.3	DH-2-10	10	1.1	DH-3-10	10	-0.1	DH-4-10	10	-1.8
DH-1-11	11	-0.4	DH-2-11	11	1.2	DH-3-11	11	0.3	DH-4-11	11	-1.8
DH-1-12	12	-0.4	DH-2-12	12	1.1	DH-3-12	12	0.4	DH-4-12	12	-2.0
DH-1-13	13	-0.5	DH-2-13	13	1.0	DH-3-13	13	0.0	DH-4-13	13	-1.8
DH-1-14	14	-0.3	DH-2-14	14	1.1	DH-3-14	14	0.8	DH-4-14	14	-2.0
DH-1-15	15	-0.3	DH-2-15	15	1.4	DH-3-15	15	-0.5	DH-4-15	15	-1.9
DH-1-16	16	-0.3	DH-2-16	16	1.1	DH-3-16	16	-0.8	DH-4-16	16	-1.8
DH-1-17	17	-0.2	DH-2-17	17	0.9	DH-3-17	17	-0.7	DH-4-17	17	-1.7
DH-1-18	18	0.0	DH-2-18	18	1.2	DH-3-18	18	-0.9	DH-4-18	18	-1.6
DH-1-19	19	-0.4	DH-2-19	19	0.6	DH-3-19	19	-0.9	DH-4-19	19	-1.6
DH-1-20	20	-0.4	DH-2-20	20	1.4	DH-3-20	20	-1.6	DH-4-20	20	1.5
DH-1-21	21	0.1	DH-2-21	21	1.1	DH-3-21	21	-1.9	DH-4-21	21	-1.4
DH-1-22	22	0.0	DH-2-22	22	1.0	DH-3-22	22	-1.1	DH-4-22	22	-1.2
DH-1-23	23	-0.4	DH-2-23	23	1.0	DH-3-23	23	-1.0	DH-4-23	23	-1.0
DH-1-24	24	-0.2	DH-2-24	24	1.0	DH-3-24	24	-1.7	DH-4-24	24	1.0
DH-1-25	25	-0.4	DH-2-25	25	0.6	DH-3-25	25	-1.8	DH-4-25	25	-1.0
DH-1-26	26	0.1	DH-2-26	26	0.6	DH-3-26	26	-2.0	DH-4-26	26	-1.0
DH-1-27	27	-0.4	DH-2-27	27	1.0	DH-3-27	27	-1.6	DH-4-27	27	-1.2
DH-1-28	28	-0.2	DH-2-28	28	0.8	DH-3-28	28	-1.4	DH-4-28	28	-1.4
DH-1-29	29	-0.1	DH-2-29	29	0.7	DH-3-29	29	-1.4	DH-4-29	29	-1.6
DH-1-30	30	-0.3	DH-2-30	30	0.8	DH-3-30	30	-1.4	DH-4-30	30	-1.8
DH-1-31	31	-0.1	DH-2-31	31	0.8	DH-3-31	31	-2.1	DH-4-31	31	-1.9
DH-1-32	32	-0.2	DH-2-32	32	0.8	DH-3-32	32	-1.9	DH-4-32	32	-2.0
DH-1-33	33	-0.1	DH-2-33	33	0.6	DH-3-33	33	-1.4	DH-4-33	33	-2.2
DH-1-34	34	-0.1	DH-2-34	34	1.0	DH-3-34	34	-1.6	DH-4-34	34	-2.5
DH-1-35	35	-0.4	DH-2-35	35	1.0	DH-3-35	35	-1.7	DH-4-35	35	-1.5
DH-1-36	36	-0.5	DH-2-36	36	1.2	DH-3-36	36	-1.9	DH-4-36	36	-1.5
DH-1-37	37	-0.2	DH-2-37	37	1.0	DH-3-37	37	-2.1	DH-4-37	37	-2.0
DH-1-38	38	-0.3	DH-2-38	38	1.0	DH-3-38	38	-2.1	DH-4-38	38	-2.5
DH-1-39	39	-0.4	DH-2-39	39	1.0	DH-3-39	39	-2.1	DH-4-39	39	-2.0
DH-1-40	40	-0.1	DH-2-40	40	0.7	DH-3-40	40	-2.4	DH-4-40	40	-1.8
DH-1-41	41	0.0	DH-2-41	41	0.6	DH-3-41	41	-2.6	DH-4-41	41	-1.5
DH-1-42	42	-0.8	DH-2-42	42	0.5	DH-3-42	42	-1.9	DH-4-42	42	-1.1
DH-1-43	43	-0.8	DH-2-43	43	0.5	DH-3-43	43	-1.8	DH-4-43	43	-1.1
DH-1-44	44	-0.9	DH-2-44	44	-0.1	DH-3-44	44	-2.0	DH-4-44	44	-1.1

A31 Change of MFT height in DH system (cont'd)

