POLLUTANT POTENCIAL OF SOIL STABILIZED WITH BOTTOM ASH TO BE USED IN PAVEMENT STRUCTURES

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SUMARY

This article presents results of a research on soil stabilization using Bottom ash from the Jorge Lacerda thermo-eletric complex (Tubarão, SC), focusing its use in layers of flexible pavement. Laboratory tests on the mechanical proprieties and pollutant potential were conducted. In this article, only results of pollutant potential are presented. The soil and bottom ash were percolated in cells containing several mixtures of both and some were stabilized with lime. Such tests aim to simulate the percolation of rain water in the pavement layers and to analyze the potentially pollutant elements found in the percolated liquid. The percolation was done in a layer of material with similar thickness and compaction conditions to the ones used in pavement. The percolation solution had similar characteristics to the rain's. The chemical elements analyzed in the percolated effluent are found on bottom ash chemical composition. Their quantities in the effluent were compared with the standard values defined by the CETESB in 2001 for soil and water quality. The cylindrical samples (15x35cm) have been molded in the conditions of optimum moisture and maximum dry density, obtained by Standard Proctor Compaction. Results obtained indicated that the efforts to improve the mechanical proprieties of the soil stabilized with bottom ash, minimize the pollutant potential for the hazard elements present in the effluent.

INTRODUCTION

In 1997, around 2,091,158 tons of coal have been consumed by the thermo-electric complex Jorge Lacerda, in Santa Catarina. Such amount originated 878.286 tons of ashes as an industrial waste, which is equivalent to, approximately, 483,058 tons of fly-ashe (55%) and 395,228 tons of bottom ash (45%).Due to its physical-chemical characteristics, the fly-ash is sold to the cement industries that use it in the Pozzolanic Portland Cement or as mineral additions to the concrete. However, the Bottom ash does not reach the same market, becoming a great environmental problem. The current deposit of Bottom ash at Jorge Lacerda Thermo-electric plant is estimated in 1,500,000 tons, increased by a continuous production of approximately 300,000 tons/year. These deposits are highly aggressive to the local ecosystem.

In countries such as The United Kingdom and The United States, the use of waste materials in pavement, including bottom ash that results from the process of burning mineral coal, is largely spread and there are experiences in the evaluation of the environmental risks of its use.

In Brazil, research lead by Rocha *et al.* (1999) and Pozzobom (1999) shows that Bottom ash used as raw material in the manufacture of cement devices, substituting the Portland cement used in the dosage of the devices, as much as the aggregate (fine and coarse sand), presented very promising results.

However, the use of Bottom ash to stabilize soil and to obtain a material with potentiality to be used in layers of pavement has not been studied yet. In 2001, a research was initiated at the Soil Mechanics Laboratory at the Federal University of Santa Catarina State. In order to do that, deposits of soil in the city of Tubarão (SC) were selected, and using the soil of one of them, an investigative procedure was developed so that it could supply technical information on the viability of such application. Several tests have been carried, such compaction tests, CBR tests with measurement of expansion, strength tests, resilience tests and tests on hazard and percolation (with chemical analysis of the effluent) with different compositions of soil/ash and still, with and without the lime addition.

In this paper, hazard and percolation tests are the only ones dealt with. Other results are peresented in the Final Research Report (Trichês *et al.,* 2003).

These tests aimed to determine the classification of hazard of the ash as an industrial waste in accordance with the Brazilian Standards as well as to determine which chemical elements present in the composition of the material have a higher hazard level to the environment. The tests also determine the concentration of these chemical elements that are solubled during the process of percolation of rain in a composed layer of soil/ash mixture.

BIBLIOGRAPHICAL REVISION

Experiences with the Use of Bottom Ash in Pavement Structures

The use of waste materials, including bottom ash, in pavement structures is a reality in countries like The United Kingdom, Dawson *et al.* (1993) and The United States, Moulton, (1973), for many years, where standardized procedures for evaluation of the materials already exist aiming its use.

References on the joint evaluation between the mechanical performance aspects and the risks to the environment from the use of waste materials have been reported by Nunes *et al.* (1996), where recommendations are made concerning the necessity of the definition of logical protocols for the evaluation of hazard of the use of waste materials in pavement. The environmental evaluation of the application of secondary materials in pavement, was based on the methods adopted by the Canadian Wastewater Techonology

Centre, for the evaluation of inertization processes of solid wastes using cementing material. These methods are similar to the leaching tests carried in Brazil, ABNT (1987). From this test, through the comparison of the leached and solubled concentrations with standardized rules for determined chemical substances, a solid waste can be classified as inert or not inert.

Aiming to analyze the materials in situations closer to the conditions to which they will be submitted in the structure of pavement, Hill *et Al.* (2001) present the use of "Lisimeter trials test", consisting of cells with 1,0m2 of superficial area, where 0,35cm of the material to be analyzed is placed in the ideal conditions of density and humidity for its use in the structure of pavement. Such cells are submitted to weather conditions and chemical analyses are made for evaluating the contaminants present in the percolated liquid.

According to these studies, in realistic conditions of compacting and grain size distribution, the potential of contamination of many materials was lower than if they had been analyzed in conventional leaching tests.

Chemical Composition of Bottom Ash

Pozzobom (1999) and Rocha (2001) studied the chemical composition, of the main elements, (bottom ash produced at the Jorge Lacerda thermo-electric complex) as it can be observed in Table 1.

Table 1. Chemical composition of bottom ash.

