Design of Watertight Barriers for Retention Ponds of Cyanide Using Sludge from Water Purification Station (Ziga)

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Abstract: In a context of sustainable development and use of eco- materials, it was examined the possibility of using sewage sludge from the water treatment plant of Ziga as an inorganic support to achieve sealing barriers that can withstand high stresses to overcome any weaknesses of the geological barrier (called passive barrier). The station Ziga that potabilises the water from the river Nakambé is located 45 km north east of Ouagadougou. Some experiments on the rheology of sludge from Ziga as well as the filtration of the mixture Ziga's sludge and clays from Nouna, Zorgho and Ticare, three regions of Burkina Faso, were conducted. These studies demonstrated the complex hydro-mechanical behavior of Ziga's slurries: Newtonian fluid thixotropic threshold for solids contents less than 16.5 wt% and non-Newtonian for higher values. Sludge from the water treatment station Ziga have a hydraulic conductivity of 10^{-8} m/s. The results are below regulatory requirements. However, the permeability can be reduced to achieve the value of 10^{-9} m/s in particular by adding the clay from Zorgho or Nouna to mixtures of Ziga's sludge and neutral leachate, typically mineral water. Beside neutral leachate, two types of leachate were used. One type is composed of acid leachate and the other type is basic. It was shown that the limewater solutions cause deterioration of the seal probably due to the presence of hydroxide ions.

Key words: Ziga's sludge, watertight barriers, leachates, hydraulic conductivity, filtration, rheology.

1. Introduction

Burkina Faso is implementing an extensive program of mining operations for the extraction of gold and manganese. In this program the mining industry uses retention ponds of cyanide.

In the mining sector, large amounts of industrial waste are produced and the difficulty to prevent soil-infiltration of cyanide and other wastes contained in retention ponds is alarming. In addition, the production of sewage sludge from the treatment plants is increasing, and currently landfilled. This is causing environmental impact with the release of chlorinated odors. Therefore it is mandatory to develop and

manage an environmental engineering plan that helps to limit the environmental impact in the short and long term. Due to the large amounts of sludge generated, and its content of fine clay, we aim to make use of a Bi-product of wastewater treatment, the sludge, by turning it into waterproof material when mixed with low hydraulic conductivity soils.

Various techniques are available to estimate soil hydraulic properties, predicting these properties based on macroscopic parameters such as texture and bulk density. The problem of estimating hydraulic properties of soils is that soils are anisotropic materials; field conditions such as degree of compaction and the presence of fissures and cracks may alter the results of hydraulic conductivity tests done in the same soil but in different locations. It is

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also possible to conduct laboratory tests with undisturbed samples, but results may differ from field tests for the same reasons explained above. In both cases, however, the larger the number of analyzed samples, a higher degree of certainty is attained. When no such tests are done, it is still possible to estimate empirical values of the hydraulic conductivity of soils if other properties, such as the particle size distribution, are known. The available methods do not give enough information about the physical relations among properties of soil [1]. Vogel [2] used microscopic observations on thin sections to predict a 3-dimensional pore distribution and connectivity of two soils.

Flores et al. [3] used a simplified image analysis to study the contamination of soils by Light Non-Aqueous Phase Liquids (LNAPLs), showing the possibility of studying soil properties using more accurate and simple methods.

The present study aims to design water barriers using sludge from Ziga's wastewater treatment station, replacing bentonite -of foreign origin- by local swelling clay, reducing the economic cost as well as the carbon footprint. This will help to find solutions to an environmental problem that is significant in many regions and countries.

However, in view of the use of clay, one must know that the clay materials have the ability to interact with the ions of the leachate [4]. This causes moisture exchange between cations contained in the leachate and the smectite [5], which may alter the hydraulic conductivity of the seal screen [6].

Paumier et al. [7] evaluated the impact of a synthetic leachate on the structure of four types of bentonite used in the manufacturing of geosynthetic clay liners (GCLs). The hydraulic properties of the dispersions were tested using filter press tests to obtain flow curves. Results of these tests were correlated with the cationic concentration, electrical conductivity and pH of the dispersions, swell indexes of the bentonite extracted from the GCLs, and

permittivity of the intact GCLs determined in oedo-permeameter tests. The results showed difference in the sensitivity to the synthetic leachate from different types of bentonite.

According to Ref. [8], the properties of bentonite are function of montmorillonite amount which determines quality of raw material as well as the specific surface area. The bentonite can be activated alkali and acid solutions and their specific area be affected [9-11]. As a result of the activation, the pore size distribution of the bentonite is modified by cation exchanges that occur in the structure [12].

