Leachate Quality from Simulated Landfills Containing CCA-Treated Wood

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ABSTRACT

Landfills represent the predominant disposal method for discarded CCA-treated wood in the US. The current lack of economically viable recycling options for this material will likely result in continued reliance on landfill disposal for the foreseeable future. Previous research has shown that arsenic, copper and chromium leach from CCA-treated wood when in contact with water. Leaching is expected to occur in a landfill as rainwater infiltrates into the waste. In a landfill, however, the biological, chemical and physical reactions that occur may have a great impact the mobility of the metals from CCA-treated wood. Research was conducted to explore this issue. Experimental landfills were constructed to represent three different disposal scenarios: construction and demolition (C&D) debris landfills, municipal solid waste (MSW) landfills, and wood-only monofills. CCA-treated wood is often managed in C&D debris landfills; in many US locations these facilities are unlined. In other locations, CCA-treated wood is disposed in lined MSW landfills. These two disposal scenarios have different chemical environments and the metals may thus behave differently in each environment. While CCA-treated wood is not currently managed in monofills, this option represents conditions where maximum metals concentrations would likely occur. Six lysimeters (simulated landfill columns), two for each disposal scenario, were constructed and operated; both a control lysimeter (containing no CCA-treated wood) and an experimental lysimeter containing CCA-treated wood were included for each scenario. Natural and simulated rainwater were allowed to infiltrate and percolate through the waste in the lysimeters creating leachate. Leachate generated by the lysimeters was collected and analyzed for arsenic, copper and chromium concentrations, as well as general leachate indicator parameters from the fall of 2001 through the summer of 2003. This paper summarizes the preliminary results of metal concentrations in the leachate over time and explores possible mechanisms for leaching. The potential environmental impacts of disposal in each scenario are discussed.

INTRODUCTION

CCA-treated wood became popular from 1970 to 1980 and the life spans of the structures made with it are in the range of 10 to 40 years; therefore, disposal amounts are increasing as the wood continues to come out of service. However, an estimated 180 million m^3 of CCA-treated wood remains in service in the United States (EBN, 2002). With the unrestricted use of CCA-treated wood, the disposal rate would continue to increase and then level off. However, phaseouts or bans on CCA-treated wood have begun to occur. In the US, the use of CCA-treated wood in decks, picnic tables, landscaping timbers, gazebos, residential fencing, patios, walkways/boardwalks, and play-structures will be phased out by the end of 2003 (US EPA, 2002; FR, 2002). With the recent draft report on the increased cancer risks to children from coming into contact with CCA-treated wood decks and playsets (USEPA, 2003a), some municipalities and private citizens may want to remove their CCA-treated wood structure immediately. Quicker removal of the CCA-treated wood may peak disposal rates sooner than previously predicted and the focus turns to disposal.

Once CCA-treated wood is removed from service, it needs to be properly managed as a solid waste. Under US Environmental Protection Agency (EPA) standardized tests, CCA-treated wood may show characteristics of a hazardous waste because of the leachability of the toxic metals in the CCA-chemical. However, it is exempt from regulation as a hazardous waste when it is used for its intended purpose and discarded by the user (CFR, 2003). Also, recycling and reuse options are not often feasible. With its high metal concentrations, CCA-treated wood should not be made into mulch. If it is burned, it releases emissions of arsenic as well as concentrating arsenic, copper and chromium in the ash (Solo-Gabriele et al., 1998). Landfills are typically where the waste wood is currently disposed, and they will likely continue to represent the primary management option for CCA-treated wood waste in the future (Solo-Gabriele et al., 1999). In the US, some landfills that accept wood waste are not lined (e.g. construction and demolition debris landfills in Florida are not lined (FAC, 2003)). Studies have found that C&D debris containing CCA-treated wood have leached concentrations of arsenic above groundwater standards (Jang, 2000; Weber et al., 2002). In order to further examine some of the impacts of CCA-treated wood on landfill leachate, a simulated landfill leaching column experiment was conducted.

LEACHING COLUMN STUDY

The objective of the research reported here was to simulate the production of leachate from the co-disposal of CCA-treated wood in simulated landfills. Six 6.7-meter high columns were constructed at the Alachua County Solid Waste Landfill, located in Archer, Florida, US. These columns were filled with waste to simulate different CCA-treated wood disposal scenarios: a wood monofill, a construction and demolition (C&D) debris landfill, and a municipal solid waste (MSW) landfill. A total of six leaching columns (also referred to as lysimeters) were constructed for this study. The lysimeters were split up into pairs, each representing a different disposal scenario, with a control lysimeter and an experimental lysimeter in each pair. The lysimeters were constructed in the following layers (from the bottom up): 0.152 meters of washed gravel, a stainless steel screen, 0.152 meters of washed gravel, 6.1 meters of simulated waste, a cap with a water distribution system, and a catchment basin for rainwater (Figure 1). Thermocouple wires were placed at three separate depths (6.1 meters, 4.6 meters and 1.5 meters) within the lysimeters to obtain temperature readings.

Size Reduction and Filling

In order to fit simulated waste materials into the lysimeters, the larger materials were size reduced. A nominal waste size of 5.1-cm by 5.1-cm pieces was used when possible. Lysimeters were filled in lifts, by weighing out appropriate masses of each material, mixing them together and then compacting the load in the lysimeter. Details of the size reduction and filling procedures are given in Jambeck et al. (2003). Figure 2 provides the composition (by mass) of the materials in each lysimeter. Further description of the composition of waste in each disposal scenario is given below.