No	t_{incu} (d)	H (cm)	No	t_{incu} (d)	H (cm)	No	t_{incu} (d)	H (cm)	No	t_{incu} (d)	H (cm)
DH-1-45	45	-0.8	DH-2-45	45	-0.1	DH-3-45	45	-2.5	DH-4-45	45	-1.8
DH-1-46	46	-0.7	DH-2-46	46	-0.1	DH-3-46	46	-2.4	DH-4-46	46	-1.5
DH-1-47	47	-0.8	DH-2-47	47	-0.2	DH-3-47	47	-2.3	DH-4-47	47	-1.4
DH-1-48	48	-0.7	DH-2-48	48	-0.1	DH-3-48	48	-2.1	DH-4-48	48	-1.3
DH-1-49	49	-1.1	DH-2-49	49	0.1	DH-3-49	49	-2.0	DH-4-49	49	-1.3
DH-1-50	50	-1.0	DH-2-50	50	-0.5	DH-3-50	50	-2.0	DH-4-50	50	1.1
DH-1-51	51	-1.0	DH-2-51	51	-0.3	DH-3-51	51	-2.0	DH-4-51	51	-1.0
DH-1-52	52	-0.7	DH-2-52	52	-0.1	DH-3-52	52	-2.7	DH-4-52	52	-1.0
DH-1-53	53	-0.7	DH-2-53	53	0.0	DH-3-53	53	-2.7	DH-4-53	53	-1.0
DH-1-54	54	-0.9	DH-2-54	54	-0.2	DH-3-54	54	-2.7	DH-4-54	54	-1.0
DH-1-55	55	-0.3	DH-2-55	55	-0.1	DH-3-55	55	-2.6	DH-4-55	55	-1.0
DH-1-56	56	-0.9	DH-2-56	56	-0.1	DH-3-56	56	-2.5	DH-4-56	56	-1.0
DH-1-57	57	-0.6	DH-2-57	57	-0.2	DH-3-57	57	2.1	DH-4-57	57	-0.9
DH-1-58	58	-0.5	DH-2-58	58	-0.2	DH-3-58	58	-2.0	DH-4-58	58	-1.0
DH-1-59	59	-1.2	DH-2-59	59	-0.2	DH-3-59	59	-2.0	DH-4-59	59	-1.0
DH-1-60	60	-1.5	DH-2-60	60	0.3	DH-3-60	60	-2.0	DH-4-60	60	-1.0

