EXPERIMENTAL STUDY ON BIOSEALING TECHNOLOGY FOR SEEPAGE PREVENTION

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ABSTRACT: BioSealing is an innovative technology developed by the Dutch research institute GeoDelft in the past a few years. It refers to a natural biological process for self-detection and sealing of seepage in water impermeable barriers. BioSealing is based on the principle that biological activity can be stimulated by injection of nutrition in the soil. Biological activity and, at a later stage chemical transpositions, cause clogging near the leak. Six experiments were done in the laboratory of GeoDelft in 2005 to investigate the possibility and effectiveness of BioSealing for seepage prevention, four with nutrition injection and two without, serving as contrast experiments. Analysis of the experimental results shows that BioSealing is an effective way to reduce the seepage discharge and to decrease the soil permeability. Further research, including more laboratory experiments and field experiments are ongoing.

KEY WORDS: BioSealing, experimental study, seepage, discharge, permeability, clogging

1 INTRODUCTION

Seepage is an unavoidable problem for most of civil engineering projects, especially when soil is concerned, e.g. earth dams, river dikes and underground works. Appropriate solution of seepage problem is an important condition to guarantee the safety and normal operation of these projects.

At present, various methods are available to deal with seepage problem, for instance, steel sheet pile, concrete cutoff and grouting. However, these methods have disadvantages such as high cost, hardly construction and adverse environmental impact. Therefore, a need exists for easier, more effective and less expensive methods.

BioSealing is an innovative technology developed by the Dutch research institute GeoDelft in the past a few years (Lambert et al., 2004; Veenbergen, 2004; Liao, 2005). It refers to a natural biological process for self-detection and sealing of seepage in water impermeable barriers. BioSealing is based on the principle that biological activity can be stimulated by injection of nutrition in the soil. Biological activity and, at a later stage chemical transpositions, cause clogging near the leak. Up to now the research conducted has proved that BioSealing is a feasible mechanism to clog leaks in dams, river and sea dikes, steel sheet piles and probably also in geomembranes. Nevertheless, BioSealing is in an embryonic phase so far. The characteristics of BioSealing are still not fully comprehended. More research, especially more experimental research is needed to gain more insight into this technology. The purpose of this study is to investigate the possibility and effectiveness of BioSealing for seepage prevention through laboratory experiments.

2 EVALUATION CRITERION OF BIOSEALING

The purpose of BioSealing is to repair the leak in the underground constructions. In practice, it is not necessary to stop the leakage entirely. The permeability at the location of the leak could be accepted as long as the seepage does not influence the function of the project or result in the failure of the project. Therefore, the meaning of the reparation here is not to clog the leak completely but to reduce the permeability at the location of the leak (Lambert et al., 2004). The degree of the permeability decrease is described by the clogging factor C:

$$C = \frac{\left(\frac{\Delta Q}{\Delta h}\right)_{t=0}}{\left(\frac{\Delta Q}{\Delta h}\right)_{t=t}} \quad (1)$$

where, ΔQ = decline in flow, m^3/s;

Δh = difference in head between two manometers, m.

At the beginning of the experiment, the clogging factor C equals 1.0. The aim of the experiments is to increase C from 1.0 to 5.0 (Lambert et al., 2004). This aim is random but realistic. For instance, the seepage discharge in 1.0 m^2 for 1 day was x m^3/d. Now because of the leakage, the seepage discharge increases to $2x$ m^3/d. Then with the increase of the clogging factor (due to the function of BioSealing), the seepage discharge in this area will decrease. When the clogging factor increases to 5.0, the seepage discharge equals $x + 1/5\, x = 1.2x$ m^3/d. It can be found from Figure 1 that this decrease of seepage discharge is acceptable compared with the previous discharge.

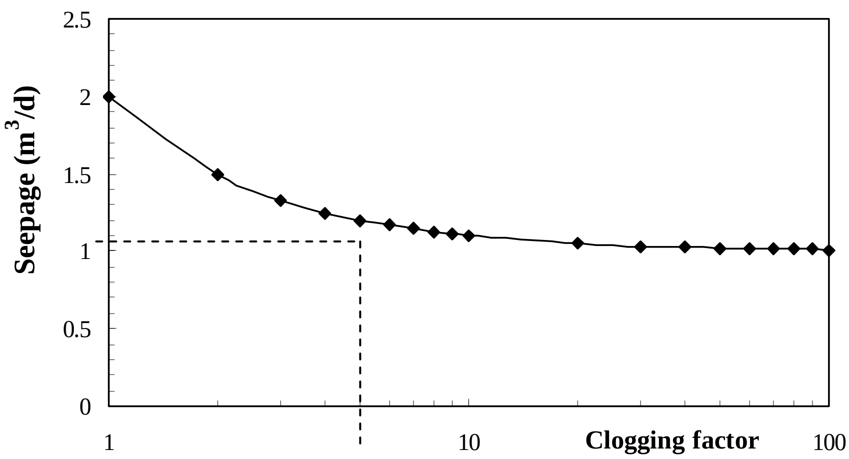


Figure 1 Seepage discharge vs. clogging factor (Lambert et al., 2004).