Wood Waste Composition

The wood monofill represents a worst-case disposal scenario for CCA-treated wood since it contains the highest percentage of treated wood. This scenario will also provide information on the leaching of metals that will occur from wood without the interference of other materials. Since the relative contribution of CCA-treated wood from demolition and construction activities varies, and has not been well-quantified, a 50:50 construction to demolition waste ratio by weight was used. The retention value (as reported on the end tag) of the new CCA-treated wood used in the experiments was 6.4 kg/m^3 (0.4 lb/ft^3), although when determined by the standard industry method for measuring retention value, X-ray fluorescence (XRF), it was shown to be 3.4 kg/m^3 (0.214 lb/ft^3). The demolition wood retention value as determined by XRF was 6.2 kg/m^3 (0.38 lb/ft^3) (Solo-Gabriele et. al, 2003). Lysimeter 1 was the control lysimeter in this disposal scenario and contained new untreated Southern Yellow Pine. The in-place densities of the wood in lysimeters 1 and 2 were 353 kg/m^3 and 324 kg/m^3, respectively.

C&D Waste Composition

The C&D waste composition selected was modeled after one used in a previous study (Jang, 2000), and was considered representative of typical C&D debris. The previous study, however, contained only a small fraction of CCA-treated wood (0.5%). The percentage of CCA treated wood currently in the waste stream has been reported to be 6% (Tolaymat et al., 2000). CCA-treated wood percentages found in C&D debris in field studies has ranged from 9% to 30%. The range of 9 and 10% were at facilities that actively sorted out CCA-treated wood if they identified it and the 30% was at a facility that did not practice sorting (Blassino et al. 2002). Projections have estimated that up to 50% of the wood waste stream could be CCA-treated wood (Townsend et al., 2001). For this study, wood was assumed to be 33.7% of the waste stream, with 30% of the wood being CCA-treated and 70% being untreated Southern Yellow Pine. The overall contribution of CCA-treated wood in the C&D debris waste stream was 10.2%. Lysimeter 3 was the control lysimeter in this disposal scenario and contained no CCA-treated wood. The in-place densities of the waste in lysimeters 3 and 4 were 345 kg/m^3 and 359 kg/m^3, respectively.

MSW Waste Composition

The MSW in lysimeters 5 and 6 was refuse derived fuel (RDF) collected from the Palm Beach County Solid Waste Authority (SWA) RDF plant. This plant processes 2,000 metric tons of MSW per day into RDF. The facility processes MSW by size-reducing it, during which the waste is homogeneously mixed. Two trips were made to SWA to collect RDF from the storage building. The first trip was in May 2001 and the second in September of 2001. Both times RDF was collected in 160-liter garbage cans directly from the RDF storage building. Because of concerns that the food waste content of the MSW was less than typical, an additional source was added. Dog food was added to the MSW at 9% by mass. The CCA-treated wood content in the MSW lysimeters should be less than the amount in the C&D lysimeters since wood is a smaller component of MSW (6.1%, US EPA, 2000). A CCA-treated wood content of 2% by mass of the total waste stream (32% of the total wood portion of the waste) was selected. This estimation is the same amount as used in a study of pentachlorophenol-treated wood co-disposed with MSW in lysimeters (Pohland et al., 1998). The in-place densities of the waste in lysimeters 5 and 6 were 294 kg/m^3 and 293.0 kg/m^3, respectively.

Operation and Monitoring of Lysimeters

Monitoring and operation of the lysimeters began after construction was completed in fall 2001 and continued until the conclusion of the experiment in fall 2003. The experiment has recently concluded and the results presented here remain preliminary. The temperature of the lsyimeters was measured weekly at 6.1 meters, 4.6 meters and 1.5 meters from the top of the lysimeter with an Omega thermocouple meter. The temperatures within the lysimeters varied with the seasons and fluctuated following ambient temperatures. The composition of gas in the lysimeters was analyzed with a Landtec GEM-500 that measured methane, carbon dioxide, and oxygen content. Gas composition readings were collected weekly for the C&D debris (3&4) and MSW (5&6) lysimeters. In the warm summer months, when the temperatures were in the range of 25 to 30 degrees C, the methane concentrations in the MSW lysimeters rose to over 60%, with carbon dioxide near 40%. The primary gas in the C&D lysimeters at this same time was carbon dioxide. During the cooler winter months, both methane and carbon dioxide decreased, while oxygen increased in both the C&D and slightly in the MSW lysimeters. The gas fluctuations reflect the fact that microorganisms that produce methane and carbon dioxide are more active in warmer conditions than in cooler conditions.