Constituents	Composition (%)	
	Pozzobom (1999)	Rocha (2001)
SiO_2	55,98	58,63
Al_2O_3	26,73	27,22
Fe_2O_3	5,8	6,29
TiO_2	1,33	1,35
P_2O_5	0,24	0,10
CaO	0,84	1,16
MnO	0,02	ND
MgO	0,59	0,72
Na_2O	0,25	0,31
K_2O	2,59	2,66

The polluting potential of bottom ash depends on the concentrations of the toxic elements and the degree of solubilization of these elements in their natural environment. The ash contains heavy metals and it must be submitted to leaching tests for classification.

CLASSIFICATION OF THE ASH AS AN INDUSTRIAL WASTE

As the bottom ash origins from an industrial process of generation of electric energy, procedures for classification of the material as a solid waste were applied. The soil has natural origin and does not need such procedure.

With the classification of sample 50/50 (50% soil, 50% bottom ash, in terms of dry weigh), evaluating a possible alteration in its classification was a goal, or even, a possible reduction in the leached or solubled concentrations in this sample. In accordance to the analysis, the materials are not corrosive, are not inflammable and they do not react violently when added to water, and both the samples were classified as class II wastes, not inert and not toxic.

In sample 50/50, significant alterations in the concentrations of the mixtures and the concentrations of leached and solubled elements have not occurred in a way to modify the classification of the material. In relation to the mass composition of the material of sample 50/50, the majority of elements present in the material, the concentrations have been higher in comparison to sample 0/100, but still , they have been much lower than the concentrations that would consider them hazardous wastes.

PERCOLATION TESTS

Definition of the Percolation Solution

Aiming to analyze the hazard in more realistic conditions, an apparatus was developed in laboratory that allows the vertical percolation of a solution with physical-chemical characteristics similar to the characteristics of the rain of the region of Tubarão (SC) which is presented in Table 2. The percolated liquid was collected and the existing chemical elements were evaluated.

After the analysis of the data referent to the physical-chemical characteristics of the rain from the region of Tubarão (Table 2), it was established that the solution should have pH equal to 5 and the concentration of the elements would have to be within the limits observed in the region.

Table 2. Physical-Chemical Characteristics of the rain in the region of Tubarão

Parameters	n	average values	Standard deviation	minimum value	maximum value
F [mg/l]	25	0,23	0,52	0,01	2,56
Cl [mg/l]	25	2,75	3,47	0,24	15,20
NO_3 [mg/l]	25	0,43	0,34	0,01	1,31
SO_4 [mg/l]	25	2,40	1,67	0,10	7,68
Na [mg/l]	25	1,83	2,05	0,07	8,39
NH_4 [mg/l]	25	0,66	0,47	0,02	1,68
k [mg/l]	25	0,28	0,31	0,07	1,63
Mg [mg/l]	25	0,23	0,25	0,03	0,99
Ca [mg/l]	25	0,41	0,36	0,15	1,75
PH	25	4,58	0,63	3,00	6,20
EC [µs/cm]	25	2,52	1,87	0,60	9,60
Volume [ml]	25	2717	2676	35	10450

Source: Tractebel Energia SA

Monitored Parameters in the Percolation Tests

The definition of the parameters to be monitored in the percolation tests and the number of samplings during the period of testing were guided by the results of the tests of characterization of the materials (tests on composition, leaching and solubilization), and by budgetary restrictions due to the cost of analysis of some chemical elements, with prominence to heavy metals. The adopted parameters for monitoring the percolation test were aluminum, iron, manganese, arsenic, lead, mercury, pH and acidity.

For the chemical elements aluminum, iron and manganese, and for pH and acidity, a systematic monitoring was made in all the samples collected during the period that the percolation tests have been carried. For the analysis of the chemical elements Arsenic, Lead and Mercury, a total of 5 samples of percolated liquid have been selected, during the period of tests, collected from different cells of percolation.

Geometry of the Percolation Cells

The percolation cells consisted of PVC tubes with nominal diameter (DN) of 200mm, cut with a length of 1,0m. CAPs for DN 200 had been placed at bottom extreme each tube, and in the center of each CAP, an orifice of 5,0mm of diameter was made. All the cells were placed over wooden trestles, making it possible to place the sampling bottle to a distance of 2,0cm from the orifice made in the CAP.

Before the assemblage of the percolation cells, all the materials were cleaned with distilled water and dried in greenhouse, in order to prevent contamination that could modify the results. The percolation cells had been assembled as demonstrated in Figure 1.

Analyzed Soil/Ash Mixtures

The soil/ash mixtures that were viable for being used in pavement were analyzed based on the mechanical performance. Soil/ash/lime mixtures were also evaluated with the purpose of verifying the influence of the stabilization with lime in the solubled concentrations. In the stabilized mixtures, 4% of lime in dry weight was added, trying to keep the minor possible percentage of lime in the mixtures, aiming to turn the mixtures more economically attractive.

Neither the pure soil (100/0) nor the pure ash (0/100) presented good characteristics to be used in the layers of sub-base and reinforcement of roadbed soil of pavement. Anyway, these materials have been individually evaluated in the percolation cells aiming to compare the results between them, that is, to determine the difference between the use of the soil and the ash in pavement, in terms of risk to the environment.

Some mixtures were kept in humid chambers for a period of 28 days of curing, in order to verify the variations in the solubled results. A cell with 1% cement in the 50/50 mixture with lime was also assembled.