Note: when t = 0, the height of MFT = 0

A32 Change of MFT height in DL system

No	t_{incu} (d)	H (cm)	No	t_{incu} (d)	H (cm)	No	t_{incu} (d)	H (cm)	No	t_{incu} (d)	H (cm)
DL-1-1	1	0.5	DL-2-1	1	0.0	DL-3-1	1	-0.1	DL-4-1	1	0.0
DL-1-2	2	1.5	DL-2-2	2	-0.4	DL-3-2	2	-0.2	DL-4-2	2	0.1
DL-1-3	3	1.6	DL-2-3	3	-0.9	DL-3-3	3	0.0	DL-4-3	3	0.4
DL-1-4	4	1.8	DL-2-4	4	-1.9	DL-3-4	4	0.1	DL-4-4	4	-0.6
DL-1-5	5	1.4	DL-2-5	5	-2.0	DL-3-5	5	0.2	DL-4-5	5	-0.7
DL-1-6	6	1.4	DL-2-6	6	-2.1	DL-3-6	6	1.1	DL-4-6	6	-2.0
DL-1-7	7	1.4	DL-2-7	7	-0.9	DL-3-7	7	0.2	DL-4-7	7	-2.4
DL-1-8	8	1.5	DL-2-8	8	-0.8	DL-3-8	8	0.0	DL-4-8	8	-2.5
DL-1-9	9	1.7	DL-2-9	9	-0.6	DL-3-9	9	-0.3	DL-4-9	9	-2.2
DL-1-10	10	1.9	DL-2-10	10	-0.5	DL-3-10	10	-0.3	DL-4-10	10	-2.3
DL-1-11	11	1.8	DL-2-11	11	-0.8	DL-3-11	11	-0.4	DL-4-11	11	-2.0
DL-1-12	12	1.8	DL-2-12	12	-0.4	DL-3-12	12	-0.5	DL-4-12	12	-1.6
DL-1-13	13	1.6	DL-2-13	13	0.0	DL-3-13	13	0.0	DL-4-13	13	-1.7
DL-1-14	14	1.9	DL-2-14	14	-0.4	DL-3-14	14	0.0	DL-4-14	14	-1.7
DL-1-15	15	1.8	DL-2-15	15	-0.4	DL-3-15	15	-0.1	DL-4-15	15	-1.6
DL-1-16	16	1.8	DL-2-16	16	0.3	DL-3-16	16	-0.2	DL-4-16	16	-1.6
DL-1-17	17	1.7	DL-2-17	17	0.7	DL-3-17	17	0.4	DL-4-17	17	-1.6
DL-1-18	18	1.6	DL-2-18	18	1.0	DL-3-18	18	-0.6	DL-4-18	18	-1.6
DL-1-19	19	1.9	DL-2-19	19	-4.0	DL-3-19	19	-0.5	DL-4-19	19	-1.6
DL-1-20	20	1.7	DL-2-20	20	-4.5	DL-3-20	20	0.7	DL-4-20	20	-1.5
DL-1-21	21	1.6	DL-2-21	21	-3.0	DL-3-21	21	-1.0	DL-4-21	21	-1.5
DL-1-22	22	1.5	DL-2-22	22	-2.0	DL-3-22	22	-0.8	DL-4-22	22	-2.0
DL-1-23	23	1.4	DL-2-23	23	-2.4	DL-3-23	23	-0.5	DL-4-23	23	-2.6
DL-1-24	24	1.4	DL-2-24	24	2.0	DL-3-24	24	-0.3	DL-4-24	24	-2.0
DL-1-25	25	1.3	DL-2-25	25	1.8	DL-3-25	25	-0.2	DL-4-25	25	1.8
DL-1-26	26	1.9	DL-2-26	26	-2.0	DL-3-26	26	0.2	DL-4-26	26	-1.8
DL-1-27	27	1.2	DL-2-27	27	-2.1	DL-3-27	27	-0.4	DL-4-27	27	-2.2
DL-1-28	28	1.1	DL-2-28	28	-2.0	DL-3-28	28	0.6	DL-4-28	28	-2.8
DL-1-29	29	0.9	DL-2-29	29	-2.0	DL-3-29	29	-0.9	DL-4-29	29	-2.9
DL-1-30	30	0.6	DL-2-30	30	-1.8	DL-3-30	30	-1.0	DL-4-30	30	-3.0
DL-1-31	31	0.5	DL-2-31	31	-2.0	DL-3-31	31	-1.0	DL-4-31	31	-3.0
DL-1-32	32	0.3	DL-2-32	32	2.0	DL-3-32	32	-1.2	DL-4-32	32	-3.0
DL-1-33	33	0.1	DL-2-33	33	-1.7	DL-3-33	33	1.2	DL-4-33	33	-3.0
DL-1-34	34	0.5	DL-2-34	34	-2.0	DL-3-34	34	-1.3	DL-4-34	34	-3.3
DL-1-35	35	0.4	DL-2-35	35	-2.0	DL-3-35	35	-1.5	DL-4-35	35	-2.8
DL-1-36	36	0.5	DL-2-36	36	-2.0	DL-3-36	36	-1.0	DL-4-36	36	-2.5
DL-1-37	37	0.4	DL-2-37	37	-1.5	DL-3-37	37	-0.5	DL-4-37	37	-2.9
DL-1-38	38	0.3	DL-2-38	38	-2.0	DL-3-38	38	-0.9	DL-4-38	38	-3.0
DL-1-39	39	0.3	DL-2-39	39	-1.8	DL-3-39	39	-1.1	DL-4-39	39	-3.0
DL-1-40	40	0.3	DL-2-40	40	-1.6	DL-3-40	40	-1.3	DL-4-40	40	-3.0
DL-1-41	41	0.0	DL-2-41	41	-1.8	DL-3-41	41	-1.6	DL-4-41	41	-3.2
DL-1-42	42	0.0	DL-2-42	42	-1.8	DL-3-42	42	-1.7	DL-4-42	42	-3.5
DL-1-43	43	0.0	DL-2-43	43	-1.0	DL-3-43	43	-1.8	DL-4-43	43	-3.4
DL-1-44	44	0.0	DL-2-44	44	-0.6	DL-3-44	44	-2.0	DL-4-44	44	-3.3
DL-1-45	45	-0.1	DL-2-45	45	0.4	DL-3-45	45	-2.1	DL-4-45	45	-2.3

A32 Change of MFT height in DL system (cont'd)