Natural precipitation was allowed to infiltrate into all of the lysimeters. If natural precipitation did not occur, it was supplemented by the addition of deionized water (1 centimeter of precipitation resulted in the addition of 0.73 L of water). The lysimeters were sampled one to two times per month. General water quality parameters, including pH, dissolved oxygen (DO), conductivity, oxidation-reduction potential (ORP), and temperature were measured in the field every time leachate was sampled. DO and temperature were measured with an YSI, Inc. DO Meter Model 55/12 FT. pH and ORP were measured with an Accumet Portable pH/mV Meter Model AP62. The conductivity was measured with a Hanna Instruments Multi-range Conductivity Meter, HI 9033. Leachate was collected in 20-

Liter containers to homogenize the sample before splitting it up into proper containers for preservation and analysis. The samples were stored in a walk-in cooler at 4 degrees C. Leachate samples were digested following US EPA method 3010A (US EPA, 2003b) and then analyzed with a Thermo Jarrell Ash, model 61E, inductively coupled argon plasma (ICAP). Leachate samples from lysimeter 1 and 3 were also digested using method 7060A (US EPA, 2003b) and analyzed on a Perkin-Elmer Atomic Absorption (AA) graphite furnace.

RESULTS

Wood Lysimeters

Lysimeters 1 and 2 represented the disposal of CCA-treated wood in a monofill where no other waste interacted with the wood. The wood lysimeters were completed and began operation on August 28, 2001. Natural precipitation has contributed 207 centimeters of rain to the columns; however both lysimeters were supplemented with deionized water to produce sufficient quantities of leachate for sampling. Lysimeters 1 and 2 had a total of 270 and 230 centimeters of water input, respectively, through the duration of the experiment. Leachate was generated from lysimeter 2 first, and collection began September 28, 2001. Leachate was collected from lysimeter 2 on a total of 29 occasions. Leachate was not generated from lysimeter 1 until August 6, 2002. Leachate has been collected from lysimeter 1 on a total of 22 occasions. Samples from both lysimeters were analyzed for general water quality parameters and metals up through the end of the experiment, September 22, 2003.

Monitoring general water quality parameters provides and indication of activity occurring within the lysimeters and assists in characterizing the leachate. Overall, the pH of both lysimeters decreased slightly over time, although the pH of lysimeter 2 (average of 5.62) remained below that of lysimeter 1 (average of 5.83). Dissolved oxygen levels began in the range of 2 to 4 mg/L, and then stabilized at approximately 1 mg/L by the end of the experiment. Conductivity was in the range of 500 to 1000 μS/cm, with a decreasing trend throughout the experiment. The ORP results began positive (approximately 100mV) for lysimeter 2, while the ORP of lysimeter 1 began in the negative (-200mV to -400mV). The lysimeter 2 ORP decreased to the range of lysimeter 1, and both remained reducing (negative) until the end of the experiment. In general, temperatures inside the lysimeters and of the leachate fluctuated with ambient temperatures. Figure 3 shows the pH, conductivity, and DO versus cumulative volume.

Figure 3 also presents the concentrations of arsenic, copper and chromium in the wood lysimeter leachate versus cumulative volume. Lysimeter 2 leached the greatest concentrations of arsenic, copper, and chromium of all the lysimeters. Arsenic leached over three magnitudes more in lysimeter 2 than in the control (lysimeter 1). Chromium and copper leached two and one order of magnitude more in lysimeter 2 than lysimeter 1, respectively. The high concentrations of metals, as well as the increasing trend, correspond to a low and decreasing pH. The low dissolved oxygen concentrations and negative ORP are indicative of microbial activity in both lysimeters. Certain bacteria have been shown to thrive on CCA-treated wood and extract the metals (Illman and Highley, 1996, Cole and Clausen, 1996). Some fungi produce oxalic and other organic acids causing chromium and arsenic to often remain in water soluble forms, while copper can be precipitated as copper-oxalate, which has low water solubility (Peek, 1999). This may explain why copper concentrations were relatively low compared with arsenic and chromium in the experimental lysimeter.

C&D Lysimeters

Lysimeters 3 and 4 represent a C&D debris landfill disposal scenario. Lysimeter 3 contained untreated southern yellow pine as the wood component along with the other C&D components. The

C&D lysimeters were completed and began operation on August 28, 2001. These lysimeters were exposed to 212 centimeters of natural precipitation and were supplemented with deionized water for a total of 321 centimeters to date. Leachate was generated from both lysimeters at the same time and was collected from lysimeter 3 and 4 on a total of 26 occasions, beginning on June 25, 2002. Samples for both lysimeters have been analyzed for general water quality parameters and metals up through the end of the experiment (October 23, 2003).

The temperature of the C&D lysimeters also fluctuated with ambient temperatures. No methane was measured, but higher percentages of carbon dioxide and less oxygen were present during the warmer summer months. The maximum carbon dioxide found was 22% (with oxygen at 1%) in July 2003. In the cooler winter months, the carbon dioxide gas percentage was around 8%, while the oxygen remained around 11%. The pH for lysimeters 3 and 4 remained consistent throughout the experiment at 6.5 to 7. This pH is typical for C&D waste and other experiments (Jang, 2000; Weber et al., 2002). Dissolved oxygen concentrations began around 3 to 5 mg/L, then decreased to almost zero in the first summer. During the cooler months of the winter, DO increased to 2 mg/L, and then decreased again to almost zero in the warmer months and for the duration of the experiment. The near zero DO levels indicate microbial activity was consuming the oxygen in the leachate at those times. The conductivity for lysimeter 4 began higher than the conductivity for lysimeter 3 (5.5 mS/cm versus 3.5 mS/cm), and then both decreased over time and cumulative volume. Lysimeters 3 and 4 exhibited reducing conditions throughout the experiment with an ORP in the range of –300mV to –600mV. Figure 4 shows the pH, Conductivity, and DO/Temperature versus cumulative volume.

