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TECHNICAL COMMUNICATION

Design of a Dry Cover Pilot Test for Acid Mine Drainage Abatement in Southern Brazil, Part II: Pilot Unit Construction and Initial Monitoring

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Abstract Pyritic coal wastes produced by a coal beneficiation plant in the state of Santa Catarina in Southern Brazil are acid generating. Here we report the second part of a study evaluating the use of a dry cover to minimize acid mine drainage generation and its release into the environment. This part encompasses the construction and initial monitoring of an experimental pilot-scale unit. Local clays and ash from a power station were used as cover materials. Monitoring started in October 2007 and will extend for at least 4 years. Initial results of the dry cover system constructed using compacted locally available clay and ash look promising. The pH of the drainage ranged from 6.0 to 7.0, within the legal limits for discharge into the environment.

Keywords Acid mine drainage · Capillary barrier · Dry cover · Pyrite · Water flow

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Introduction

Coal wastes exposed to the atmosphere can have adverse environmental impacts. Rainwater that percolates through the coal waste can leach contaminants into the ground and surface waters (CETEM 2001). One of the alternatives in mitigating this environmental impact is the use of a dry cover, which can be made out of different materials (Borma et al. 2002, 2003; Cabral et al. 2000; Heineck et al. 2003; Ubaldo 2005) to minimize the water and air flux into the wastes. The use of dry covers on mining wastes has been widely reported in the literature (Adu-wusu and Yanful 2006; Ayres et al. 2002, 2005; MEND 2001; Simms and Yanful 1999; Waugh and Smith 2004; Yanful et al. 2006). The selection of a cover material is usually based on its physical–chemical and geotechnical characteristics, its availability near the area where the cover will be applied and local climate conditions. A comprehensive project for field assessment of a dry cover performance should encompass a three—step design as follows (O'Kane et al. 2002):

- Step 1: Investigation program of the available materials in the area (sampling program, field characterization, laboratory test program).
- Step 2: Design and numerical modeling of the dry cover;
- Step 3: Pilot test at the site to monitor the cover performance in field conditions.

A project to evaluate the performance of the dry cover solution for abatement of acid mine drainage (AMD) generated in coal waste piles has been developed in a mining area (Forquilhinha), in the state of Santa Catarina, in Southern Brazil, as a partnership between the Centre for Mineral Technology (CETEM), a Brazilian Ministry of

Science and Technology Research Centre, and the Carbonífera Criciuma S.A., a Brazilian coal mining company. Steps 1 and 2 have been previously reported (Borghetti Soares et al. 2009). The present technical communication refers to Step 3, which is the construction of the experimental pilot unit; the instrumentation and monitoring procedures used and some preliminary results are presented. As previously reported, we decided to use bottom ash from a local power station as a cover material, after evaluating this possibility with numerical modeling and laboratory and field tests (Borghetti Soares et al. 2009; Souza et al. 2007; Ubaldo 2005). Others have previously suggested the use of bottom ash as dry cover material (Borma et al. 2002, 2003; Heineck et al. 2003).

The Experimental Pilot Unit

The experimental pilot unit comprised: a 3 m high embankment with four experimental cells (Borghetti Soares et al. 2009) where different covers were applied; a laboratory for physical chemical analysis; and a weather station. The cells were built to study the behavior of three different types of dry covers designed based on the previous laboratory and field tests and numerical simulations (Borghetti Soares et al. 2009). The Soilcover software was used for the numerical simulations (GeoAnalysis 2000; Wilson 1990; Wilson et al. 1994). One cell was kept uncovered as a reference. Sensors were installed in each layer to measure suction (granular matrix sensor, 253 model, Watermark, range 0–200 kPa), water content (TDR, CS616 model, Campbell Scientific, range 0–100% volumetric water content) and temperature (T108 model, Campbell Scientific, range 5–95°C). Figure 1 shows a schematic view of the four cells and the location of the sensors. The four cells were:

Cell 1: waste with no cover;

Cell 2: waste, covered with a layer of mixed waste (0.3 m thick);

Cell 3: waste covered with a three-layer configuration. Each layer is 0.3 m thick. The first layer is mixed waste, the second layer is compacted clay, and the third is organic soil; and

Cell 4: waste covered with a five-layer configuration. Each layer is 0.3 m thick. The first layer is mixed waste, the second is compacted ash (capillary barrier), the third is compacted clay, the fourth is compacted ash (capillary barrier), and the fifth is organic soil.