No	t_{incu} (d)	H (cm)	No	t_{incu} (d)	H (cm)	No	t_{incu} (d)	H (cm)	No	t_{incu} (d)	H (cm)
DL-1-46	46	0.0	DL-2-46	46	0.5	DL-3-46	46	-2.1	DL-4-46	46	-2.3
DL-1-47	47	-0.4	DL-2-47	47	1.0	DL-3-47	47	-2.2	DL-4-47	47	-2.3
DL-1-48	48	0.4	DL-2-48	48	0.6	DL-3-48	48	-2.1	DL-4-48	48	-2.8
DL-1-49	49	-0.5	DL-2-49	49	0.9	DL-3-49	49	-2.0	DL-4-49	49	-3.2
DL-1-50	50	-0.5	DL-2-50	50	0.7	DL-3-50	50	-1.8	DL-4-50	50	-3.3
DL-1-51	51	-0.2	DL-2-51	51	0.5	DL-3-51	51	-1.5	DL-4-51	51	-3.4
DL-1-52	52	-0.2	DL-2-52	52	0.0	DL-3-52	52	-1.3	DL-4-52	52	-3.4
DL-1-53	53	-0.2	DL-2-53	53	0.0	DL-3-53	53	-0.6	DL-4-53	53	-3.5
DL-1-54	54	-0.3	DL-2-54	54	0.0	DL-3-54	54	-0.5	DL-4-54	54	-3.5
DL-1-55	55	-0.2	DL-2-55	55	-0.1	DL-3-55	55	-1.5	DL-4-55	55	-3.5
DL-1-56	56	0.3	DL-2-56	56	0.1	DL-3-56	56	-2.1	DL-4-56	56	-3.6
DL-1-57	57	-0.2	DL-2-57	57	-0.2	DL-3-57	57	-2.0	DL-4-57	57	-2.5
DL-1-58	58	0.4	DL-2-58	58	-0.5	DL-3-58	58	-1.8	DL-4-58	58	-2.5
DL-1-59	59	-0.9	DL-2-59	59	-0.5	DL-3-59	59	-1.5	DL-4-59	59	-2.5
DL-1-60	60	-0.9	DL-2-60	60	-0.4	DL-3-60	60	-1.1	DL-4-60	60	-2.5
DL-1-61	61	-1.0	DL-2-61	61	-0.4	DL-3-61	61	-1.5	DL-4-61	61	-2.6
DL-1-62	62	-0.9	DL-2-62	62	-0.5	DL-3-62	62	-1.9	DL-4-62	62	-2.5
DL-1-63	63	-0.7	DL-2-63	63	-0.5	DL-3-63	63	-2.1	DL-4-63	63	-2.5
DL-1-64	64	-0.7	DL-2-64	64	-0.5	DL-3-64	64	-2.4	DL-4-64	64	-2.5
DL-1-65	65	-0.8	DL-2-65	65	-0.6	DL-3-65	65	-2.1	DL-4-65	65	-2.5
DL-1-66	66	-0.4	DL-2-66	66	-0.7	DL-3-66	66	-2.0	DL-4-66	66	-2.5
DL-1-67	67	-1.0	DL-2-67	67	-0.5	DL-3-67	67	-2.1	DL-4-67	67	-2.6
DL-1-68	68	-1.0	DL-2-68	68	-0.4	DL-3-68	68	-2.3	DL-4-68	68	-2.8
DL-1-69	69	-1.0	DL-2-69	69	-0.5	DL-3-69	69	-1.4	DL-4-69	69	-2.7
DL-1-70	70	-1.0	DL-2-70	70	-0.6	DL-3-70	70	-1.3	DL-4-70	70	-2.8
DL-1-71	71	-1.0	DL-2-71	71	-0.7	DL-3-71	71	-1.4	DL-4-71	71	-1.5
DL-1-72	72	-1.1	DL-2-72	72	-1.0	DL-3-72	72	-1.4	DL-4-72	72	-1.4
DL-1-73	73	-0.9	DL-2-73	73	-0.8	DL-3-73	73	-1.5	DL-4-73	73	-1.5
DL-1-74	74	-1.0	DL-2-74	74	-0.8	DL-3-74	74	-1.6	DL-4-74	74	-1.6
DL-1-75	75	-0.8	DL-2-75	75	-0.8	DL-3-75	75	-2.0	DL-4-75	75	-1.8
DL-1-76	76	-1.0	DL-2-76	76	-1.0	DL-3-76	76	-1.4	DL-4-76	76	-2.4
DL-1-77	77	-0.9	DL-2-77	77	-0.8	DL-3-77	77	-1.0	DL-4-77	77	-3.0
DL-1-78	78	-0.5	DL-2-78	78	-0.8	DL-3-78	78	-0.8	DL-4-78	78	-3.1
DL-1-79	79	-0.5	DL-2-79	79	-0.9	DL-3-79	79	1.2	DL-4-79	79	-3.2
DL-1-80	80	-0.5	DL-2-80	80	-0.9	DL-3-80	80	-1.8	DL-4-80	80	-3.2
DL-1-81	81	-0.5	DL-2-81	81	-0.9	DL-3-81	81	-2.0	DL-4-81	81	-3.3
DL-1-82	82	-0.5	DL-2-82	82	0.3	DL-3-82	82	-2.0	DL-4-82	82	-3.4
DL-1-83	83	-0.5	DL-2-83	83	0.0	DL-3-83	83	-2.1	DL-4-83	83	-3.5
DL-1-84	84	1.0	DL-2-84	84	-0.2	DL-3-84	84	-2.2	DL-4-84	84	3.0
DL-1-85	85	1.3	DL-2-85	85	-0.7	DL-3-85	85	-1.8	DL-4-85	85	-2.5
DL-1-86	86	1.0	DL-2-86	86	-1.6	DL-3-86	86	-1.5	DL-4-86	86	-2.2
DL-1-87	87	1.0	DL-2-87	87	-3.0	DL-3-87	87	-1.5	DL-4-87	87	-2.0
DL-1-88	88	1.2	DL-2-88	88	-2.4	DL-3-88	88	-1.6	DL-4-88	88	-2.0
DL-1-89	89	1.5	DL-2-89	89	-2.4	DL-3-89	89	-1.7	DL-4-89	89	-2.0
DL-1-90	90	1.5	DL-2-90	90	-2.5	DL-3-90	90	-1.8	DL-4-90	90	-2.5