Figure 4 also presents the concentrations of arsenic, copper and chromium in the C&D lysimeter leachate versus cumulative volume. In lysimeter 4, which contains 10.2% CCA-treated wood, arsenic and chromium were found in the leachate at higher concentrations than those found in the control lysimeter (lysimeter 3). The arsenic and chromium concentrations of lysimeter 4 varied slightly remaining in the range of 1 to 4 mg/L for arsenic and 1 to 2 mg/L chromium. Copper had a unique leaching trend in that it was initially detected in lysimeter 4 only and then began to leach at very low concentrations (around 0.05mg/L) in both lysimeter 3 and 4 when the temperature decreased and the DO and ORP increased in the middle of the experiment. The copper concentration then decreased again after the DO and ORP decreased towards the end of the experiment. The more oxidizing environment slightly mobilized the copper; however, concentrations still remained relatively low because copper tends to form complexes with numerous organic and inorganic ligands, especially at a pH of 6.5 and above (Snoeyink and Jenkins, 1980).

MSW Lysimeters

Lysimeters 5 and 6 represent an MSW landfill scenario. Lysimeter 5, the control lysimeter, contained only MSW, food waste, and untreated southern yellow pine. The MSW lysimeters were completed and began operation on September 27, 2001. These lysimeters have been exposed to 200 centimeters of natural precipitation and 23 centimeters of deionized water from September 27, 2001 through October 23, 2003. Leachate was initially generated from lysimeter 5 and was collected on a total of 25 occasions, beginning on June 27, 2002. Leachate was generated in lysimeter 6 on July 17, and was collected on a total of 24 occasions. Samples for both lysimeters were analyzed for general water quality parameters and metals up through the end of the experiment (October 23, 2003).

In the warm summer months, when the temperatures were in the range of 25 to 30 degrees C, the methane concentrations in the MSW lysimeters rose to over 60%, with carbon dioxide near 40%. During the cooler winter months, both methane and carbon dioxide decreased, while oxygen increased slightly. The pH of the lysimeters stabilized over time. The MSW lysimeters began with a low pH (4.5), assumedly in the volatile acid forming stage of the biodegradation process (Pohland et al., 1983). After a few months, methane production was noted and the pH increased and stabilized to approximately 7.5 in both lysimeters. Dissolved oxygen was less dependent on temperature for the MSW lysimeters and DO decreased initially to remain around 0.5 mg/L for the duration of the experiment. Conductivity began higher for the MSW lysimeter with CCA, but both lysimeters followed the same trend for conductivity decreasing from a maximum of 40 mS/cm to below 10mS/cm. The ORP for lysimeters 5 and 6 were primarily in the range of –400mV to –650mV, except for at the beginning and end of the experiment where ORP ranged from –100mV to –200mV. Figure 5 presents the pH, conductivity, and DO/Temperature versus cumulative volume.

An interesting trend for metals appeared in lysimeter 6, which has 2% CCA-treated wood by mass in it. During the initial time period when the pH of the leachate was lower, higher concentrations of both arsenic and chromium were found in the leachate (as compared to the control). As pH values increased and stabilized, the concentrations of arsenic and chromium decreased to concentrations lower than the other lysimeters with CCA (wood and C&D) and then reached concentrations near those of the control MSW lysimeter. Copper concentrations increased and decreased slightly over the duration of the experiment in lysimeter 6; however, concentrations remained relatively low and were similar to those of lysimeter 5 at the end of the experiment. Figure 5 shows the metal concentrations discussed here, versus cumulative volume.

SUMMARY

CCA-Treated wood will be entering the waste stream for years to come. Disposal in the US has not likely peaked yet as much of the wood remains in service. Landfill disposal continues to be the primary form of management in Florida and the US (US EPA, 2000; FDEP, 2002). This research examined three different disposal scenarios to evaluate potential impacts from CCA-treated wood landfill disposal. Leaching columns (lysimeters) were constructed to simulate these three different landfill situations: CCA-treated wood monofill, C&D landfill, and an MSW landfill.

The greatest concentrations of metals were found in the CCA-treated wood monofill scenario. This column contained the greatest percentage of CCA-treated wood (100%) and no other waste materials were co-disposed to interact with it. The arsenic, chromium, and copper concentrations increased slightly while the pH decreased. An advantage to disposing of CCA-treated wood individually would be that the leachate could be controlled separately; however, the concentrations of arsenic and chromium in the leachate (both above 5 mg/L) would classify it as a hazardous waste under US regulations for toxicity (CFR, 2003). Disposal of this leachate would be very costly. It is not realistic or likely that anyone would desire to have a CCA-treated wood monofill creating leachate concentrations shown in this experiment.

The C&D and MSW landfill scenarios showed a similar range of metal concentrations in the leachate. The arsenic and chromium concentrations were in the range of 1 to 4 mg/L, while copper remained relatively low. This is somewhat surprising since the percentage of CCA-treated wood in the simulated waste streams are different (the C&D lysimeters contain 10.2% CCA-treated wood and the MSW lysimeters contain 2% CCA-treated wood); however, the overall leaching trends of the metals from the C&D and MSW scenarios were very different. The arsenic and chromium concentrations in the C&D lysimeters were initially constant around 1 mg/L. However, over time, arsenic concentrations eventually increased to 4 mg/L and chromium increased to 2 mg/L. The MSW lysimeters behaved very differently. The initial arsenic and chromium concentrations were similar to those found later in the C&D leachate at 3.8 mg/L for arsenic and 4.2 mg/L for chromium. Then, after the pH increased and methane was formed in the MSW lysimeters, the metal concentrations decreased to the lowest of the three landfill scenarios with CCA-treated wood at less than 0.5 mg/L.

