

TECHNICAL NOTE

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A Simple Field Method to Qualify the State of Saturation in Capillary Barriers

ABSTRACT: A simple and straightforward field method to rapidly qualify the state of saturation of moisture retaining layers (MRL) is proposed and the details of its calibration and operation, described. The technique is based on the simple fact that if gas samples cannot be taken from a stainless tube that is inserted to the desired depth within the MRL, the air filled voids at that depth are not interconnected and the material can be qualified, for all practical purposes, as saturated. In this case, the threshold degree of saturation beyond which gas flux substantially decreases (approximately 85 %), has been attained. In several sites covered with deinking by-products (DBP), an industrial residue that can be used as alternative construction material for landfills and acid-producing mine sites covers, it has been often impossible to collect gas samples below approximately 20 cm from the surface of the DBP layer. The question was thus to know if this is a reliable indicator that the threshold degree of saturation has or not been attained and that the layer is performing its role of gas barrier. In order to answer this question, a calibration was performed in the laboratory and in the field. The calibration consisted mainly on attempting to extract gas from samples compacted at different degrees of saturation. The results show that the threshold degree of saturation for DBP is attained at approximately 83 %.

KEYWORDS: capillary barriers, moisture retaining layer, landfill gas extraction, acid rock drainage

Introduction

Acid rock drainage (ARD) resulting from the oxidation of reactive sulphide-rich mine tailings or waste rock can be controlled by reducing the O₂ input, i.e., by creating a barrier to oxygen migration. Likewise, the efficiency of landfill gas (LFG) extraction can be improved when a barrier to atmospheric air is created within the cover system. This reduces the costs associated with LFG pumping and purification before conversion to energy.

Such barrier to gas migration can be achieved by different techniques, among which covers with capillary barrier effect (CCBE) have been a choice in many cases (Bussi re et al. 2003; Aubertin et al. 1997; Yanful 1993; Yanful and St-Arnaud 1991). The hydraulic principles of CCBEs have been extensively reported in technical literature (Nicholson et al. 1989; Yanful 1993; Bussi re et al. 2003). In simple terms, by placing a moisture retention layer (MRL; typically fine-grained soils with high water retention capacity) over a capillary break layer (CBL; typically coarse-grained soils with comparatively low water retention capacity), a capillary break is created at the interface between the two materials. As a result, a high degree of saturation is maintained in the MRL— independently of the degree of saturation within the CBL—which drastically reduces the migration of atmospheric O₂ through the MRL.

The MRL can be constructed using several types of materials, including natural soils, nonreactive tailings (Bussi re et al. 2003; Bussi re et al. 1999), and organic-rich by-products, such

as deinking by-products (DBP) (Audet et al. 2002; Cabral et al. 2000a,b). Cabral et al. (2004), among other researchers (e.g., Rahman et al. 2002), observed that beyond a threshold degree of saturation (Sr) of approximately 85 %, a one order of magnitude drop in the oxygen diffusion coefficient occurs; the air filled voids are no longer interconnected and gas migration can only occur through the liquid phase. The performance of a CCBE is thus tributary of the degree of saturation (Sr) inside the MRL. As such, this is an important parameter to be monitored, particularly when alternative materials are being tested to be used as MRL.

Several techniques have been used to monitor the evolution of moisture within MRLs, including TDR (Cabral et al. 1999) and various types of pore pressure probes. In order to determine the degree of saturation, moisture data from calibrated probes are converted into degree of saturation using density data. In both cases, one has to rely on the precision of probe readings and their calibration. Destructive methods that allow more precise estimation of Sr based on density and moisture data obtained from exhumed samples are preferably to be avoided during the monitoring phase.

There is thus a need to develop a method to assess the performance of CCBEs as oxygen barriers (as far as its state of saturation is concerned) in a more straightforward manner. This paper describes the details of a simple monitoring methodology that allows instantaneous field qualification of the state of saturation of a MRL. A stainless steel tube is inserted to the desired depth within the MRL and capped with a septum. Gas samples are then taken using a syringe. If gas cannot be pumped from the tube, the air filled voids are not interconnected and the material can be qualified, for all practical purposes, as saturated. In this case, the threshold degree of saturation beyond which oxygen flux decreases substantially has been attained. The method was calibrated both in the laboratory and in the field.