Fifteen instruments of the same type were installed, totaling 45 sensors connected to a data logger. A rain gauge was installed to record rain precipitation. Table 1 shows the amount of each type of instrument and their position in each cell. All sensors were installed vertically at the center of the cells (horizontal position, $x = 0$). Data are downloaded by internet connection.

The experimental pilot unit is shown in Fig. 2. The pilot experiment started in October 2007 and is scheduled to run for at least 4 years. A cylindrical lysimeter was installed within the excavation so that the rainwater that percolates through the wastes could be collected at the bottom and sent to a sampling well. The software SEEP/w (Geo-slope International Ltda 1998) was used to define the position of the lysimeters inside the cells so that not be disturbed the water flow in the waste (Borghetti Soares et al. 2009). Figure 3 shows a cross section of the embankment with cells 3 and 4.

A weather station was installed to collect data on precipitation (rain gauge), wind (speed and direction), relative humidity, atmospheric pressure, and temperature. A laboratory for physical–chemical analysis (pH, oxidation–reduction potential, electrical conductivity, dissolved oxygen) was built adjacent to the cells. Water samples are collected and analyzed Fe, Fe^{++}, Fe^{+++}, Al, Mn, $SO_4{}^{-}$, acidity, Cu, Zn, As, Ba, Ca, Hg, Pb, Ni, Se. The cells are actually phenomenological models of a waste-cover system and were designed so that a water balance could be performed, as follows:

(a) Water volume at the bottom of the cells: The drainage system for water collection was designed as two separate pipelines. The first one collects the water that flows to the bottom of the lysimeter and sends it to a 5 m deep sampling well. At the sampling well, the water volume is measured and sampled for chemical and physical–chemical analysis. The second pipeline collects the water volume that percolates out of the lysimeter and sends it to a tank.

(b) Runoff: Channels were built on the perimeter of the cells so that the runoff can be collected and directed by the pipelines to a tank. The runoff volume is periodically measured and sampled for physical–chemical analysis.

(c) Water storage: Water content sensors are being used to measure the water storage in each layer of the cover.

(d) Precipitation: Precipitation data are obtained from rain gauges.

(e) Evaporation: Evaporation is estimated from temperature, relative humidity, wind velocity and rain precipitation measured in the weather station of the pilot unit and checked by water balance (precipitation, water volume at the bottom, runoff, and water storage).

Fig. 1 Experimental cells and sensors locations (dimensions in meters)