Neither the C&D nor the MSW leachates are classified as hazardous waste under US regulations; however, when compared to the control lysimeter in each scenario, it is clear that the co-disposal of CCA-treated wood in both of these situations has influenced the arsenic, copper and chromium concentrations in the leachate. Even though the MSW lysimeters leached high concentrations initially, it appears that the trend of the metals decreasing to lower concentrations makes the MSW disposal scenario the most desirable at this point. Also, MSW landfills are lined in Florida, unlike C&D landfills. Further evaluation and modeling of the concentrations of metals found in the C&D leachate may determine whether or not CCA-treated wood disposal in unlined C&D landfills may contaminate groundwater.

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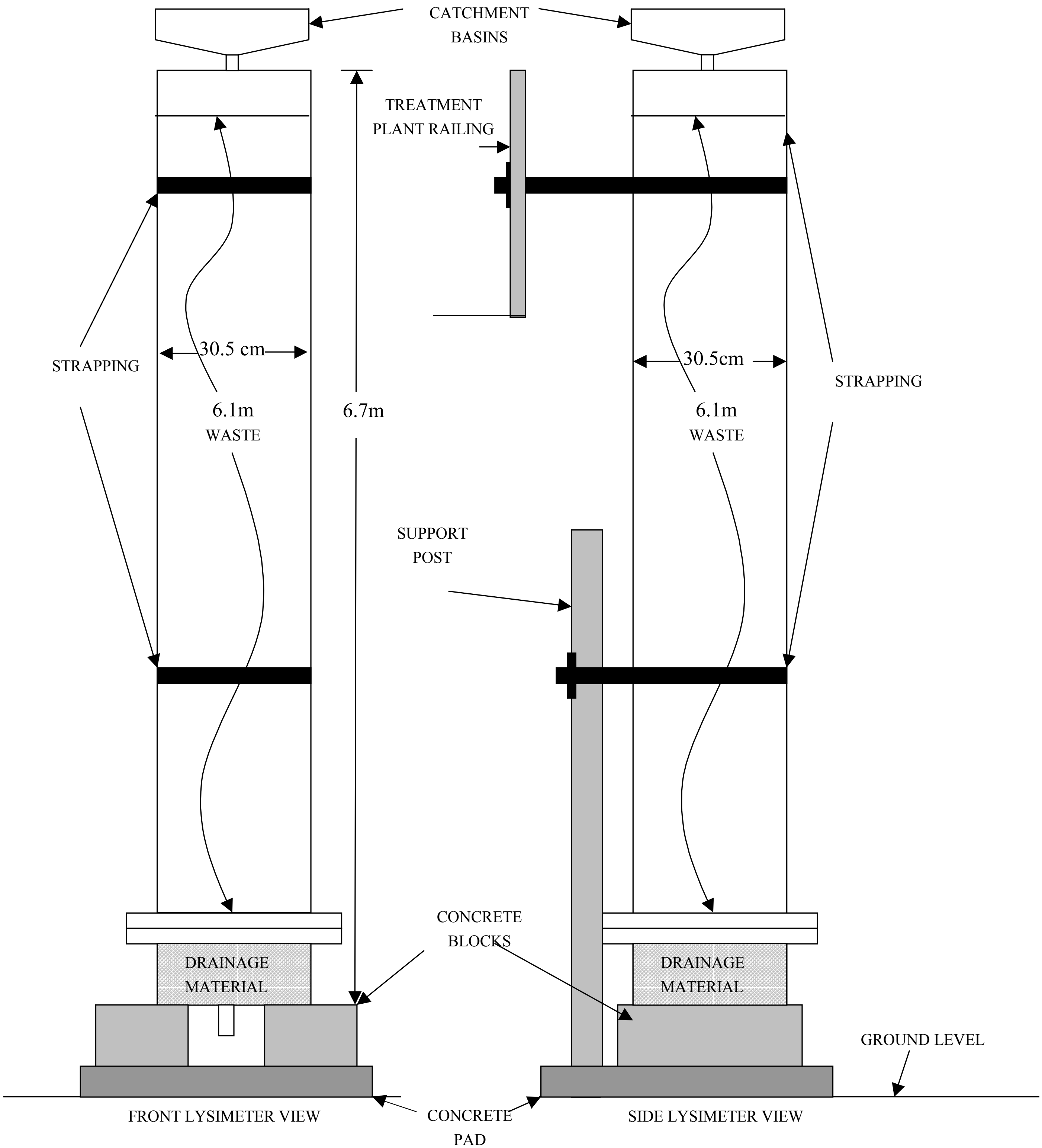