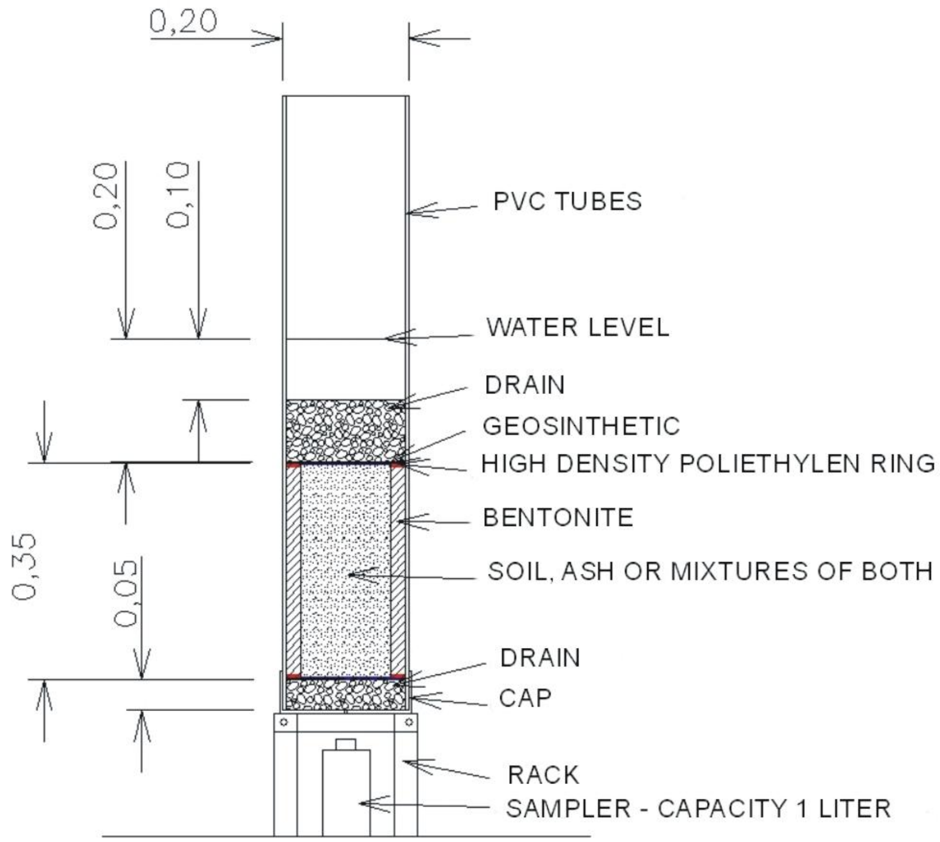


Figure 1. Percolation cells geometry (units in meters).

This way, the following mixtures showed on Table 3 were assembled in the percolation cells

Table 3. Mixtures assembled in the percolation cells

100% soil	30% ash	50% ash	100% ash
100/0 without lime	70/30 without lime	50/50 without lime	0/100 without lime
100/0 with lime,28 days of curing;	70/30 with lime, 1 day of curing;	50/50 with lime, 1 day of curing;	0/100 with lime, 1 day of curing;
	70/30 with lime28, days of curing;	50/50 with lime 28, days of curing;	0/100 with lime 28, days of curing;
	50/50; without lime	50/50 with lime +1% cement 28 days of curing.	

Control tests and Sample Collection

All the cells have been submitted to an initial hydraulical head of 20cm, on the top surface of the samples submitted to the percolation. It was left to lower the level until the moment of the collection of the sample of percolated liquid. At this moment, the height of percolated water was measured and the date and hour of the collection were recorded, and initial 20cm hydraulical head was refilled with the percolating solution.

Results of the Chemical Analyses

For the chemical elements Aluminum, Iron and Manganese and for pH and acidity, graphics with results obtained during the period of tests in the percolation cells were presented in figures 2 to 5. All the parameters have been compared to drinking water standards established by the federal legislation (NBR 10004). From these results the following comments can be made:

- The behaviour of results obtained from samples with 30% ash or 50% ash were very similar, having no relation between the increase in the solubled concentrations due to the increase of the percentage of ash in the mixture. In both situations, in all the percolation cells, the solubled concentrations, did not present a clear curve of increase or decrease during the period of test;
- For these parameters, the solubled concentrations in the cells with pure soil (100/0) and pure ash (0/100), had very similar values. And only for the Iron parameter , in the cell with pure ash without lime, the solubled concentration was higher than the established drinking water standards. In this sample the concentration was of 0,47mg Iron/l and the standard of drinking water for the Iron was 0,30mg Iron/l;
- The solubilization of the chemical element Manganese was lower than the limit of detection in all the analyzed samples. Comparing to the test on solubilization, according to the methodology proposed by NBR 10004, this chemical element was responsible for the classification of the bottom ash (0/100) and of the soil/ash mixture (50/50) as not inert materials;
- In relation to the chemical element Iron, the lime addition caused 100% of the samples to be within drinking water standards, after elimination of spurious values. In the samples without lime, from the of total of 19 samples, only 9 of them were above the drinking water standards and in 13 samples this element was detected;
- In relation to the chemical element Aluminum, in samples without lime, from the 19 analyzed samples , only 2 of them had values above the drinking water standards and in only 3 of them it was above the limits of detection of the test. With the lime addition, the taxes of solubilization of Aluminum were higher, being above the drinking water standards in 100% of the samples. The same behaviour was detected in the samples of pure ash and of pure soil;
- In relation the average acidity, values in mixtures 70/30 and 50/50 without lime were of 22 mg$CaCO_3$/l, considering that in the pure ash sample this value was below the detection limit. With the addition of lime in 100% of the samples the values were below the limit of detection of the test;
- In relation to pH, in the samples without lime the values have had a normal distribution with a level of 95% reliability, using the Kolmogorov/Smirnof test method, with an average of 7,88 and a standard shunting line of 0,63. In the samples with lime, a higher alkalinity of the percolated liquid was confirmed, considering that, the values also had a normal distribution with a level of 95% reliability, using the Kolmogorov/Smirnof test method, with an average of 10,83 and a standard shunting line of 0,44.