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Materials and Methods

The proposed method was developed during the monitoring phase of several experimental field covers constructed over potentially ARD-generating abandoned mine sites (Cabral et al. 2000b, 2002; Audet et al. 2002). In these projects, deinking by-products (DBP) were used as alternative MRL material. The composition of the DBP, a fibrous and highly compressible industrial by-product produced in large quantities by the pulp and paper industry, has been described by Cabral et al. (1997). Typically, DBP contain from 50 to 70 % organic matter by weight (mainly cellulose fibers) with calcite and kaolinite forming most of the mineral part. The material has a low hydraulic conductivity (typically in the 10^{-8} to 10^{-9} m/s range) and a relatively high water retention capacity (Cabral et al. 2004b); Burnotte et al. 2000). Attempts to classify the material in geotechnical terms did not prove successful: due to its fibrous nature it is impossible to obtain a grain size distribution and determine the Atterberg limits (Cabral et al. 2000a; Kraus et al. 1997).

Figure 1 presents a typical profile of a CCBE constituted of DBP. The DBP layer acts as moisture retention layer (MRL), whereas the underlying coarse mine residues acts as CBL, i.e., their superposition creates a capillary barrier. Figure 1 also presents some of the monitoring instruments installed at the Clinton site (Cabral et al. 2000b), including TDR.

The initial field degree of saturation of the MRL was estimated based on density-water content data determined right after compaction of the DBP layer. Density measurements were performed using the sand cone method (ASTM D 1556). At the Clinton site, the

evolution of the degree of saturation was initially assessed indirectly using volumetric water content data obtained from TDR readings (Cabral et al. 1999). A limitation of this method of estimating S_r is that it requires the estimation of the volume of voids, which may be quite difficult and imprecise due to compression of the MRL caused by mechanical consolidation due to the overburden of the protective layer and solid loss due to biodegradation (Teixeira 2001; Panarotto et al. 1999). Indeed, important settlements have been observed at several experimental plots where DBP have been used (Audet et al. 2002).

Required periodical gas quality monitoring at the Clinton site was done by sampling gas at various depths inside the DBP layer. The gas monitoring system consists of: 1) a stainless steel tube with a sharp bottom end; 2) a stainless steel bar 10–20 mm longer than the tube, also sharpened at the bottom and equipped with a handle at the top (Fig. 2a); 3) a 7-mm septum (Aldrich Chemical Company, Inc.) and a 60-ml plastic hypodermic syringe with a 21-G needle (Becton Dickinson and Company).

Gas samples were taken according to the following procedure: The tube with the bar inside is first inserted down to the desired depth. The bar is then removed and a septum is placed tightly at the top of the tube (Fig. 2b). The needle of the syringe is then pushed through the septum, and its piston pulled in 2 s up to the 60-ml reading (see Fig. 3). The piston is maintained in this position for 5 s and then released. Laboratory calibration of this procedure has shown that if the piston goes back to approximately the 15-ml reading (for a 1-m long tube) or to the 30-ml reading (for a 2-m long tube), no gas has entered the tube; i.e., the air filled voids are not interconnected. Due to the low hydraulic conductivity of