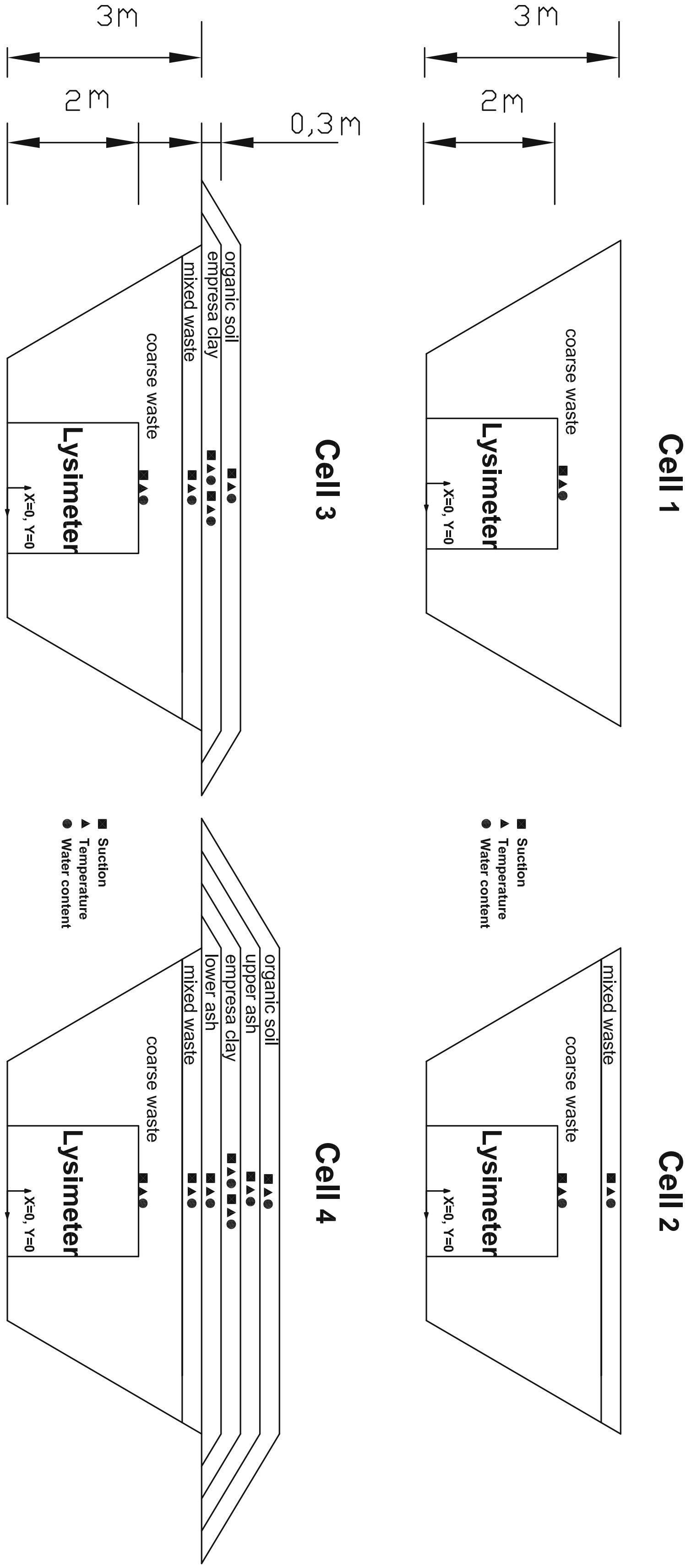


Table 1 Number and vertical position (in m) of the temperature, suction, and water content sensors in the cells

Cell	Layer	Sensors	Vertical position
Cell 1	Coarse waste	1	$y = 2$
Cell 2	Coarse waste	1	$y = 2$
	Mixed waste	1	$y = 2.85$
Cell 3	Coarse waste	1	$y = 2$
	Mixed waste	1	$y = 2.85$
	Empresa clay	2	$y = 3.15$
	Organic soil	1	$y = 3.45$
Cell 4	Coarse waste	1	$y = 2$
	Mixed waste	1	$y = 2.85$
	Ash	1	$y = 3.15$
	Empresa clay	2	$y = 3.45$
	Ash	1	$y = 3.75$
	Organic soil	1	$y = 4.05$