A32 Change of MFT height in DL system (cont'd)

No	t_{incu} (d)	H (cm)	No	t_{incu} (d)	H (cm)	No	t_{incu} (d)	H (cm)	No	t_{incu} (d)	H (cm)
DL-1-91	91	1.5	DL-2-91	91	-2.5	DL-3-91	91	-1.1	DL-4-91	91	-3.0
DL-1-92	92	1.7	DL-2-92	92	-2.5	DL-3-92	92	-1.0	DL-4-92	92	-3.2
DL-1-93	93	2.0	DL-2-93	93	2.1	DL-3-93	93	-1.1	DL-4-93	93	-3.3
DL-1-94	94	2.0	DL-2-94	94	4.1	DL-3-94	94	-1.2	DL-4-94	94	-3.3
DL-1-95	95	2.0	DL-2-95	95	4.5	DL-3-95	95	-1.8	DL-4-95	95	-3.4
DL-1-96	96	2.1	DL-2-96	96	6.5	DL-3-96	96	-2.1	DL-4-96	96	-3.6
DL-1-97	97	2.5	DL-2-97	97	6.4	DL-3-97	97	-2.4	DL-4-97	97	-3.7
DL-1-98	98	1.5	DL-2-98	98	6.4	DL-3-98	98	-2.5	DL-4-98	98	-3.8
DL-1-99	99	2.0	DL-2-99	99	6.5	DL-3-99	99	-2.6	DL-4-99	99	-2.2
DL-1-100	100	-0.4	DL-2-100	100	5.8	DL-3-100	100	-1.7	DL-4-100	100	-2.3
DL-1-101	101	0.6	DL-2-101	101	5.6	DL-3-101	101	-1.6	DL-4-101	101	-2.2
DL-1-102	102	1.2	DL-2-102	102	5.5	DL-3-102	102	-1.7	DL-4-102	102	-2.1
DL-1-103	103	1.0	DL-2-103	103	5.4	DL-3-103	103	-1.8	DL-4-103	103	-2.5
DL-1-104	104	0.9	DL-2-104	104	5.3	DL-3-104	104	-1.9	DL-4-104	104	-3.0
DL-1-105	105	0.8	DL-2-105	105	5.3	DL-3-105	105	-2.0	DL-4-105	105	-3.4
DL-1-106	106	0.7	DL-2-106	106	5.3	DL-3-106	106	-2.1	DL-4-106	106	-3.4
DL-1-107	107	0.7	DL-2-107	107	5.5	DL-3-107	107	-2.2	DL-4-107	107	-3.5
DL-1-108	108	0.5	DL-2-108	108	5.5	DL-3-108	108	-2.5	DL-4-108	108	-3.4
DL-1-109	109	0.5	DL-2-109	109	5.4	DL-3-109	109	-2.7	DL-4-109	109	-3.2
DL-1-110	110	0.4	DL-2-110	110	5.5	DL-3-110	110	-2.5	DL-4-110	110	-2.5
DL-1-111	111	0.3	DL-2-111	111	5.5	DL-3-111	111	-2.4	DL-4-111	111	2.0
DL-1-112	112	0.3	DL-2-112	112	6.2	DL-3-112	112	-2.4	DL-4-112	112	-1.8
DL-1-113	113	0.3	DL-2-113	113	6.3	DL-3-113	113	-2.5	DL-4-113	113	-1.6
DL-1-114	114	0.5	DL-2-114	114	6.2	DL-3-114	114	-2.6	DL-4-114	114	-1.6
DL-1-115	115	0.3	DL-2-115	115	6.3	DL-3-115	115	-2.5	DL-4-115	115	-1.5
DL-1-116	116	0.0	DL-2-116	116	6.3	DL-3-116	116	-2.6	DL-4-116	116	1.5
DL-1-117	117	0.0	DL-2-117	117	6.2	DL-3-117	117	-2.2	DL-4-117	117	-1.4
DL-1-118	118	0.0	DL-2-118	118	6.1	DL-3-118	118	-2.0	DL-4-118	118	-1.4
DL-1-119	119	0.0	DL-2-119	119	6.1	DL-3-119	119	-2.0	DL-4-119	119	-1.4
DL-1-120	120	1.2	DL-2-120	120	6.2	DL-3-120	120	-2.0	DL-4-120	120	-1.3
DL-1-121	121	0.0	DL-2-121	121	6.2	DL-3-121	121	-2.0	DL-4-121	121	-1.4
DL-1-122	122	-0.1	DL-2-122	122	6.2	DL-3-122	122	-2.0	DL-4-122	122	-1.8
DL-1-123	123	-0.2	DL-2-123	123	6.2	DL-3-123	123	-2.0	DL-4-123	123	-2.0
DL-1-124	124	-0.2	DL-2-124	124	6.2	DL-3-124	124	-2.0	DL-4-124	124	-3.5
DL-1-125	125	0.3	DL-2-125	125	6.2	DL-3-125	125	-1.9	DL-4-125	125	-3.6
DL-1-126	126	0.5	DL-2-126	126	6.2	DL-3-126	126	-1.8	DL-4-126	126	-4.0
DL-1-127	127	0.0	DL-2-127	127	6.2	DL-3-127	127	-1.8	DL-4-127	127	-4.5
DL-1-128	128	0.0	DL-2-128	128	6.2	DL-3-128	128	-1.8	DL-4-128	128	-4.7
DL-1-129	129	0.0	DL-2-129	129	6.2	DL-3-129	129	-2.0	DL-4-129	129	-4.5
DL-1-130	130	0.0	DL-2-130	130	6.2	DL-3-130	130	-2.5	DL-4-130	130	-4.5
DL-1-131	131	0.0	DL-2-131	131	6.2	DL-3-131	131	-2.8	DL-4-131	131	-4.8
DL-1-132	132	0.0	DL-2-132	132	-2.1	DL-3-132	132	-2.9	DL-4-132	132	-5.0
DL-1-133	133	0.0	DL-2-133	133	-2.1	DL-3-133	133	-3.2	DL-4-133	133	-5.0
DL-1-134	134	0.0	DL-2-134	134	-2.1	DL-3-134	134	-2.5	DL-4-134	134	-5.0
DL-1-135	135	0.0	DL-2-135	135	-2.1	DL-3-135	135	-2.1	DL-4-135	135	-5.0