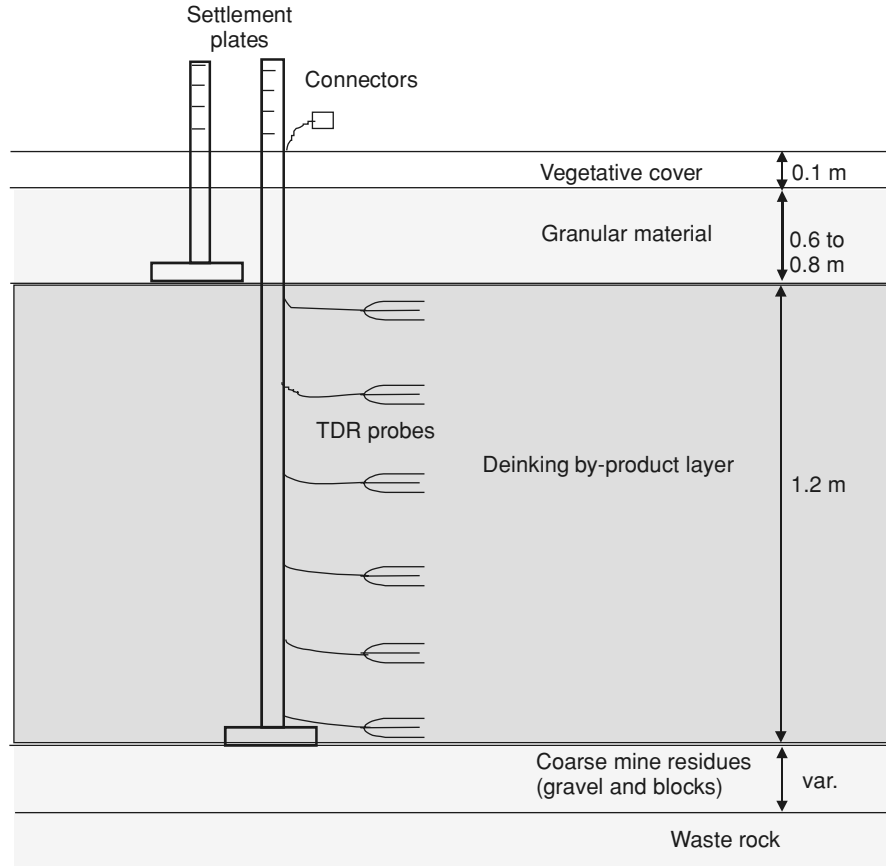


FIG. 1—Typical Profile of the CCBE Constructed at the Clinton Site and Detail of Part of the Monitoring Instrumentation Installed.

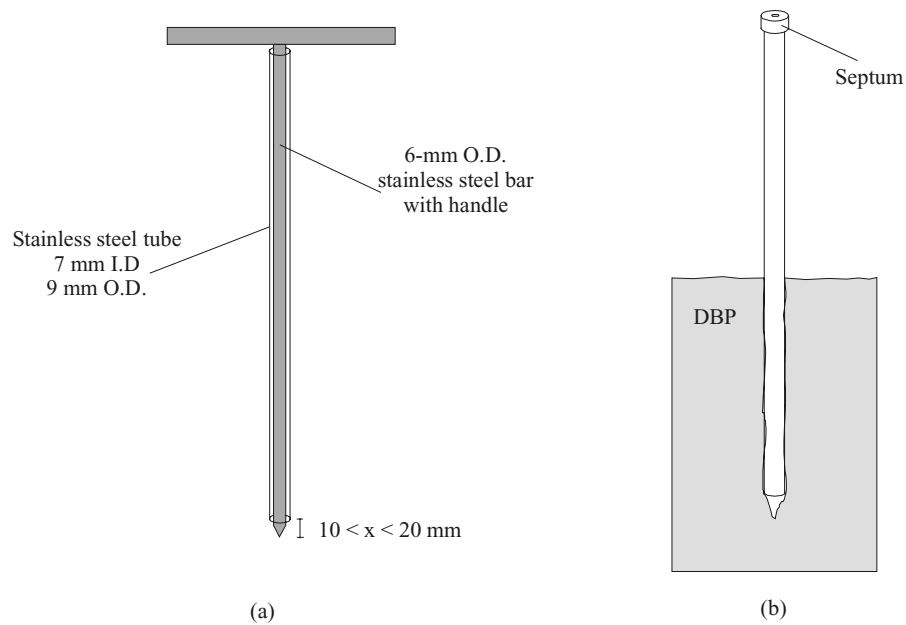


FIG. 2—Scheme of the sampling tube: (a) Before Insertion; (b) After Insertion.



FIG. 3—Piston at the 60 ml reading.

typical DBP layers ($\sim 10^{-8}$ m/s), water does not enter the tube fast enough to influence the reading. If the piston stays at the 60 ml reading, the state of saturation is such that the air-filled voids in the MRL are interconnected and chances are that the oxygen flux will be high—or much higher than in the opposite case. It is important to use a clean and dry syringe and needle.

At the Clinton site, as well as in other sites covered with DBP, it was often impossible to collect gas samples below approximately 20 cm from the surface of the DBP layer (Cabral et al. 1997, 2000b); i.e., the piston retreated back to a lower reading. This was attributed to the high level of saturation within the MRL (DBP layer). The question was thus raised whether the fact that gas cannot be sampled could be a reliable indicator of a threshold degree of saturation beyond which one can affirm that the MRL (or for that matter, the CCBE) is performing well its role of oxygen barrier.

In order to answer this question and to establish a link between the behavior observed in the field (piston retreated back to a lower reading) and the state of saturation, a calibration was performed in the laboratory following the procedure described below.