3 EXPERIMENTAL SET-UP AND EXECUTION

3.1 Experimental set-up

Altogether six experiments were done in the laboratory of GeoDelft in 2005, four with nutrition injection (experiments 1, 2, 3 and 4) and two without (experiments 5 and 6), serving as contrast experiments (Liao, 2005). Four different situations were modeled: seepage appears under water and water flows out without sand (experiment 1); seepage appears under water and water flows out with sand (experiment 2); seepage appears at ground surface and water flows out with sand (experiment 3); and seepage appears at ground surface and water flows out without sand (experiment 4).

Large PVC column was used in the experiment (see Figures 2 and 3). Natural Dutch Pleistocene sand with D_{10} = 0.093 mm, D_{50} = 0.234 mm and D_{90} = 1.30 mm was filled in the column. Two wooden plates with a hole in the centre and a rubber tube with 4 cm inner diameter were connected together to simulate clay layer with seepage passage, see Figures 2 and 3. This tube was also filled with sand in the experiment. The wooden plates were connected tightly with the inner wall of the column with no gap in between. Six small holes were set in the wall of the column to connect with the manometers (see p1, p2, p3, p4, p5 and p6 in Figures 2 and 3), of which the top two holes were just blocked by the two wooden plates, therefore two manometers were installed in the rubber tube first. Two tubes with symmetrical distributed small holes were inserted into the lower part of the column. One tube was to inject water into the soil, and the other was to inject nutrition into the soil. The column was connected with a water tank. The water level in the tank was kept at a constant level during performing the experiment. Figure 2 and Figure 3 show the set-up of experiment 1 and experiment 3, respectively. The set-up of experiment 2 and experiment 4 are similar.

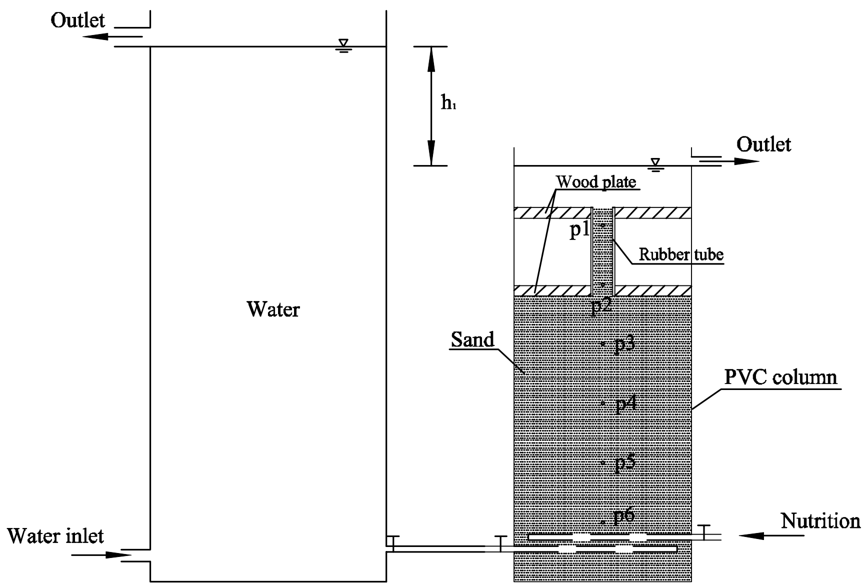


Figure 2. Sketch of the set-up of experiment 1.