Babaki et al. developed a kinetic model based on activation temperature and time to estimate the specific surface area of ca-bentonite in the presence of sulfuric acid [13].

Karimi and Salem [14] have studied the activation of a typical bentonite in the presence of sodium carbonate by a modified kinetic model. These authors showed that the activation rate significantly depends on carbonate concentration and it was maximized in the presence of 4.5wt% of alkali solution. It was found that the specific surface of bentonite was greatly affected by particle size distribution of starting raw material.

Toguyeni, (2012) [15] studied the rheology of sludge from Ziga considering different solid contents. These studies demonstrated the complex hydro-mechanical behavior of Ziga's slurries: Newtonian fluid thixotropic threshold for solids contents less than 16.5 wt% and non-Newtonian for higher values. Unpublished results showed that mixtures of bentonite with Ziga's sludge have been found suitable as waterproof materials. Adding bentonite clay improved particularly the hydraulic impermeability. However, bentonite commercialized for its use, increases the costs of any mixture that includes it, economically and environmentally.

2. Methods and Materials

2.1 Origin and Physical Properties of Sludge Study

Besides the health requirements, the axis of

recovery requires that we explore characterize the fine sludge fraction Ziga both in terms of colloidal stability and rheological tests with in terms of permeability with filtration tests.

Natural or raw water dam Ziga first undergoes a natural settling. Then the raw water is fed to the treatment plant through a pumping station, located at the foot of the Ziga dam. It is finally discharged to the treatment plant by means of pumps where the raw water passes through five stages of treatment before arriving in Ouagadougou ; cascade aeration (to restore water dissolved oxygen and allow the removal of iron), coagulation and flocculation (floc forming heavy to allow them to settle, remove the colloidal fraction), filtration (removing particles in suspension), disinfection by sodium hypochlorite (disinfection and destruction of pathogenic microorganisms).

This treatment leads to the production of quality water meets WHO standards and stored sludge stored on the site, which it is possible to consider recovery methods.

The sampling was done in line with two storage pools (one out of order, the other in operation) with vials and bags waterproof and dustproof. Four series of five samples of 2 L were made at different points on different heights. Before chemical analysis, the sludge collected from each pool were homogenized and an overall sample 2 L, each representative is appointed ancient mud (dating from 2004) and young sludge (from February 2008).

The sludge from the treatment plant Ziga consisting of a mixture of water and fine grain to coarse (sand and silt) with clays and organic matter, were dried at room temperature prior to analysis, then rehydrated a defined by the ratio of the mass of dry powder to the water mass and denoted by W%. Particle size characterization was performed using a Malvern 2000 laser granulometer Mastersizer. To ensure a good disintegration of aggregates dry powder preparation was gently mixed for 7 days. In addition to the

chemical analysis of the methylene blue test (standard NF P94-068) were also performed to determine the sludge shaliness.

2.2 Rheological Characterization

There are in practice, field tests, which certainly help prioritize grout (Marsh cone, cone Abrams ...) and mixtures with very useful empirical parameters for applications but do not help not find sizes rheological characteristics of the fluid flow or to link with the fundamental physico-chemical characteristics of the material and its constituents.

Very often, mineral slurries have a complex non-Newtonian fluid behavior at threshold, which may be characterized by a model or Bingham Herschel-Bulkley. The main rheological characteristics (apparent yield stress, viscosity and thixotropy) were studied using the Physica MCR rheometer (Anton Paar-) under imposed shear rate ($\dot{\gamma}$). The geometry used is the cone-type and cylinder or Couette. Taking into account local climatic conditions (Burkina Faso), the tests were performed at temperatures between 25 °C and 45 °C. Suspensions assayed at W were all pre-sheared at $\dot{\gamma} = 200 \text{ s}^{-1}$ for 30 s, and then kept at rest for 15 s to put in a neighboring structural condition. The protocol used is the application of a shear cycle rise-bearing-descent (shear increasing- shear constant- shear decreasing) with $\dot{\gamma}$ ranging from 0 to 200 s^{-1} , followed by a decrease to 0 s^{-1} . Fig. 1 shows the curves of flow for Ziga's sludge.