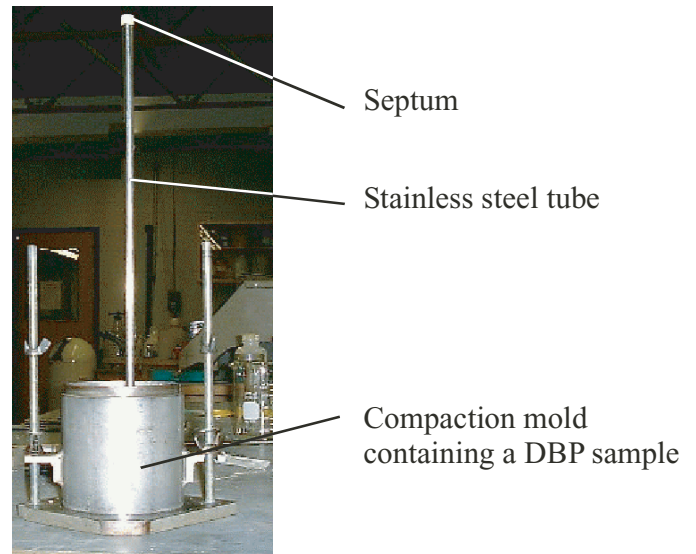


FIG. 4—Laboratory Setup.

Laboratory Calibration

DBP layers have been typically compacted in the field with gravimetric water contents between 140 and 160 % for degrees of saturation in the vicinity of 90 % (Cabral et al. 2002). A total of 19 DBP samples were prepared in the laboratory at several gravimetric water contents. The material was compacted in three lifts into the compaction mold (Fig. 4), following an adaptation of the standard Proctor procedure (ASTM D 698); the number of blows per lift was adjusted to obtain different degrees of compaction. Since the volume, mass, and water content of each sample can be easily obtained, a precise estimation of the degree of saturation can therefore be made.

The same equipment used for field gas monitoring was employed to verify whether the fact that gas cannot be sampled is indicative of the state of saturation. The tube and bar assembly was inserted at the center of the sample to a depth of approximately 60 mm

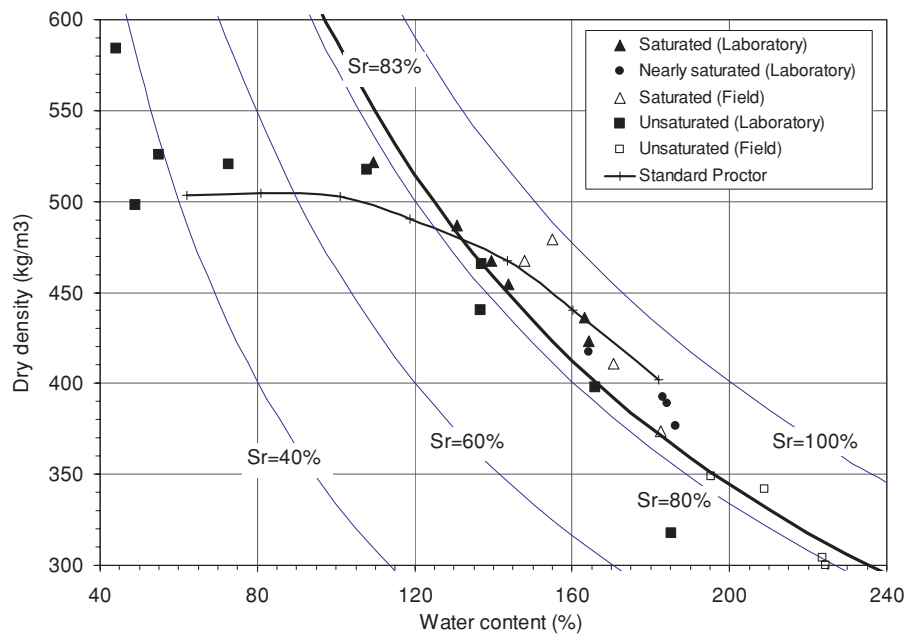


FIG. 5—Standard Proctor curve of DBP and values of degree of saturation obtained in the laboratory and in the field.

(Fig. 4). After removing the bar, the septum was installed and the syringe was pushed through in order to try to sample gas following the procedure described previously.

The degrees of saturation of the 19 samples prepared in the laboratory are presented in Fig. 5 (black filled symbols). The standard Proctor curve obtained for the same batch of DBP is also presented. Samples were qualified as in “saturated” condition (black filled triangles in Fig. 5), when it was not possible to sample gas. Otherwise, i.e., when gas sampling was possible, they were qualified as in “unsaturated” condition (black filled squares in Fig. 5). An intermediate state of saturation, qualified by the term “nearly saturated,” was associated with four samples (indicated in Fig. 5 by circles) for which the piston retreated back to a reading between 60 ml and 15 ml.