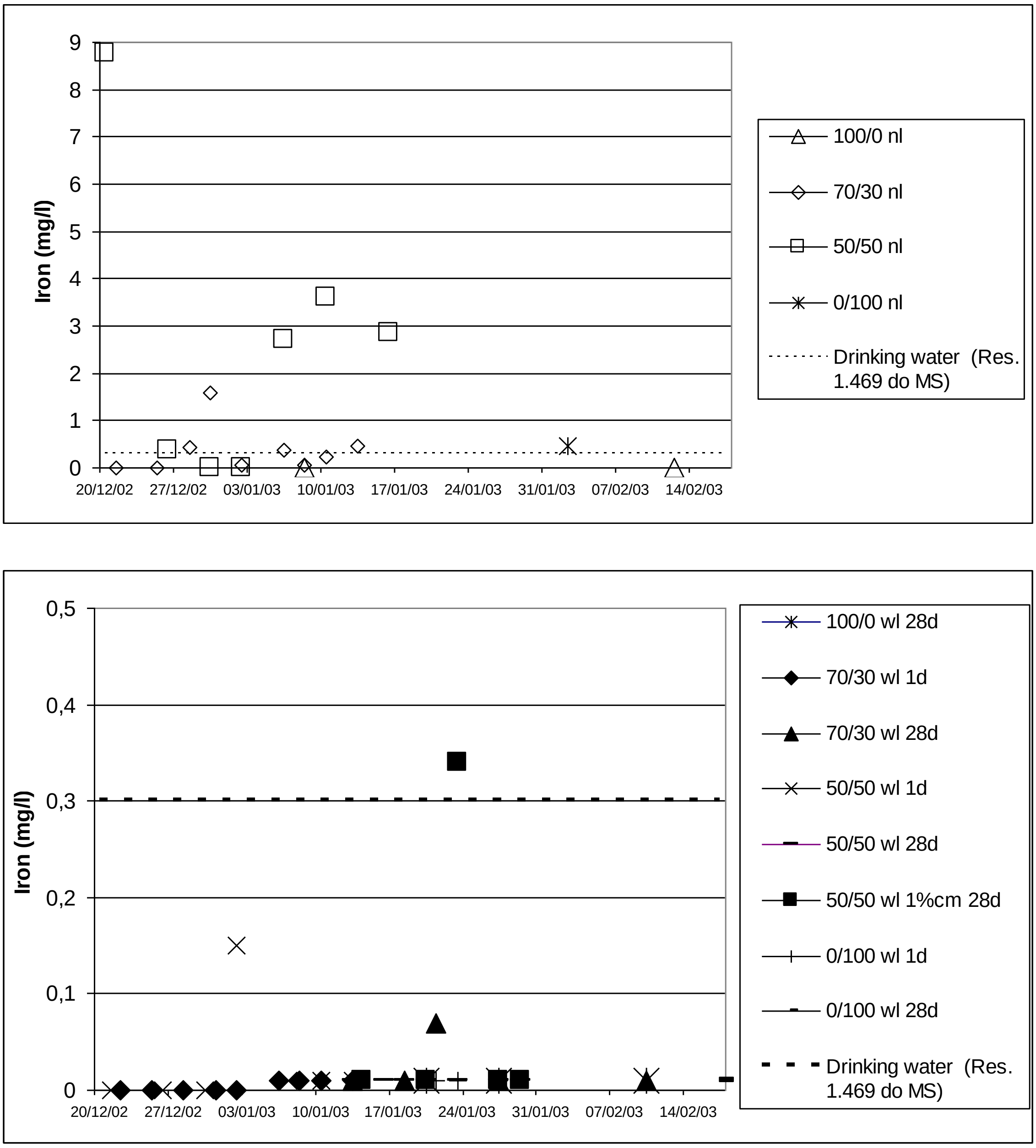
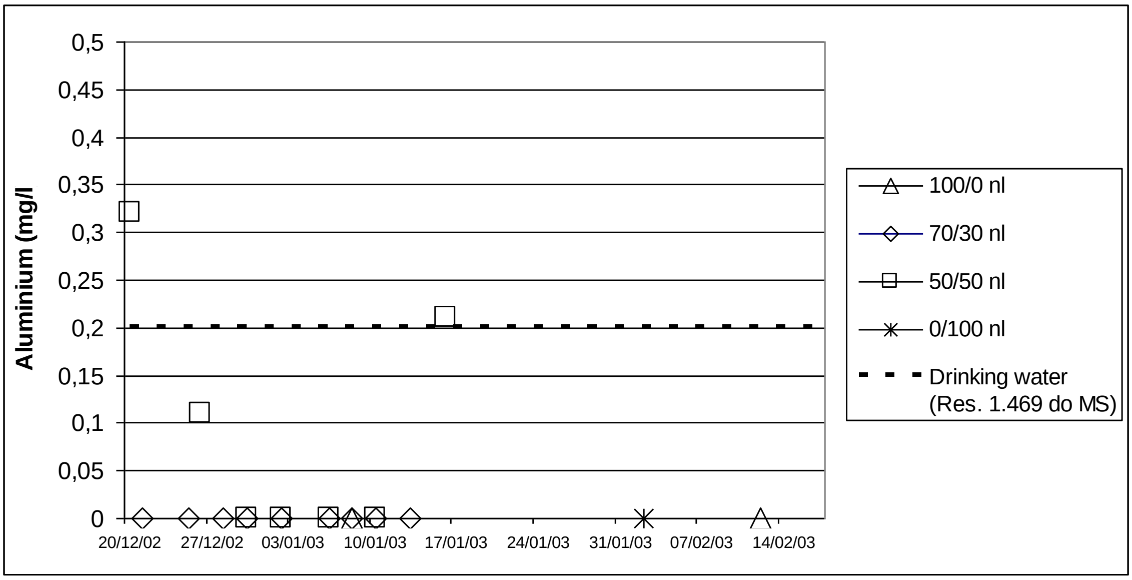


Figure 2. Solubled concentrations of Iron in the samples without lime (nl) and with lime (wl).