2.3 Origin (and Physical Properties) of the Soils

For this study, four clays (sedimentary rock composed largely of clay minerals) were taken in three locations of Burkina Faso. One comes from Tikaré land: it is a Grave lateritic Clayey Rouge (Red GAL). Two others from Nouna and Zorgho and the last is the sewage sludge from the treatment of Ziga station. Fig. 2 is a map showing the location of sampling clays.

Table 1 Estimation of the amount of sludge.

	Raw water (m ³)	Treated water (m ³)	Liquid sludge dryness = 2%	Dry matter (tones)
Monthly average value	1,928,900	1,900,000	28,000	578

Fig. 1 Curves of flow for Ziga's sludge. **Fig. 2** Map of sampling localities clays.

2.4 Choice of the Leachates

Before performing the filtration, it took prepare mixtures in suspension. The choice of solvents is justified by the need to know the behavior of soils when they are solicited by the chemical action of leachates of various kinds. The solvents were prepared from mineral salts and water LAFI (in annex for the composition) with data corresponding to a desired pH concentration.

Depending on the stage of development of waste, there are three types of leachate [16]. The first, in chronological order, is composed of young leachate.

These leachates are characterized by a relatively high organic biodegradable load. They consist mainly of volatile fatty acids and metal loaded. These correspond to the first non leachate methanogenic phases of the evolution of a dump. They have a pH below 6.5. To obtain a synthetic young leachate, a diluted solution of acetic acid (CH_3COOH) was used. A concentration of 3 g/L corresponds to a pH = 3.

When the discharge ages and waste stabilize their organic load decreases and fatty acids are scarce. The appearance of compounds of high molecular weight decreases the biodegradability of leachate. The filler metal becomes negligible and the pH is close to neutral (between 6.5 and 7.5). We are in a stable methanogenic phase. The realization of a synthetic leachate neutral pH was performed using a solution of mineral water LAFI.

Another neutral pH leachate was used. It was obtained by dissolving calcium chloride (CaCl_2) concentration of 2.94 g/L. This will evaluate the action of chloride ions Cl^- and Ca^{2+} calcium on materials. It is thus possible to know if the degradation of permeability is only related to the pH of the medium, or if in addition the predominance of certain chemical species may also affect it. The chloride ions concentration increases from 5.88 g/L and the calcium ions of 2.94 g/L.

Stabilized leachates correspond to the maturation phase of a landfill. They have a low organic load and are very sensitive to biodegradation. They have a pH above 7.5.

A water solution of lime concentration of 2 g/L was prepared to make a stabilized synthetic leachate. This concentration provides a pH = 12.6.

2.5 Filtration Tests

Soils are dissolved in 400 mL of solution to form a slurry containing 40 g of soil and 400 mL of solvents.

The dissolved 40 g may be from the same soil or can be made up of 2 soils in the proportions 20 g each. This suspension was homogenized and stored for at least 24 h. The filtration tests were conducted using an API filter press of 90 mm diameter and 90 mm in height (Fig. 3).

The pressure cell of the filter press is filled with 300 ml of the mixture obtained. Then it is assembled against it bed. The installation of the inlet pipe of compressed air at the head of cell and a container under the tube of drainage finalizes the assembly of equipment for its use.

The filtration test can begin as soon as the pressure is adjusted to the desired value: a pressure between 600 and 700 kPa. The applied pressure causes the liquid to flow through the filter paper while the latter retains the solid particles in the mixture.

Experiment is carried out while taking care to note frequently the cumulative volume and the time required for the filtration of this volume. The experiment is stopped after one hour. The cell is removed from the frame and then performs a release to collect a solid named cake which is more or less dry and deposited on the filter (Fig. 4). The cake results from the agglutination of the solid particles which were present in the mixture. Stop the filtration at the end of one hour of time will keep the cake in a state of saturation. Occasionally, the retention properties of the material do not allow reaching one hour of filtration. In this case, the filtration is stopped when appearing the first air bubbles.

After conducting these operations, the cake is weighted and its thickness is measured. This provides sufficient data to calculate the characteristics of different materials including key parameter: permeability.

The fine powder (40 g) of sludge or mud Ziga Ziga-bentonite mixture is suspended in 400 ml of fluid then stirred 3 min at 11,000 rev/min. The suspension is left to stand for 24 h before the test to allow hydration and swelling of the clay phase and reach a steady state.

The suspension (300 mL) is placed in the cell and subjected to a constant pressure (700 kPa) by direct application of pressurized air. Under the effect of the

Fig. 3 API filter press.

Fig. 4 Cake obtained after filtration of water by used clay.