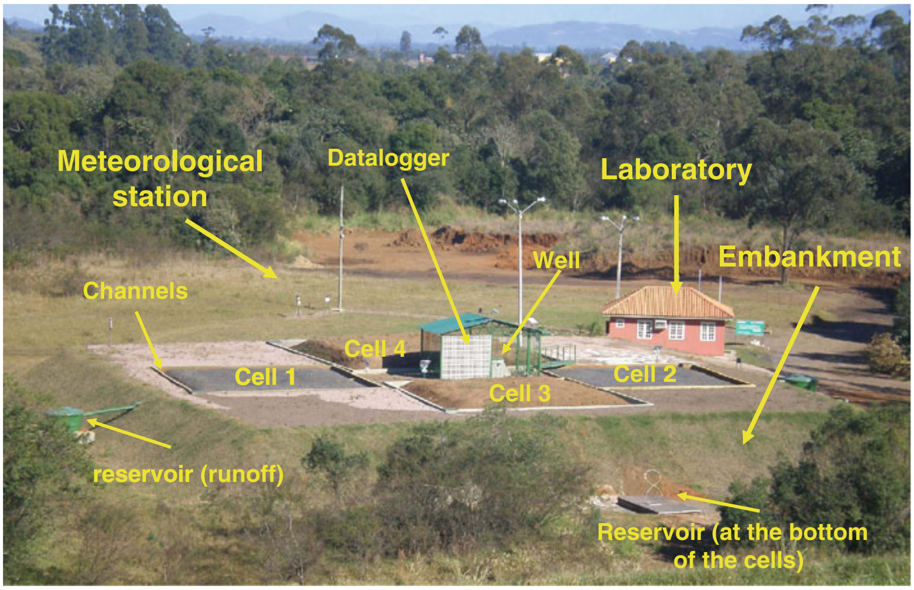
Building of the Experimental Pilot Unit

A preliminary survey at the site chosen for construction revealed a superficial water table. An embankment was then designed and built to install the cells. Clay available on site was used to build the embankment, which was compacted by trucks. The excavations inside of the embankment were subsequently filled with coarse waste.

The sidewalls of the excavations were layered with a geosynthetic liner to prevent leakage of the percolate and consequent soil contamination. The lysimeters, polypropylene cylindrical tanks (2 m high and 2 m in diameter and bottom sealed) were placed at the center of the excavation.

The in situ dry unit weight of the materials was adjusted to a previously determined value. The four excavations were filled with non-compact coarse waste (dry unit weight = 1.35 t/m^3). In cells 2, 3, and 4, mixed wastes

Fig. 2 View of the pilot unit (mining area, Forquilhinha, Brazil)



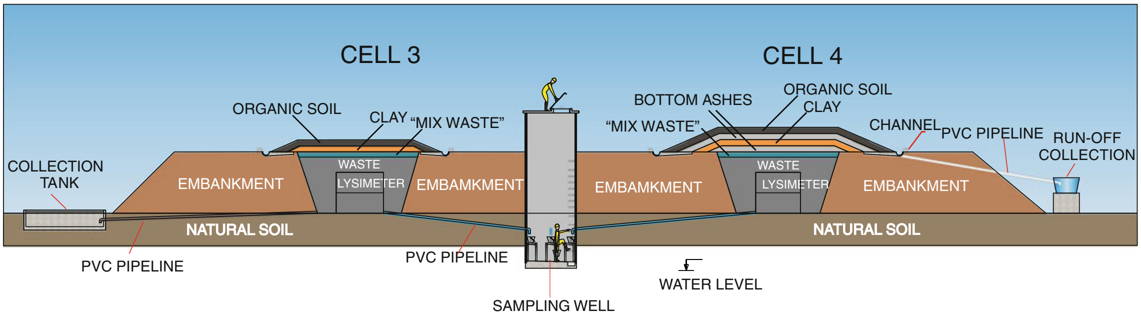


Fig. 3 Cross section of the embankment with cells 3 and 4

Table 2 Compaction results

Materials	Laboratory compaction		Parameters of field compaction		Compaction degree GC (%)	Deviation from optimum water content D (%)
	γ_d (t/m^3)	ω_{otm} (%)	γ_d (t/m^3)	ω (%)		
Mixed waste (Cell 2)	–	–	2.01	–	–	–
Mixed waste (Cell 3)			2.06	–	–	–
Mixed waste (Cell 4)			1.99	–	–	–
Clay (Cell 3)	1.68	16.3	1.69	15.4	100.7	−0.9
Clay (Cell 4)			1.75	14.7	104	−1.7
Ash (lower layer)	0.990	42	0.90	32	90.2	−10
Ash (upper layer)			0.89	34	89.7	−8