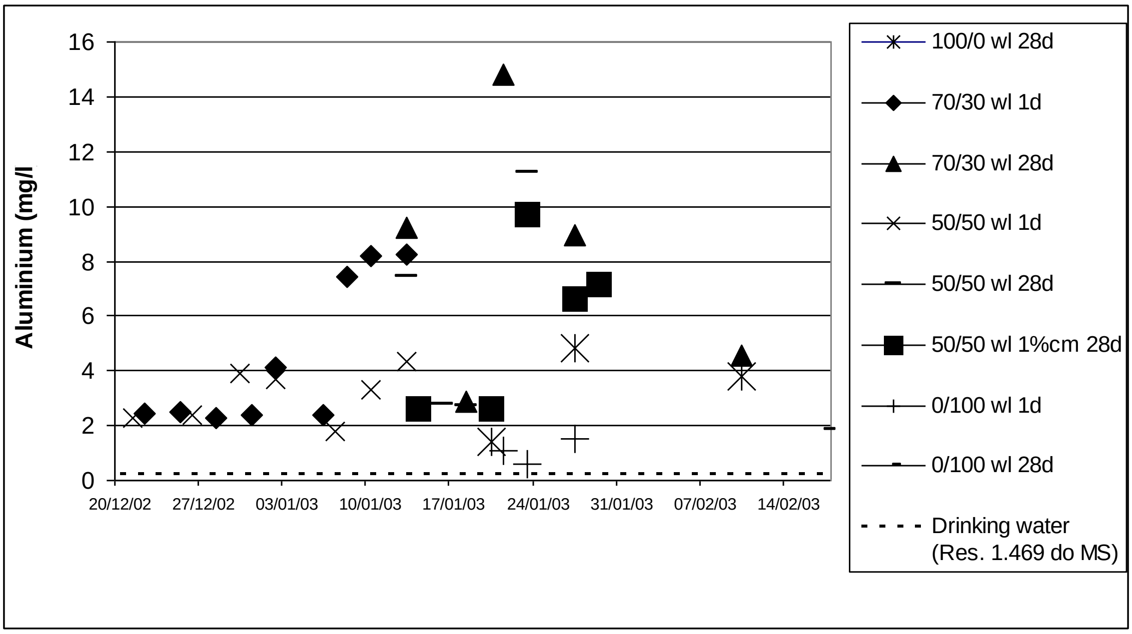
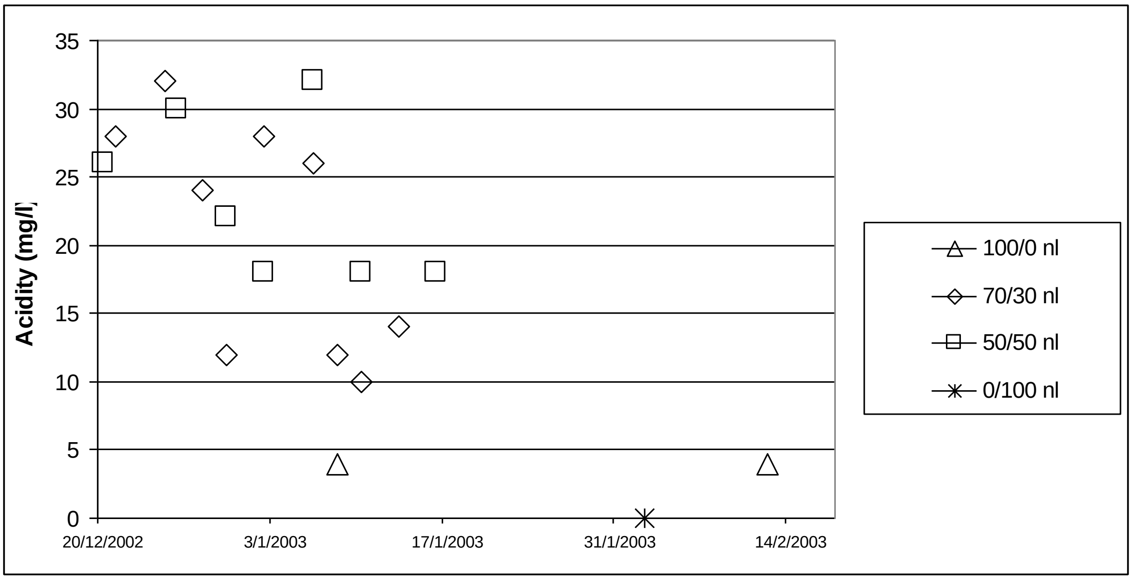


Figure 3. Solubled Aluminum concentrations in the samples without lime (nl) and with lime (wl).