A32 Change of MFT height in DL system (cont'd)

No	t_{incu} (d)	H (cm)	No	t_{incu} (d)	H (cm)	No	t_{incu} (d)	H (cm)	No	t_{incu} (d)	H (cm)
DL-1-136	136	0.0	DL-2-136	136	-2.1	DL-3-136	136	-2.4	DL-4-136	136	-5.0
DL-1-137	137	0.0	DL-2-137	137	-2.1	DL-3-137	137	-2.6	DL-4-137	137	-5.0
DL-1-138	138	0.0	DL-2-138	138	-2.1	DL-3-138	138	-2.7	DL-4-138	138	-5.0
DL-1-139	139	0.0	DL-2-139	139	-2.1	DL-3-139	139	-2.5	DL-4-139	139	-5.0
DL-1-140	140	0.0	DL-2-140	140	-2.8	DL-3-140	140	-2.5	DL-4-140	140	-5.0

Note: when t = 0, the height of MFT = 0

Appendix B Jar Test and Static Barrel Mesocosms Results

B1 Results of chemical analysis in barrel and C1 system

System	Sample ID	Sample Type	Incub. Time (y)	pH	Cond	Br^+	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	SO_4^{2-}	CO_3^{2-} (wt ppm)	HCO_3^- (wt ppm)	Total Cations	Total Anions	Ratio Cat/Ani	Alkalinity expressed as HCO_3^-	ALK pH	S^{2-}
Barrel 1	B1-TOP	RelW	2	7.99	5700	170	1340	18.1	21.1	35.8	1100	445	0.0	1400	62.3	65.3	0.95	1148	8.3	160
Barrel 1	B1-MFT-U	PoreW	2	8.20	5040	230	1130	13.6	11.0	14.9	1070	96.3	0.0	1260	51.1	55.7	0.92	1033	8.0	27.3
Barrel 1	B1-CT-U	PoreW	2	8.15	4860	210	1170	14.5	10.1	17.9	1100	135	0.0	1130	53.0	54.9	0.96	926	7.9	132
Barrel 1	B1-CT-L	PoreW	2	8.28	4870	270	1190	15.1	9.9	17.4	1200	161	0.0	1080	53.8	58.2	0.92	885	7.8	106
Barrel 2	B2-TOP	RelW	2	8.10	5480	180	1280	17.0	19.0	26.5	1000	358	21.6	1340	59.0	60.6	0.97	1134	8.4	131
Barrel 2	B2-MFT-U	PoreW	2	8.21	7830	210	1140	15.4	10.6	13.3	1100	194	0.0	992	51.5	53.9	0.96	813	8.0	65.1
Barrel 2	B2-MFT-L	PoreW	2	8.20	7800	210	1120	14.1	10.1	13.3	1100	148	0.0	1010	50.6	53.3	0.95	828	8.1	48.5
Barrel 2	B2-CT-U	PoreW	2	8.19	4890	210	1140	13.8	10.2	18.5	1100	167	0.0	1050	51.7	54.3	0.95	861	7.9	80.3
Barrel 2	B2-CT-L	PoreW	2	8.15	4810	210	1130	14.7	10.0	18.5	1100	171	0.0	1000	51.3	53.6	0.96	820	7.8	71.7
Barrel 3	B3-TOP	RelW	2	8.23	4580	0	1080	15.3	13.7	18.2	900	8.0	40.2	1470	49.4	51.0	0.97	1272	8.5	7.2