γ_d dry unit weight; ω_{otm} optimum water content; ω field water content (before compaction); *GC* compaction degree (γ_d field/γ_d laboratory)

were compacted as 0.30 m layers (dry unit weight = 2.00 t/m^3), with a vibratory plate. Cover materials, ash and clay, were disposed with compaction control on top of the mixed waste (cells 3 and 4), as 0.3 m thick layers. The materials were compacted with a rammer (clay) and a vibratory plate (ash). Compaction control was based on the field water content and dry unit weight (ABNT 1986a) and by laboratory compaction tests (ABNT 1986b). Table 2 shows the field and laboratory compaction parameters for each material used.

The ash (lower layer) was compacted at about 30% of gravimetric water content because at this percentage, the unsaturated hydraulic conductivity of the ash is smaller than that of the clay for the same suction. Furthermore, the dry unit weight of the ash does not change significantly with its water content (Ubaldo 2005).

Organic soil was applied on top of the cover materials in cells 3 and 4. This non-compacted layer was used to protect and minimize erosion and evaporation from inner layers.

Monitoring Procedures

Data on suction, water content, and temperature of the layers (waste and soil), climate (precipitation, relative humidity, air temperature, atmospheric pressure, wind velocity and direction velocity), and water volumes (flow into waste and run-off) have been collected periodically at the experimental pilot unit.

The water volume that flows to the bottom of the all lysimeters is measured daily. Monthly water samples (from each lysimeter) are collected and physical–chemical data (pH, electrical conductivity, oxidation–reduction potential, and dissolved oxygen) as well dissolved metals are determined. The runoff volumes of each cell are collected and measured after a rainfall event.

Data collected at each sensor installed in the layers (suction, water content, and temperature) are collected at 30 min intervals and stored in a data logger and downloaded periodically by internet connection. Data such as temperature, relative humidity, rain precipitation, atmospheric pressure, and wind velocity and direction are recorded automatically from the weather station at 30 min intervals.

Initial Results

The following figures show some preliminary results for the experimental pilot unit. Figure 4 shows the pH, conductivity, and temperature in 2008 for the four cells. We observed in cell 3, where the dry cover was constructed using a layer of compacted clay, and cell 4, where the dry cover contained layers of compacted clay and ash, that the water pH was nearly 7.0. On the other hand, the pH of the water collected from both cells 1 and 2, where no soil covers were used, was less than 3.0. These results are in agreement with conductivity and temperature data when these same pairs of cells are compared. Conductivity is an index of the flow of electrical current in a substance and was higher for water samples from cells 1 and 2 than for cells 3 and 4 (Fig. 5). Likewise, in cells 1 and 2, the