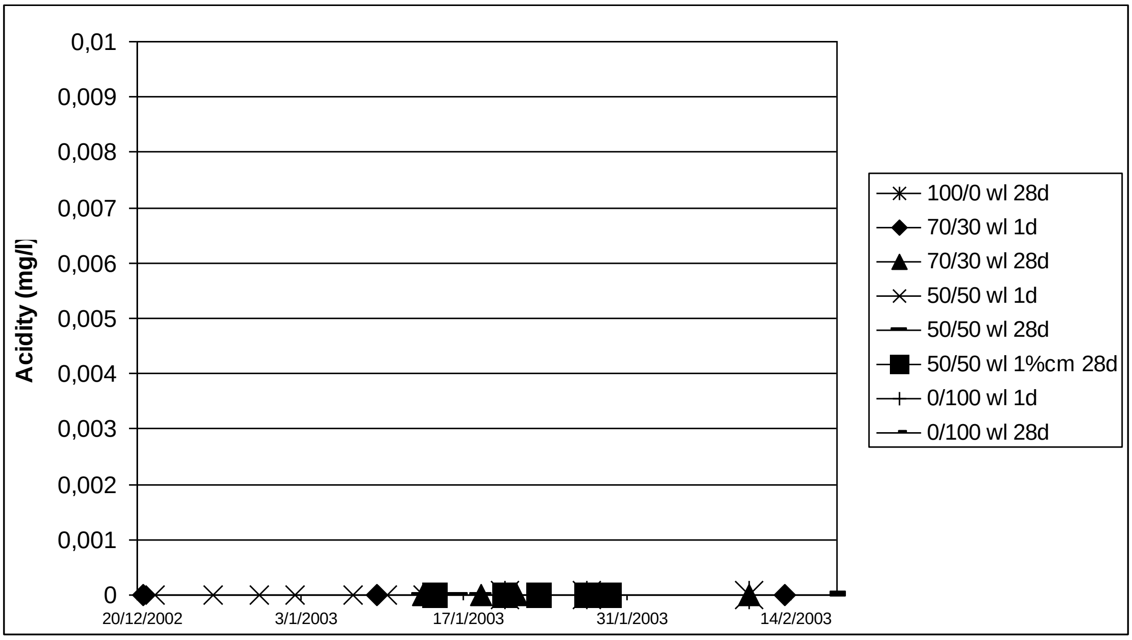
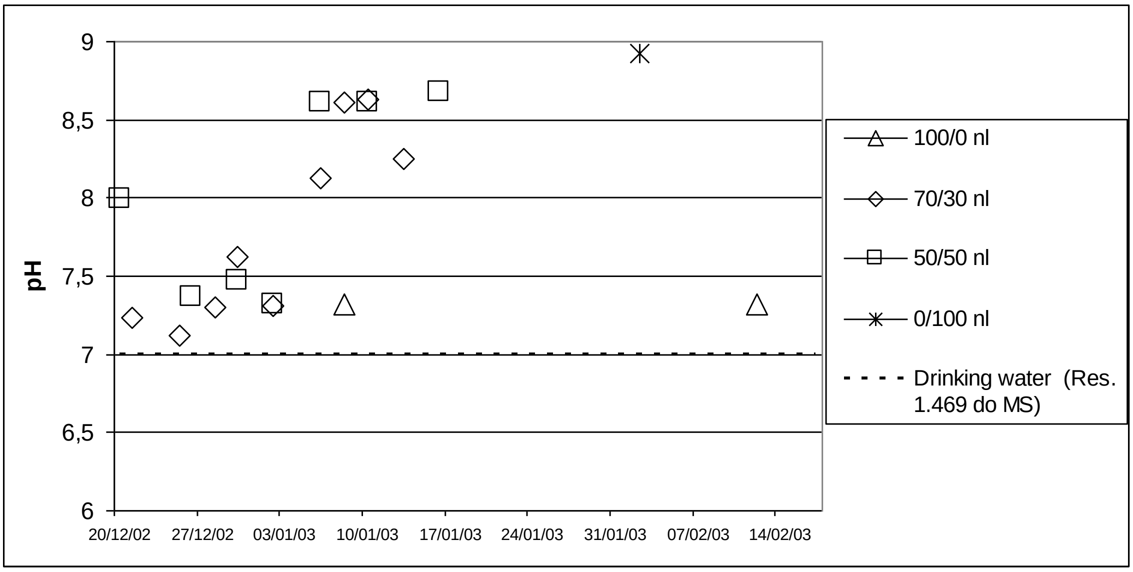


Figure 4. Acidity (CaCO3) observed in the samples without lime (nl) and with lime (wl).