Fig. 5 Evolution of the cumulative filtrate volume versus time: Case Nouna in the presence of water LAFL.

Table 2 Hydraulic conductivities of the soils (m/s) according to the leachates used (tests lasting more than one hour).

Materials	Leachates LAFI	LAFI + Calcium chloride	LAFI + Acetic acid
Zorgho	1.75×10^{-10}	-	-
Zorgho + GAL Rouge	1.54×10^{-10}	-	-
Nouna	1.38×10^{-10}	2.96×10^{-10}	4.52×10^{-10}

pressure of the quantity of filtrate outlet cell is weighed continuously. The test takes about 3 h and end cell is removed. Forming a cake consisting roughly in contact with the filter and a supernatant suspension is observed. Their weight and the thickness of the cake are rated output test and after drying at 110 °C.

The intrinsic permeability of cake Kc is determined using Darcy's law. This method, described by many authors assumes that the permeability and the specific volume of the cake are constant during the filtration [17-20]. The shape of filtrate curves obtained is shown in Fig. 5. The volume of filtrate increases linearly with the square root of time; we can also determine the slope of the characteristic curve of the filter and therefore the intrinsic permeability value (Kc) in m². Intrinsic permeabilities are transformed into hydraulic conductivities (Kc) in m/s, with the assumption that the viscosity of water to 1 mPa.s.

3. Results and Discussion

Taken alone, soils that have the most interesting features are the soil of Zorgho, the soil of Nouna and Red GAL because among our soils they are those having led to tests lasting more than one hour; so they led to the lowest hydraulic conductivities (Table 2). This results in the possibility of using these materials so long as the proportions used to allow us to go below the prescribed threshold. Note that the solution of lime water is the one with the lowest occurrence in this table. So the synthetic leachate is most detrimental to the sealing properties of our clays.

Table 2 shows that taken in isolation clay Nouna and the Zorgho are less permeable because filtrations lasted over 1 h. Hydraulic conductivities are often of the order of 10^{-10} m/s.

Nouna soil is one having the most instances in this table. It is also the one with the lowest even in the presence of leachate hydraulic conductivities. Clay Nouna is probably the least permeable of all clays in our study.

The deterioration of the seal caused by the limewater solution properties may be due to its basic nature. But it could also be due to the presence of hydroxide ions. According to Neyroud [21], alteration of hydroxides is often deep, because no chemical bonding of the clay cannot resist the attack of the OH⁻ anion. No clay is stable in a medium containing strong hydroxides. Furthermore, the reaction of kaolinite with the materials present in the calcium hydroxide would moderate alteration of clay. It therefore seems worthwhile to perform permeability tests with alkali hydroxides (NaOH, KOH, etc.). Because they would be able to dissolve kaolinite and form zeolites: tectosilicates crystalline porous and therefore permeable.

4. Conclusions

In this study, it was shown that Sludge from the water treatment station Ziga has a hydraulic conductivity of 10^{-8} m/s. The results are below regulatory requirements. However, the permeability can be reduced to achieve the value of 10^{-9} m/s, and even less, in particular by adding the soils of Zorgho or Nouna.

In all tests, we realize that young leachate and stabilized leachate are those that alter most hydraulic performance materials. Intermediate leachate (neutral pH) lead to the lowest hydraulic conductivities. As against, in acid or basic medium, the permeability increases. According to Bonte (2007) [22], this alteration of the hydraulic properties could find its

origin in several factors:

- The dissolution of clays by acids or bases;
- Acids cause flocculation and attack the crystalline structure of the clays, especially the octahedral layer;
- The Basics cause dispersion and attack the tetrahedral layer clays.

The study shows that Burkina Faso has in various areas materials that can be recovered with respect to their sealing potential. This enhancement can be achieved through the realization of passive barriers. These passive barriers can enter into the constitution of sealing landfills waste systems, leach pads, etc. In the future, numerical analysis and computer modeling will be used to study the hydraulics, fissure propagation, and mechanical stability of the mixtures.

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Appendix

Chemical Composition of Mineral Water Lafi

Involved ions	Concentrations (mg/L)
Calcium Ca^{2+}	2.00
Magnésium Mg^{2+}	0.70
Potassium K^{+}	0.24
Sodium Na^{+}	1.00
Bicarbonate HCO_3^{-}	12
Sulfate SO_4^{2-}	1.00
Silice SiO_2^{2-}	15.4
Nitrate NO_3^{-}	Absent