Barrel 3	B3-MFT-U	PoreW	2	8.09	4220	6.3	1030	14.8	9.8	12.1	1000	13.1	0.0	1220	46.6	48.5	0.96	1000	8.1	6.6
Barrel 3	B3-MFT-L	PoreW	2	8.11	4220	0.0	993	14.1	9.7	12.5	1000	6.3	0.0	1240	45.0	48.6	0.92	1016	8.0	5.9
Barrel 4	B4-TOP	RelW	2	8.24	6100	270	1370	16.9	18.3	25.5	1100	853	13.5	838	62.8	66.3	0.95	709	8.4	305
Barrel 4	B4-CT-U	PoreW	2	8.25	5580	330	1320	14.8	13.2	23.3	1200	665	0.0	798	60.0	64.9	0.93	654	7.9	221
Barrel 4	B4-CT-L	PoreW	2	8.27	5460	340	1300	14.0	11.3	20.2	1200	524	0.0	861	58.8	63.1	0.93	706	7.9	194
C1	C1-17-Top	PoreW	2	7.54	5470	130	1160	15.1	20.3	31.0	950	137	0.0	1630	54.1	58.0	0.93	1336	7.6	49.7
C1	C1-17-U	RelW	2	8.17	6730	180	1340	18.6	21.3	23.5	1200	104	0.0	1790	61.7	67.6	0.91	1467	7.7	37.8

B1 Results of chemical analysis in barrel and C1 system (cont'd)

System	Sample ID	Sample Type	Incub. Time (y)	pH	Cond	Br^+	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	SO_4^{2-}	CO_3^{2-} (wt ppm)	HCO_3^- (wt ppm)	Total Cations	Total Anions	Ratio Cat/Ani	Alkalinity expressed as HCO_3^-	ALK pH	S^{2-}
C1	C1-17-M-U	PoreW	2	8.14	5270	150	1090	15.7	12.6	17.0	1000	15.9	0.0	1790	49.7	59.7	0.83	1467	7.6	8.6
C1	C1-17-M-L	PoreW	2	8.36	5450	190	1130	13.9	12.4	18.5	1100	72.8	0.0	1290	51.4	56.0	0.92	1057	7.7	26.4
C1	C1-17-L	PoreW	2	8.23	5500	210	1240	15.0	13.2	22.3	1100	52.4	0.0	1540	56.5	59.9	0.94	1262	7.5	22.3
C1	C1-18-Top	PoreW	2	7.64	5510	150	1250	16.2	21.2	32.6	960	132	0.0	1640	58.2	58.6	0.99	1344	7.6	50.6
C1	C1-18-U	PoreW	2	8.14	6140	180	1380	18.5	20.5	25.1	1200	67.9	0.0	1690	63.4	65.2	0.97	1385	7.6	27.6
C1	C1-18-M-U	PoreW	2	8.12	5330	180	1180	16.1	14.0	19.8	1000	15.2	0.0	1440	53.9	54.3	0.99	1180	8.2	8.3
C1	C1-18-M-L	PoreW	2	8.35	5370	210	1200	14.6	11.5	17.0	1100	124	0.0	1130	54.4	54.7	0.99	926	7.6	52.9
C1	C1-18-L	PoreW	2	8.32	5790	250	1240	14.4	13.7	21.2	1100	85.8	0.0	1310	56.5	57.4	0.98	1074	7.5	35.8