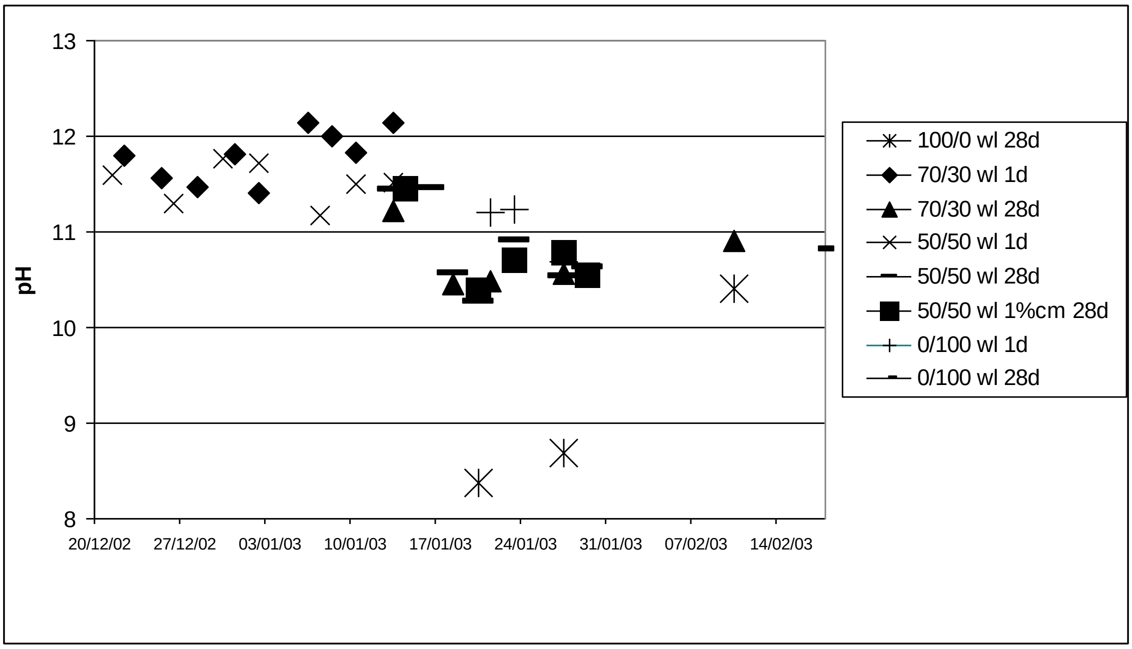
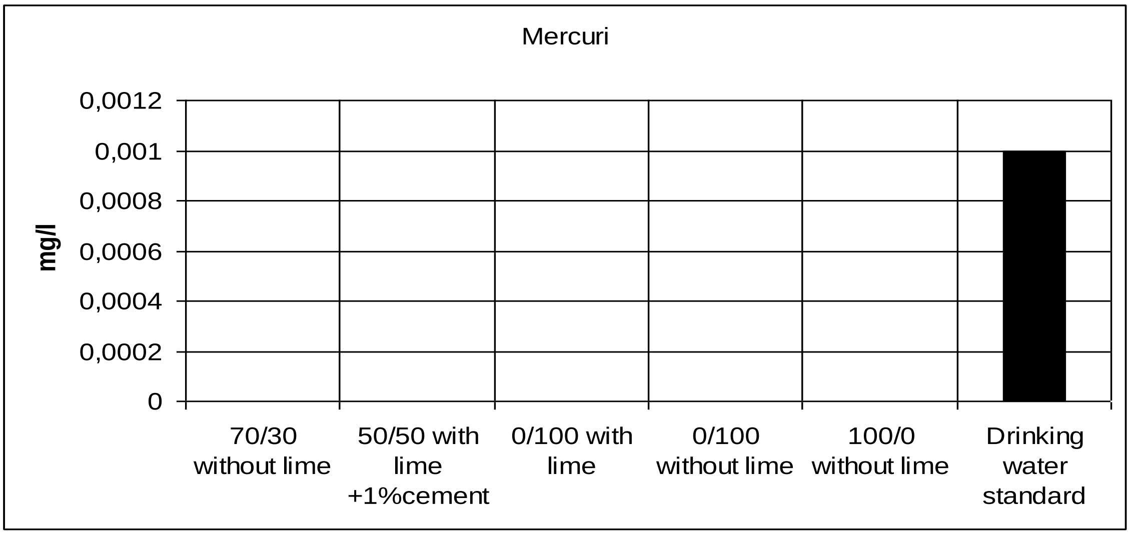
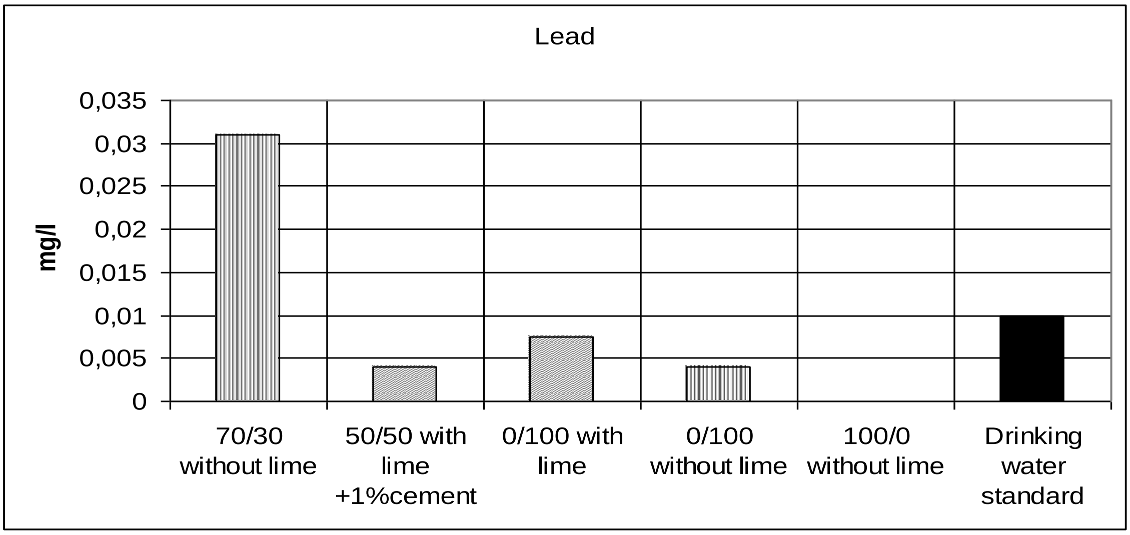


Figure 5. pH observed in the samples without lime (nw) and with lime(ww) analyzed during the period of the test.

For the chemical elements Mercury, Lead and Arsenic the 5 analyzed samples have been compared among themselves (Figure 6), trying to detect relations between the solubled concentrations and the bottom ash concentrations and the effect of the stabilization with lime.