The thin lines in Fig. 5 represent equal degree of saturation lines. The continuous thick line ($S_r = 83\%$) was identified (by trial and error) as the approximate border line between “unsaturated” and “saturated” conditions. With the exception of one black triangle at a water content equal to 110%, “saturated” samples fall right of the $S_r = 83\%$ line, whereas “unsaturated” samples fall left of it. It can thus be said that the threshold degree of saturation is 83%, a value comparable to the $S_r = 85\%$ obtained by Cabral et al. (2004) for the same material. It should be noted that the degree of saturation of the samples qualified as “nearly saturated” fall just right of the threshold line and just under the $S_r = 85\%$ line (not presented).

Field Calibration

The state of saturation inside two MRLs constructed with DBP was assessed in the field using the procedure presented above. Three measurements were made right after compaction of the MRL, whereas five others were made after the overlying protective layers of the CCBE had been in place for nearly five years. In the latter case, excavation of the protective layers was necessary and done in the following manner: a 5-cm hole was augered through the top granular layer and a 5-cm diameter PVC was inserted (Fig. 6; see also Fig. 3). The stainless steel tube—with the bar inside—was then pushed down to the desired depth (Fig. 6). After measurement, the

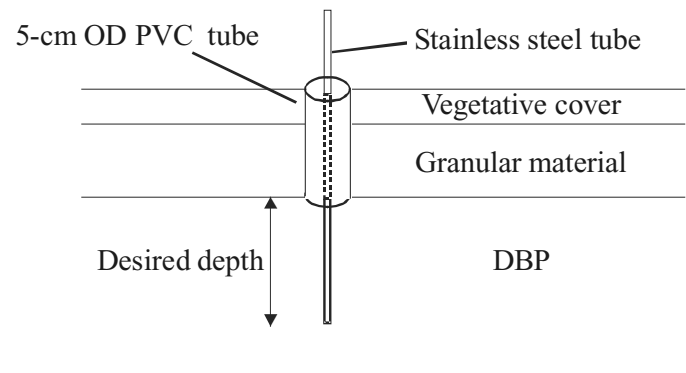


FIG. 6—Sketch of the installation requiring excavation of the protective layers.

PVC tube was removed and the hole was sealed with bentonite paste.

In order to determine the degree of saturation in the field, density and moisture content data were required. For that reason, sand cone tests (ASTM D 1556) were performed at the same depths where attempts to sample gas were made. The values obtained are plotted in Fig. 5 (hollow symbols). Only two types of conditions were obtained, namely “saturated” (indicated by hollow triangles on Fig. 5) and “unsaturated” (hollow squares). It can be observed that, with the exception of one result at a water content value of 210%, “unsaturated” samples fall left of the border line ($S_r = 83\%$), whereas “saturated” samples fall right of it.

These results seem to confirm that the method to estimate the state of saturation is reliable. If a simple laboratory calibration is made, it is possible to assess instantaneously and reliably whether a MRL is performing or not as an oxygen barrier.

Conclusions

Deinking by-products have been used as alternative material for the construction of moisture retention layers in CCBEs that act

as barriers to the migration of atmospheric air. The performance of such barriers depends on maintaining a state of saturation such that the air-filled voids are not interconnected, which substantially reduces oxygen migration. Direct measurement of the degree of saturation of the barrier using destructive methods are costly and often to be avoided, whereas indirect evaluation often involves many assumptions in terms of density and moisture content, particularly in the case of highly compressible materials, such as DBP.

A quick and reliable field method to assess the state of saturation of MRLs was developed and the details of its use presented. It requires the use of inexpensive equipment and limited skills. The proposed method indicates when, in the field, one can consider that the material is sufficiently "saturated," i.e., that the air-filled voids are no longer interconnected. In order to determine the value of this threshold degree of saturation for a given material (DBP in this case), a simple laboratory calibration is necessary.

The details of the laboratory and field calibration procedure were presented. The laboratory calibration data indicate that the method is reliable. For DBP, the threshold S_r value obtained in the laboratory was 83 %. For values greater than that, the method consistently indicated a "saturated" state, whereas for values under $S_r = 83$ %, the method indicated an "unsaturated" state. This corroborates the results of Cabral et al. (2004) who observed that beyond $S_r = 85$ %, the oxygen diffusion coefficient through DBP is significantly reduced. Moreover, field calibration revealed the same value of threshold degree of saturation (83 %), confirming the reliability of the method in situ.

Acknowledgments

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