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EFFICIENCY ANALYSIS OF A WATER RESERVOIR ALTERNATIVE LINING

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ABSTRACT

Cost of lining reservoirs, whether for storage or water treatment, can be made it with different materials. As these structures have a relatively large surface area the investment amount can be economically unfeasible. A sustainable alternative method that can be used is the reduction of water infiltration in the soil, carried out through the use of a chemical dispersant such as Sodium Hydroxide (NaOH). Therefore, the aim of the present research was to define the lower NaOH concentration and volume to be applied in samples of a Red Latosol in the southern region of Minas Gerais state, Brazil. The samples, in triplicate, were treated with 5 NaOH concentrations (0, 5, 10, 15 and 30 g L^{-1}) and 3 volumes per square meter application (5, 15 and 25 L m^{-2}), submitting it to saturated hydraulic conductivity in constant head permeameters tests. The results showed that the application of different concentrations of NaOH reduced the saturated hydraulic conductivity in relation to the control treatment. The ratio of condutivity to NaOH concentration is best represented by the cubic regression $y = 22.46 - 6.06x + 0.45x^2 - 0.01x^3$ ($r^2 = 0.97$). Regarding the different application rates, the difference was not significant indicating equality between the treatments analyzed. Therefore, the use of the 5 g L^{-1} of NaOH, applied at 5 L m^{-2}, was economically more feasible and could therefore be a low-cost lining alternative.

Keywords: alternative lining, dystroferric Red Latosol, saturated hydraulic conductivity, sodium hydroxide, water infiltration.

ANÁLISE DE EFICIÊNCIA DE REVESTIMENTO ALTERNATIVO PARA RESERVATÓRIO DE ÁGUA

RESUMO

O custo do revestimento de reservatórios, seja para armazenamento ou tratamento de água, pode ser realizado com diferentes materiais. Como estas estruturas apresentam área superficial relativamente grandes, o montante do investimento pode inviabilizar economicamente seu projeto técnico. Uma alternativa que pode ser utilizada é da redução de infiltração de água no solo, realizada através do uso do dispersante químico Hidróxido de Sódio (NaOH). Neste contexto, a presente pesquisa teve como objetivo definir a melhor concentração e o melhor volume de NaOH a serem aplicados em amostras de um Latossolo Vermelho na região de Lavras, MG. As amostras, em triplicata, foram tratadas com 5 concentrações de NaOH (0, 5, 10, 15 e 30 g L^{-1}) e 3 volumes de aplicação por metro quadrado

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(5, 15 e 25 L m^{-2}), sendo as mesmas submetidas a testes de condutividade hidráulica saturada em permeâmetros de carga constante. Os resultados encontrados permitiram concluir que a aplicação das diferentes concentrações de NaOH reduziram a condutividade hidráulica saturada em relação a testemunha. A relação da mesma em função da concentração de NaOH é melhor representada pela regressão cúbica $y = 22,46 - 6,06x + 0,45x^2 - 0,01x^3$ ($r^2 = 0,97$). Em relação as diferentes taxas de aplicação, a diferença não foi significativa indicando igualdade entre os tratamentos analisados. Logo, a utilização do dispersante NaOH na concentração 5 g L^{-1}, aplicada em 5 L m^{-2}, mostrou-se economicamente mais viável, podendo assim ser uma alternativa de revestimento de baixo custo.

Palavras-chave: condutividade hidráulica saturada, hidróxido de sódio, infiltração da água, Latossolo Vermelho distroférrico, revestimento alternativo.

INTRODUCTION

The need to storage water in reservoirs has several purposes, such as for pumped or rainwater storage, water treatment for human or animal supply, or even for cattle or swine wastewater treatment. Such water reservoirs and sewage treatment projects needs adequate waterproofing systems to ensure the durability of structures and safety of necessary sanitation operations (MEDEIROS et al., 2011).