Figure 1. Lysimeter Construction Schematic

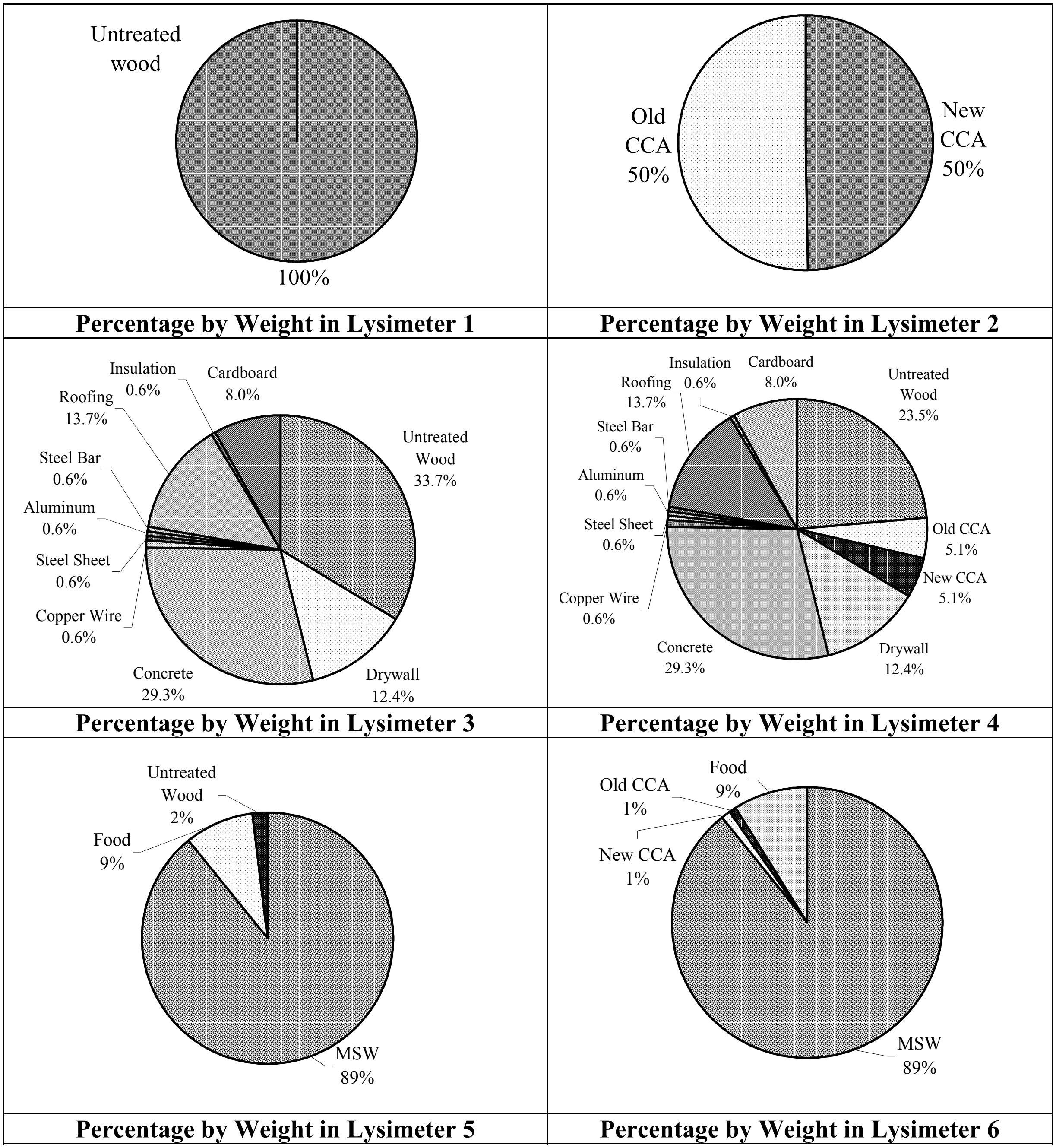

Figure 2. Composition of Materials in the Lysimeters (by total mass)