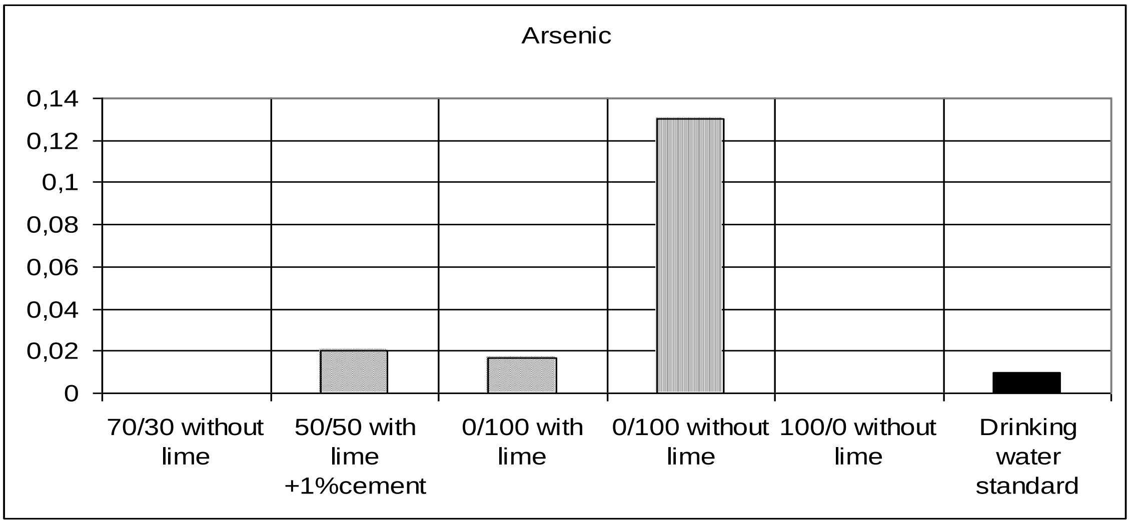


Figure 6. Comparative degree between the solubled concentrations of mercury, lead and Arsenic and the drinking water standards established by the federal legislation.

Because of the occurrence of a neutralization in the value of pH during the percolation, and because in the solution it was stabilized in 5, and in the samples without lime it have presented an average of 7,88 and a standard shunting line of 0,63, the chemical element mercury was not solubilized in any of the samples sent for analysis.

For the lead, the 70/30 sample presented a concentration of 0,031mg/l, value above the drinking water standards established by the federal legislation. According to the twentieth Resolution of the CONAMA (Baumgarten et al, 2001), the maximum lead content in the water of class 1[1] rivers should be of 0,03mg/l, practically the same value of the ones obtained in the percolation cells. For class 3[2] rivers this value can not exceed 0,05mg/L. This value was not reached in any of the analyzed samples.

In relation to the chemical element Arsenic, in the pure ash sample, the concentration of the percolated liquid was of 0,133mg/l. The drinking water standards are of 0,010mg/l, however, in the 70/30 without lime samples, such chemical element was not detected. In the samples with lime, the concentrations were below the drinking water standards.

In all the samples stabilized with lime the concentrations were within the drinking water standards.

CONCLUSIONS AND RECOMMENDATIONS

The bottom ash is an industrial solid waste that, in accordance to the NBR 10004 of classification of solid wastes in relation to hazard, is classified as not inert and not toxic.

From the analysis of the results obtained for the chemical elements iron, aluminum, manganese and pH, a standard of distribution of the solubled concentrations that could be correlated with variations in the bottom ash concentration in the mixtures was not detected. However, for the chemical element arsenic, more studies aiming to track this correlation are suggested, due to the concentration obtained in the percolation sample cell with not stabilized pure bottom ash with lime.

In relation to the not stabilized pure bottom ash, with lime and without addition of soil, more studies aiming its application are suggested, considering the solubled arsenic levels in the percolation cells.

In the samples of mixtures soil/ash without lime addition, from the analysis of the solubled elements in the percolation cells, it is noticed that only for the lead the concentrations were above the drinking water standards, but were below the values of water quality established for rivers class 3 in the CONAMA 20 Resolution.

For the samples stabilized with lime, except for the chemical element aluminum, the concentrations were within the drinking water standards when the solubled

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[1] The river waters of class 1 are destinated for public water supply with simplified treatment.

[2] The river waters of class 3 are destinated for public water suplly with conventional treatment.

concentrations from the percolating cells were analized. The same behaviour was observed in the pure soil sample stabilized with lime.

All results obtained in the chemical analyses were compared to drinking water limits and very rigid standards of classification of the quality of water resources.

The tests using percolation cells have simulated a critical draining situation , that is, the material was saturated and submitted to a constant hydraulic head. Such procedure aimed to submit the materials to the most critical situation possible, considering risks to the environment.

According to the procedures adopted by DER/SC (1998), to assure the integrity and durability of the pavement structure; the base layers, sub-base and the final layer of earthworks shouldn't be exposed to high humidity levels. The minimum required distance of water table level is 1,50 meter from the top of the final layer of earthworks. This measure improves the performance of the materials in relation to its mechanical performance and also reduces the risks of contamination of the underground water.

Because it is an industrial waste, it is necessary that a previous research is done in the site where the material is intended to be used, searching for information and mapping the superficial or underground capitation points of water, places where the underground water may come up or even biotypes that are important for the aquatic fauna. The cumulative aspects of metals are very important and should be consider.

In areas where an intense use of the water resources is detected, for human or animal consumption, a risk analyses is suggested, aiming to guide the process of decision in relation to the use of the material.

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