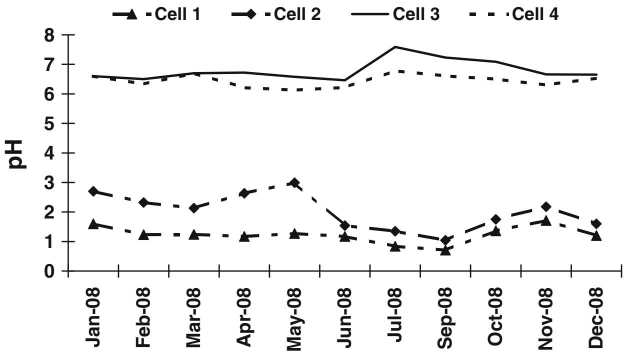


Fig. 4 pH over time

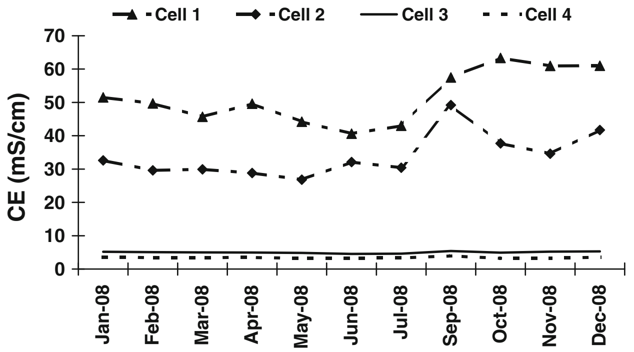


Fig. 5 Conductivity over time

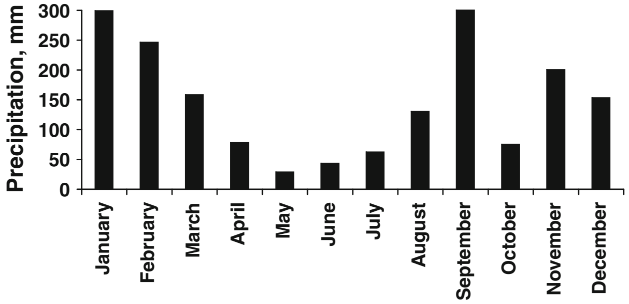


Fig. 7 Rainfall in 2009

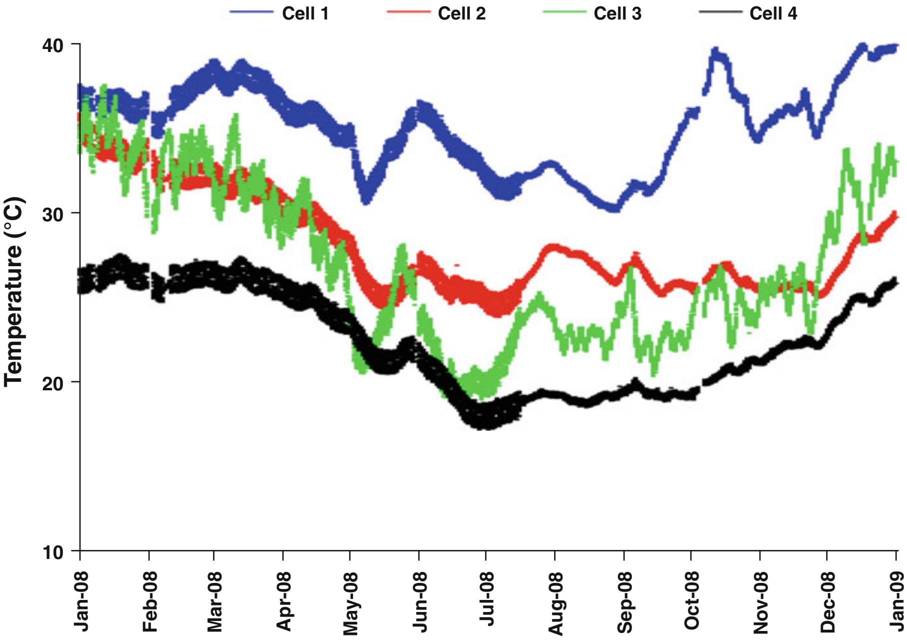
temperature of the coarse wastes was higher than in cells 3 and 4 (Fig. 6). The oxidation reactions that generate AMD are exothermic and the higher temperatures indicate that such reactions are occurring. We observe that temperatures are higher in cell 1 (waste with no cover) and lower in cell 4 (cover with a capillary barrier).

Data on rainfall and on water content of the layers are necessary to quantify the annual and seasonal water balance of the cells. Figure 7 shows the 2009 monthly precipitation, which is typical for the region. The highest precipitation occurs from September to March with peaks in January, February, and September. The lowest precipitation occurs from April to August with minimum values in May, June and July.

Figure 8a shows rainfall in June 2008. As precipitation occurs, water content in cell 4 (Fig. 8b) increases in the upper layers of the cell (ash and organic soil). This behavior is controlled by the initial water content of the layers, by the saturated hydraulic conductivity of the materials, and by the rainfall intensity. The water content of the clay layer remained 100% saturated (clay-saturated volumetric water content is 40%) and the water content of the layers that underlie the clay layer did not change significantly during or after rainfall events. High saturation level corresponds to negligible oxygen diffusion into the waste (Cabral et al. 2000; Yanful 1993).