In Brazil, several technologies can be used to waterproof reservoirs. Material selection will depend on the liquid stored characteristics, structure design, and on structure acceptable movement. Local environmental properties, such as temperature and air moisture, should also be considered when selecting the waterproofing technology. Among several possibilities, use of concrete, CBUQ asphalt (hot worked bituminous concrete), tarpaulins and chemical dispersant are the most used.

However, the pursuit of efficiency and low-cost alternative water reservoir linings can reach economically unfeasible values. For instance, a high-density polyethylene tarpaulin lining costs approximately R$15.00 to R$20.00 per square meter, while other alternatives can have a purchase monetary value even higher. As reservoirs or channels have a relatively large surface area, the investment amount may even make the technical project unfeasible, whether for storage or water treatment purposes.

One of the water losses main reasons in reservoirs is due to soil infiltration. Water losses by infiltration in Red Latosol can reach up to 300 mm h^{-1} (ALVES et al., 2007). Considering such infiltration potential, a 3 meters deep reservoir can lose up to 10% of its volume per hour. These losses strongly justify the need to coat reservoirs.

Another lining requirement is on wastewater storage. Elevated nitrogen level on some wastewater can be extremely detrimental. As the anionic form, specifically nitrate, does not have any soil absorption conditions in tropical soils, such elevated concentration will result in groundwater contamination. Nitrate concentration, if higher than 10 mg L^{-1}, is contaminant in several parts of the world, including Brazil (CETESB, 2010).

Aiming to avoid such incidents, chemical dispersants stands out as an interesting reservoirs lining possibilities. According to LIMA (1987), Sodium Hidroxide (NaOH) or Sodium Carbonate (Na_2CO_3) application in soil can lead to clay particles expansion or even to particle degradation.

Although tropical soils does have elevated clay particle size levels, generally more than 40%, soil particles are aggregated and cemented together by iron and aluminum oxides (KÄMPF et al., 2012). In order to disperse all the clay from a soil sample, it is common to add a chemical dispersant: sodium hexametaphosphate or NaOH

(EMBRAPA, 1997). Thus, all clay particles are dispersed and this particle soil content can be more accurate determined, easily exceeding 40%.

NaOH treatment can decrease hydraulic conductivity in different magnitudes depending on the total solution concentration, clay particles sodium concentration and cementing agents content in soil (LIMA, 1987). Such cementing agents, like iron and aluminum oxides, are naturally found in soils at advanced weathering stage, such as Latosols, the most frequent soil class on Brazilian territory (ANJOS et al., 2012).

Therefore, the aim of the present research was to define the lower NaOH concentration and volume to be applied in samples of a Red Latosol in the southern region of Minas Gerais state, Brazil.

MATERIAL AND METHODS

In order to evaluate the efficiency of NaOH chemical dispersant as an alternative water reservoir lining, soil samples were collected at Federal University of Lavras (UFLA), Lavras, Minas Gerais State, Brazil (21.13° S, 44.58° E). The soil profile was classified as a dystroferric Red Latosol (LVdf), according to the Brazilian System of Soil Classification (EMBRAPA, 2013). Soils main properties were determined (EMBRAPA, 1997).

Laboratory analysis were conducted at the Soil Mechanics Laboratory of Unilavras, in which soil samples were treated, in triplicate, with different volumes (5, 15 and 25 L m^{-2}) and rate concentrations (0, 5, 10, 15 and 30 g L^{-1}) of sodium hydroxide.

Water movement in soil can be measured by saturated hydraulic conductivity, once if potential difference is present, water movement in soil can be predicted by Darcy:

$$q = -K \frac{\Delta Pt}{\Delta L}$$

where: q is the water flow (cm^3 cm^{-2} hour); K is the hydraulic conductivity (m h^{-1}); Pt is the total potential (hydraulic potential + gravitational potential); and L is the soil sample height.