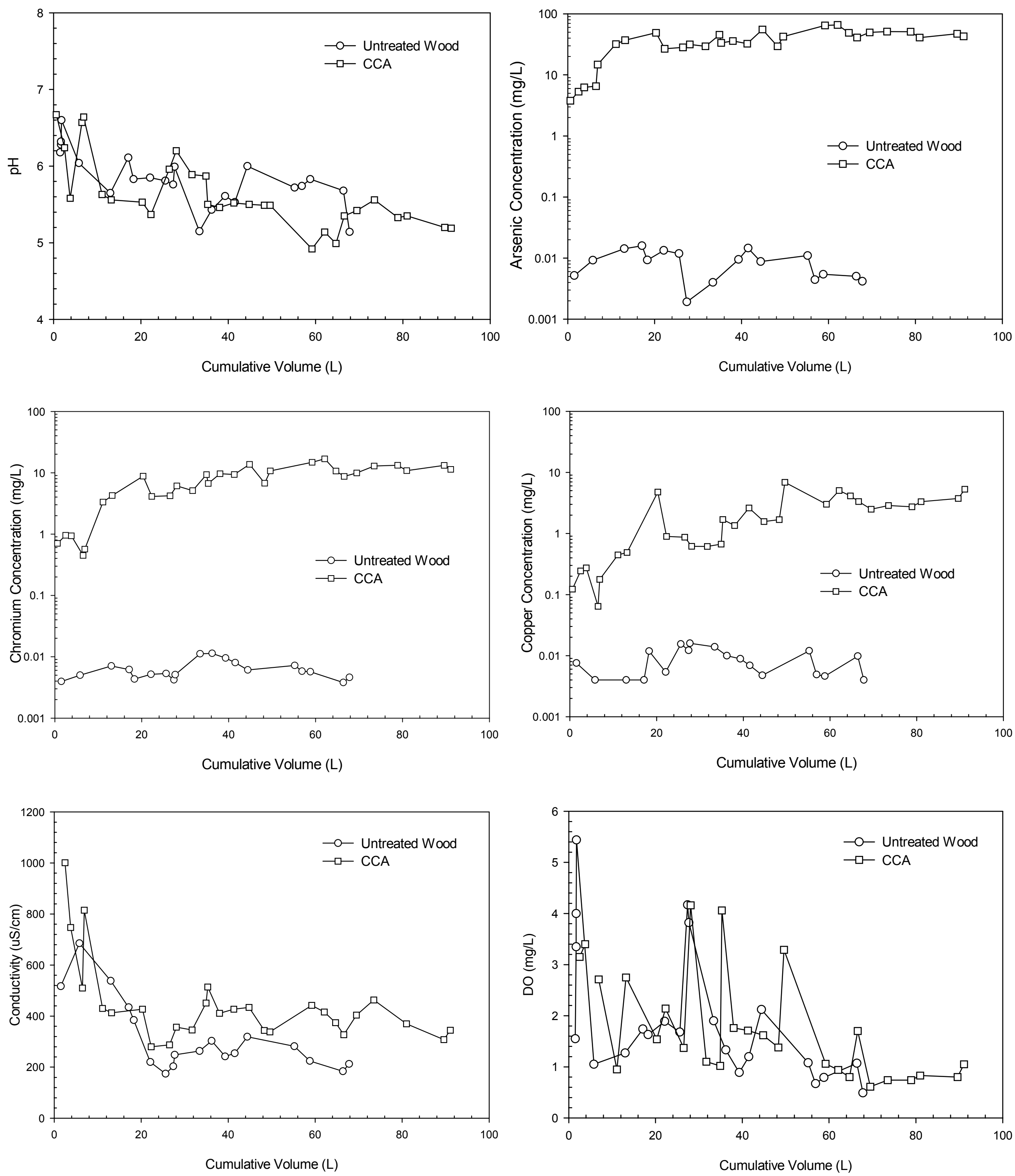

Figure 3. pH, Arsenic, Chromium, Copper, Conductivity and DO in Wood Lysimeters
(Copper results under the reporting level of 0.004mg/L shown at 0.004mg/L)