The volume of water collected at the bottom of each lysimeter is measured regularly. Figure 9 shows the cumulative volume of water in each lysimeter until the first half of 2009. The cumulative volume of water in the lysimeters in cells 3 and 4 (the cells covered with compacted clay and compacted clay and ash) was less than that for cells 1 and 2, reflecting the performance of the compacted clay layers in reducing the amount of rainwater that reach the waste.

Fig. 6 Temperature on the top of the lysimeters in coarse waste



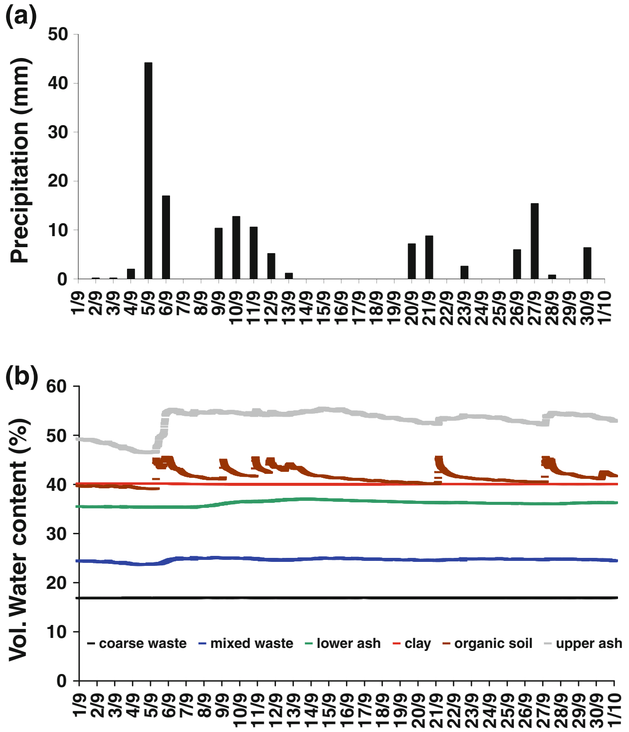


Fig. 8 **a** Rainfall in September 2008; **b** Water content of layers in cell 4 in September 2008

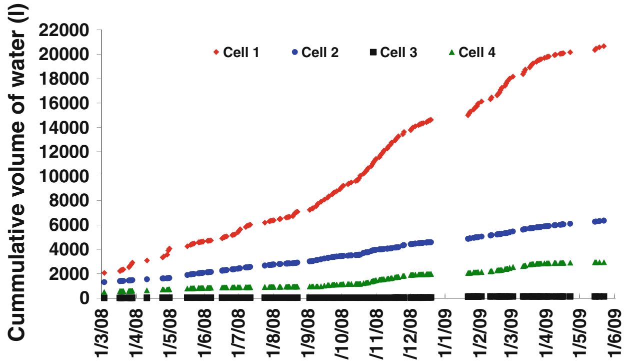


Fig. 9 Cumulative volumes of water collected at the bottom of the experimental cells

Concluding Remarks

This paper describes the construction and initial monitoring of a pilot unit to evaluate the performance of a dry cover to mitigate AMD being generated by coal wastes. The initial results have shown that the dry cover systems with compacted clay as a capillary barrier and with bottom ash as an alternative cover material are effective in reducing AMD generation. Data being collected will support the interpretation of the water balance, water flow, and geochemistry involved in AMD generation. The experiment is subjected to weather conditions that vary annually so a conclusive assessment on the performance of the different dry covers can only be reached after an adequate monitoring period. The pilot project is scheduled to last a minimum of 4 years. Then, the results of the experimental unit will be used to engineer a cover system that can be used to prevent AMD in southern Brazil. The experience obtained in the project will be also potentially applicable to mitigate AMD in other Brazilian mining areas.

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