B2 MPN data of barrels & C1 system

System	Sample	t (d)	Methanogen MPN/ g DRY WT	SRB MPN/g DRY WT
5	B1-MFT	750	1.94E+04	3.82E+04
	B2-MFT	750	4.17E+04	1.55E+05
	B1-CT	750	7.18E+02	2.09E+03
	B2-CT	750	7.26E+03	4.14E+02
6	B3-MFT	750	1.83E+04	3.96E+04
7	B4-CT	750	4.79E+03	1.05E+02
C1	C1-17-U	910	2.41E+04	6.28E+04
	C1-17-M-U	910	8.81E+03	4.44E+02
	C1-17-M-L	910	5.76E+02	3.53E+01
	C1-17-L	910	3.38E+02	5.03E+02
	C1-18-U	910	4.13E+04	2.07E+04
	C1-18-M-U	910	5.44E+03	4.43E+02
	C1-18-M-L	910	1.83E+03	1.94E+01
	C1-18-L	910	2.00E+03	1.81E+02

B3 Results of S^{2-} analysis in barrels & C1 system

ID	S^{2-}	ID	S^{2-}
B1-MFT-U	BDL	C1-17-U	BDL
B1-MFT-L	BDL	C1-17-M-U	BDL
B1-CT-U	BDL	C1-17-M-L	BDL
B1-CT-L	BDL	C1-17-L	BDL
B2-MFT-U	BDL	C1-18-U	BDL
B2-MFT-L	BDL	C1-18-M-U	BDL
B2-CT-U	BDL	C1-18-M-L	BDL
B2-CT-L	BDL	C1-18-L	BDL
B3-MFT-U	BDL		
B3-MFT-L	BDL		
B4-CT-U	BDL		
B4-CT-L	BDL		

B4 Results of Redox potential analysis in barrels

ID	Eh (mV)		ID	Eh (mV)		ID	Eh (mV)	
	1 hr	2 hr		1 hr	2 hr		1 hr	2 hr
B1-MFT-U	174	96	B2-MFT-U	297	199	B3-MFT-U	84	57
B1-MFT-L	189	116	B2-MFT-L	185	116	B3-MFT-L	54	34
B1-CT-U	337	253	B2-CT-U	324	245	B4-CT-U	449	238
B1-CT-L	222	153	B2-CT-L	226	136	B4-CT-L	334	257

B5 Results of Redox potential analysis in C1 system

ID	Eh (mV)		ID	Eh (mV)	
	1 hr	2 hr		1 hr	2 hr
C1-17-U	89	50	C1-18-U	105	53
C1-17-M-U	87	52	C1-18-M-U	-1	-39
C1-17-M-L	290	215	C1-18-M-L	280	230
C1-17-L	165	110	C1-18-L	61	48

B6 Solids content of barrels & C1 system

System	Sample ID	Solids (g/100g)	Bitumen (g/100g)	22 μm	11 μm	5.5 μm	2.8 μm	1.4 μm	0.5 μm
Barrel 1	B1-MFT-U	43.5	3.6	75.3	61.0	44.9	28.7	12.9	1.7
Barrel 1	B1-MFT-L	51.5	3.0	67.4	55.1	40.5	25.0	10.7	1.3
Barrel 1	B1-CT-U	76.5	0.60	44.8	37.7	26.8	15.1	6.7	1.9
Barrel 1	B1-CT-L	76.8	1.36	40.6	33.2	24.6	15.6	7.1	1.2
Barrel 2	B2-MFT-U	53.4	3.70	79.0	66.2	47.8	27.3	11.2	2.0
Barrel 2	B2-MFT-L	53.3	3.18	74.6	62.6	45.9	26.8	11.4	2.1
Barrel 2	B2-CT-U	76.2	0.42	40.3	34.0	23.4	12.7	5.9	2.0
Barrel 2	B2-CT-L	75.8	1.44	26.8	21.7	16.1	10.6	5.3	0.9
Barrel 3	B3-MFT-U	47.0	3.33	79.9	66.7	49.3	29.4	12.3	1.9
Barrel 3	B3-MFT-L	47.9	3.85	78.8	65.1	48.5	30.4	13.4	1.9
Barrel 4	B4-CT-U	74.3	0.78	34.8	29.4	20.5	11.1	5.1	1.8
Barrel 4	B4-CT-L	76.4	0.59	46.9	39.6	27.1	14.4	6.5	2.1
C1	C1-17-U	42.9	3.42	74.1	60.5	44.5	28.4	13.0	1.9
C1	C1-17-M-U	49.8	4.01	72.0	59.0	43.1	26.4	11.7	1.8
C1	C1-17-M-L	78.3	0.17	37.3	31.2	21.6	12.1	5.5	1.4
C1	C1-17-L	78.7	0.16	38.3	32.0	22.2	12.3	5.4	1.4
C1	C1-18-U	41.9	3.61	75.3	60.9	44.6	28.7	13.3	1.9
C1	C1-18-M-U	47.3	3.85	74.9	60.4	44.3	28.9	13.8	2.1
C1	C1-18-M-L	76.3	1.11	28.6	23.5	17.5	10.7	4.8	0.8
C1	C1-18-L	78.5	0.51	34.5	29.1	20.5	11.4	5.2	1.5