Samples were then subjected to saturated hydraulic conductivity tests under constant head parameters. The constant head permeameter method basically consists in maintaining a constant hydraulic head, using a Mariotte flask, while measuring the drained flow rate. Water mass, collected in a predetermined time, was then determined in a digital scale.

Data obtained were then submitted to variance analysis, through AgroEstat software (BARBOSA & MALDONADO JÚNIOR, 2009), in which average values were compared through Scott-Knott test at a probability significance level of 5%.

RESULTS AND DISCUSSION

Mean soil chemical and physical characteristics are presented in table 1. The dystroferric Red Latosol soil was formed from a gabbro intrusion in a flat relief. Low or no quartz presence in the parent material added to long exposure time of this soil to bioclimatic agents facilitated by a smoothed slope, provides elevated pedogenesis rates. Therefore, very deep/elevated drainage soils were formed, with elevated gibbsite and sesquioxide mineralogy, featuring very old soils (KER, 1997; KÄMPF et al., 2012).

Table 1. General characterization of the soil at 0-20 cm depth.

Property	Values
pH	5.0
P (mg dm^{-3})	0.56
K (mg dm^{-3})	30.0
Ca ($cmol_c$ dm^{-3})	0.5
Mg ($cmol_c$ dm^{-3})	0.1
Al^{+3} ($cmol_c$ dm^{-3})	0.2
H+Al ($cmol_c$ dm^{-3})	4.52
t ($cmol_c$ dm^{-3})	0.88
T ($cmol_c$ dm^{-3})	5.20
BS (%)	13.02
SOM (g kg^{-1})	16.4
Sand (g kg^{-1})	260
Silt (g kg^{-1})	120
Clay (g kg^{-1})	620

t: effective cation exchange capacity; T: potential cation exchange capacity; BS: base saturation; SOM: soil organic matter.

Variance analysis of saturated hydraulic conductivity in Red Latosol samples under different concentrations and application rates of NaOH are presented in table 2.

Table 2. Variance analysis.

Source of Variation	DF	SS	MS	F	P
NaOH Concentration (A)	4	3517.23	879.31	75.77**	< 0.0001
Application Rate (B)	2	69.33	34.67	2.99^{ns}	0.0656
(A x B)	8	63.12	7.89	0.68^{ns}	0.7053
(Treatments)	14	3649.69	-	-	
Residual	30	348.13	11.60	-	
Total	44	3997.82	-	-	

Variance analysis results indicate that there was a statistical significant difference between the analyzed concentrations. However, the different application rates applied (5, 15 and 25 L m^{-2}) were statistically equal, with no effect on hydraulic conductivity values. There was also no interaction effect between the factors studied.

After the variance analysis (Table 2), a Scott-Knott averages comparison test was performed to identify any treatments difference. Average values of saturated hydraulic conductivity, in mm day^{-1}, submitted to different concentrations of NaOH can be observed in table 3.

Table 3. Average saturated hydraulic conductivity values of soil samples submitted to different concentrations of sodium hydroxide (NaOH).

NaOH Concentration (g L^{-1})	K_0 (mm day^{-1})
0	23.03 a
5	0.25 b
10	0.48 b
15	1.33 b
30	1.84 b

Means followed by same letter in column does not differ significantly by Scott-Knott test at 5% probability.

A hydraulic conductivity decrease when NaOH is applied can be stated in all concentrations analyzed (5, 10, 15 and 30 g L^{-1}). Such decrease, even on small concentrations, can be due to clay particles expansion or even by some particles degradation (LIMA, 1987).

Results presented here corroborate with some authors who have proposed that the use of NaOH does decrease soil hydraulic conductivity. LIMA (1987) in order to present alternative soil channels lining, tested sodium-based dispersants associated with soil compaction to reduce water infiltration losses in uncoated soil channels. According to the results presented, the application of 25 L m^{-2} of sodium hydroxide (30 g L^{-1}) added by soil compaction can reduce about 90% of infiltration losses bare soil channels constructed in Red Latosol soil of “Cerrado” biome.