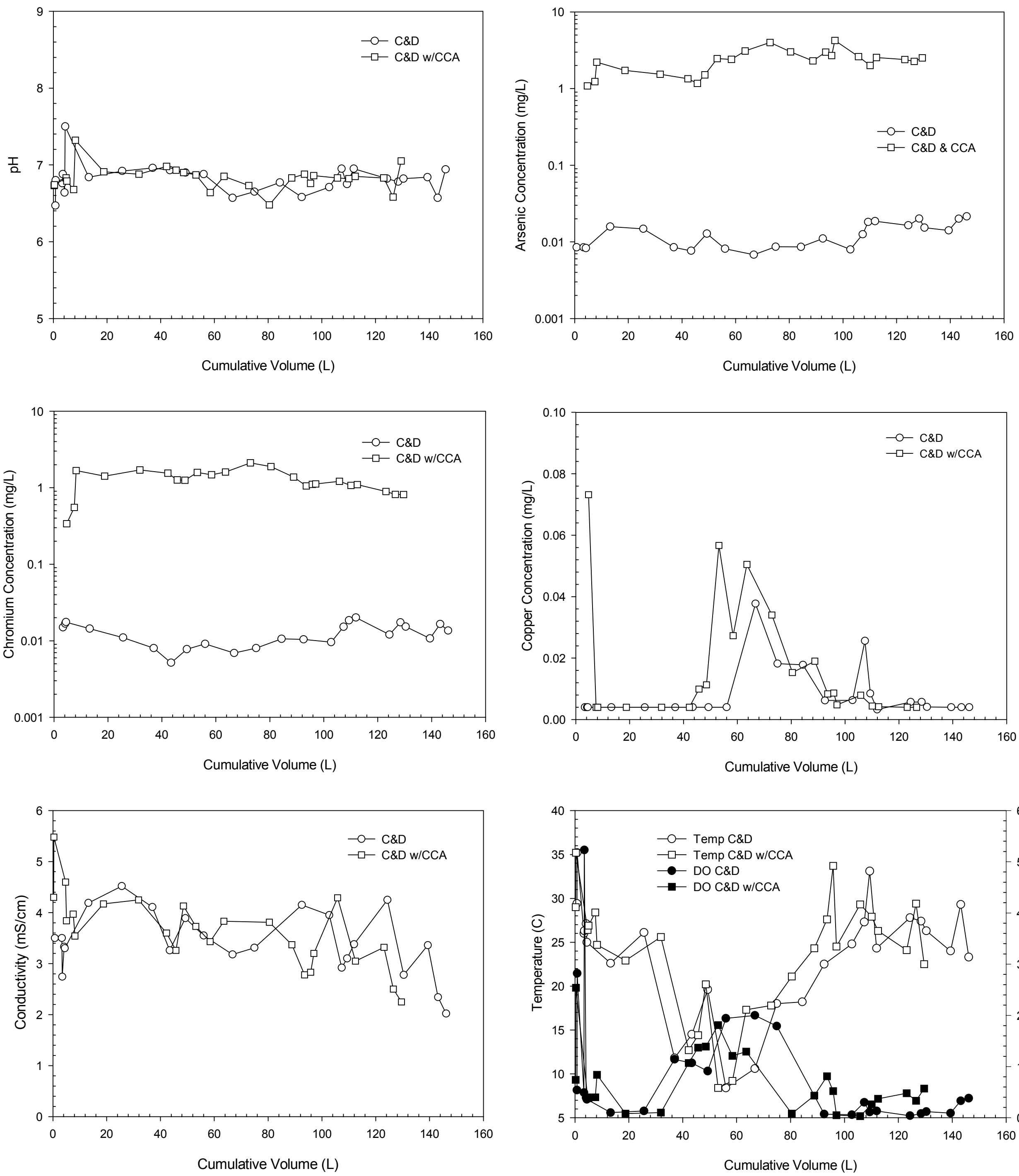

Figure 4. pH, Arsenic, Chromium, Copper, Conductivity and Temperature/DO in C&D Lysimeters (Copper results under the reporting level of 0.004mg/L shown at 0.004mg/L)

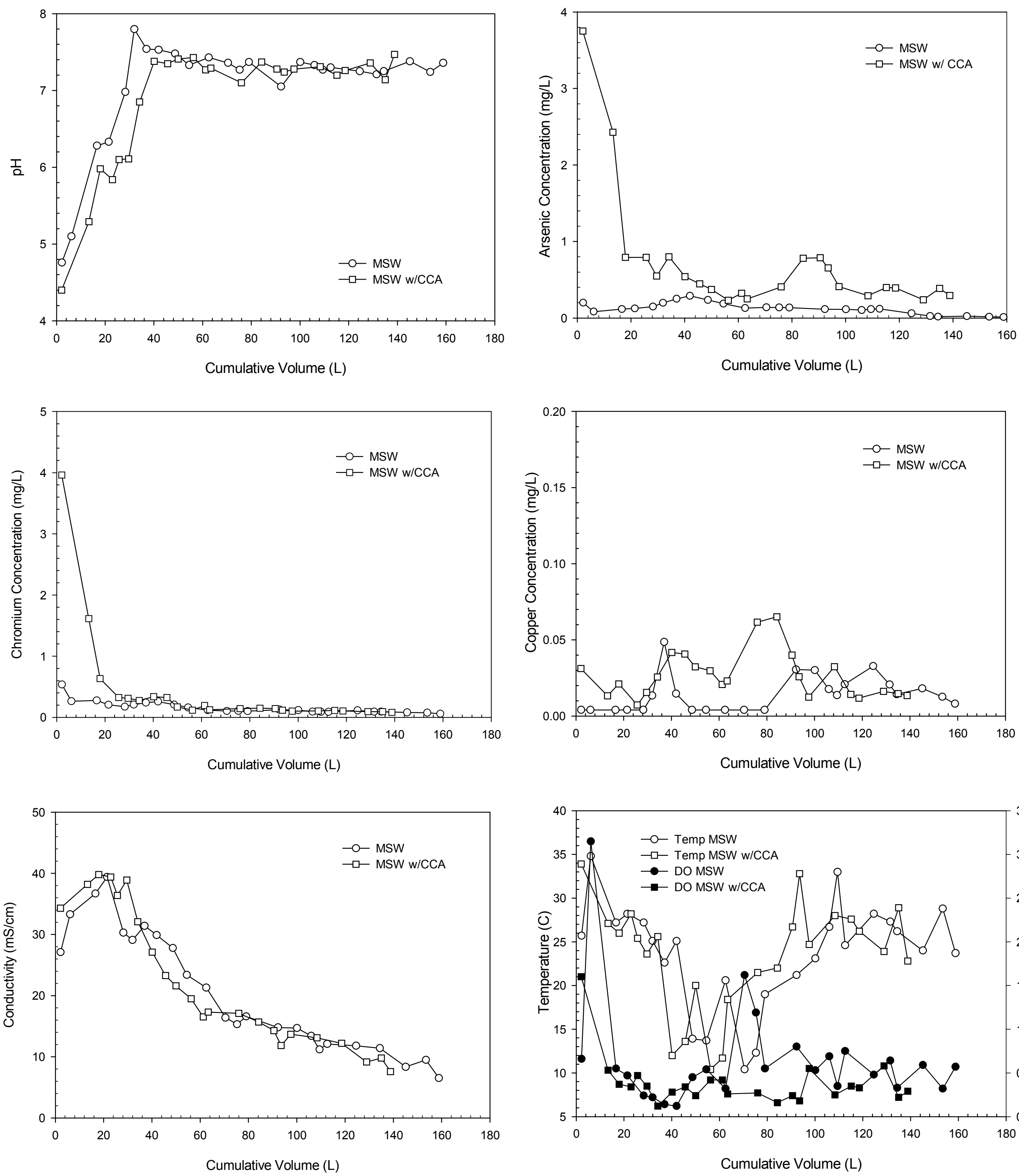

Figure 5. pH, Arsenic, Chromium, Copper, Conductivity and Temperature/DO in MSW Lysimeters (Copper results under the reporting level of 0.004mg/L shown at 0.004mg/L)