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Recently, ALMEIDA (2016) analyzed a 30 g L^{-1} in soil concentration of sodium hydroxide to reduce losses by infiltration in uncoated reservoirs, 2 hectares size, significantly decreasing losses infiltration in 88%.

At the present research, the lowest NaOH concentration analyzed (5 g L^{-1}) decreased saturated hydraulic conductivity in about 98.90%, highlighting its enormous potential for use as an alternative reservoirs lining.

The ratio of saturated hydraulic conductivity as a function of different NaOH concentration can be described by a cubic regression equation: $y = 22.46 - 6.06x + 0.45x^2 - 0.01x^3$. Such regression presented a determination coefficient (R^2) of 96.81%. The same is presented in Figure 1.

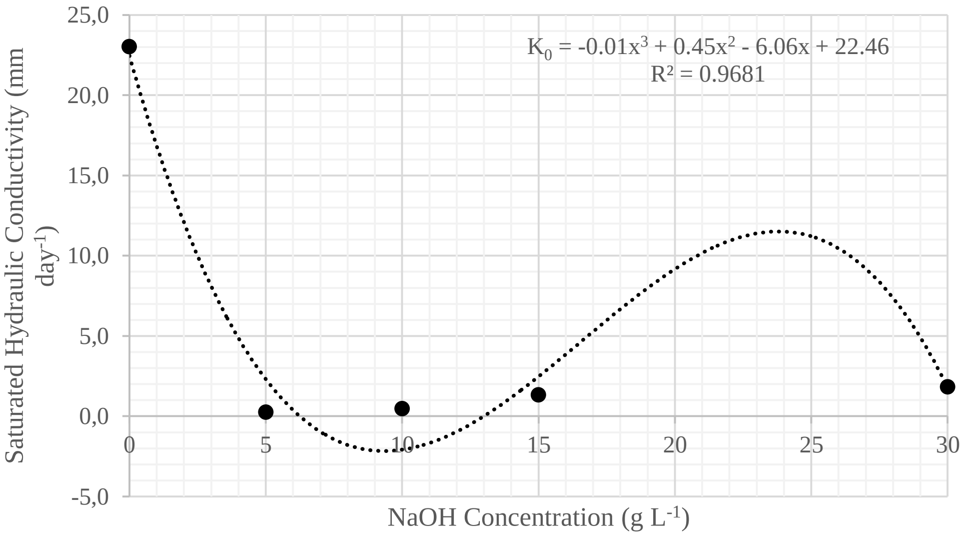

Figure 1. Saturated hydraulic conductivity as a function of different NaOH concentration in a Red Latosolo (LVdf) samples.

The authors highlight the efficiency longevity possibility of this method, once the chemical dispersant use is directly related to reservoir necessary maintenance. Among them, do not dry the reservoir once it can generate cracks or fractures in soil.

Flocculants cannot be used as well in the stored water. In general, this method, when used correctly, can last a long time since the clay, when dispersed, does not return to its normal state, only when adding a flocculant.

CONCLUSIONS

Application of different concentrations of NaOH reduced the saturated hydraulic conductivity when compared to bare soil. The ratio of saturated hydraulic conductivity with NaOH concentration is best represented by a cubic regression: $y = 22.46 - 6.06x + 0.45x^2 - 0.01x^3$ ($r^2 = 0.97$). Regarding the different application rates analyzed, the difference was not statistically significant, indicating equality between treatments analyzed.

Therefore, use of the chemical dispersant NaOH in a 5 g L^{-1} concentration, applied at a 5 L m^{-2} rate, was economically more feasible, since there is a smaller dispersant quantity use need, thus being an alternative low-cost lining for water reservoirs produced in Red Latosol areas. This concentration is lower than ones previously recommended in literature, with NaOH concentrations around 30 g L^{-1}.

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