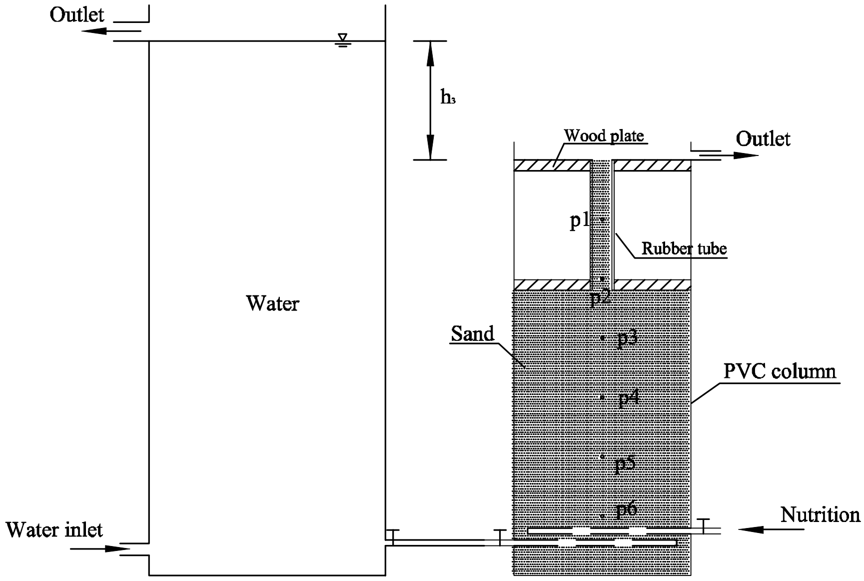


Figure 3. Sketch of the set-up of experiment 3.

3.2 Experimental execution

After all the preliminary works had been finished (for details reader is referred to Liao, 2005), the water taps connected to the six columns were opened and water began to flow into the columns. This state lasted for one week to form a steady flow state in the columns. During this week, air in the columns was exhausted and the discharge of the seepage was measured every day for each of the six columns.

When a steady flow state was formed in the column, the nutrition can be injected. The injected nutrition was a mixture of Nutrolase and water with a proportion of 1:5. The volume of injected nutrition depends on how much seepage water has flowed out from the column. According to the experiences from previous experiments, the proper proportion between the volume of injected nutrition and the volume of seepage water is 1:40. Every morning after the volume of the seepage water was measured, the volume of nutrition can be calculated for each column. The mixture of Nutrolase and water was then prepared and filled into a 5 liter container which was connected with the nutrition injection tube (see Figure 4). The nutrition flowed into the column under the effect of gravity.

For each of the four experiments (i.e. experiments 1, 2, 3 and 4), totally 9 times of nutrition injection were implemented (see Figure 5). In the beginning of the experiments, the frequency for the injection was roughly once per day and this lasted for 4 days. Then, with the decrease of the seepage discharge, the injection frequency was reduced to once per week. However, the clogging factor did not increase to 5 and the seepage discharge increased again. Therefore, later the injection frequency was changed to twice per week. From then on, the seepage discharge decreased continuously for the four columns with nutrition injection.

Figure 4 Set-up of nutrition injection.

4 RESULTS AND ANALYSIS

The period of observation of the experimental development lasted for 48 days. During this period, the volume of the seepage discharge and the piezometric heads were measured. Accordingly the clogging factors for different positions in the column (i.e. positions of p1, p2, p3, p4, p5 and p6) were calculated through Equation (1). Besides, the chemical properties (i.e. electric conductivity EC, pH and redox potential EH) of the seepage water collected from the column water outlet were measured.

The chemical properties have changed during the testing of experiments 1, 2, 3 and 4 (i.e. experiments with nutrition injection). On the contrary, for experiments 5 and 6 that have no nutrition injected, the chemical properties were in a more or less stable situation. The variations of the chemical properties of experiments 1, 2, 3 and 4 proved that biological activity and chemical transpositions did occur in these columns.

Since the mass of sand filled in and the filling quality for each column was different, it was difficult to compare the seepage discharge from the magnitude point of view among different columns. However, when comparing the variation trend of the seepage discharge, it can be discovered easily that the variations of the seepage discharge present a steady degressive trend for those columns with nutrition injection (see Figure 5). To the contrary, the seepage discharge of experiments 5 and 6 remained almost stable. It can then be concluded that BioSealing was an effective method to decrease the permeability of the soil (Liao, 2005). As a result, the seepage discharge can also be reduced effectively. Figure 5 shows the variation of the seepage discharge of experiment 3.

The clogging factor increased during the experiment for those have nutrition injection (i.e. experiments 1, 2, 3 and 4), whereas the clogging factor keeps almost stable for the two experiments without nutrition injection (i.e. experiments 5 and 6), see Figures 6 and 7. This demonstrates again that BioSealing is effective to increase the impermeability of the soil. It can also be discovered from the experimental results (see e.g. Figures 6 and 7) that the clogging factors between manometers 3 and 2 (i.e. p3-p2, see Figures 2 and 3) are much larger than that of the whole column (i.e. p6-p1). This indicates that the main clogging occurred near the rubber tube in the column. The permeability between manometers 3 and 2 was much lower than those of other positions in the column. This was probably because that the nutrition injected into the column assembled near the rubber tube due to the encumbrance of the wooden plate. Therefore, the concentration of the nutrition near the rubber tube was higher than that of other positions in the column. Thus, microorganisms also assembled close to the rubber tube because of the high concentration of nutrition and the concentration of the streamlines. Accordingly, the clogging degree near the rubber tube was higher than the one at other positions in the column. Figures 6 and 7 show the comparison of experiments 3 and 5 in clogging factors.

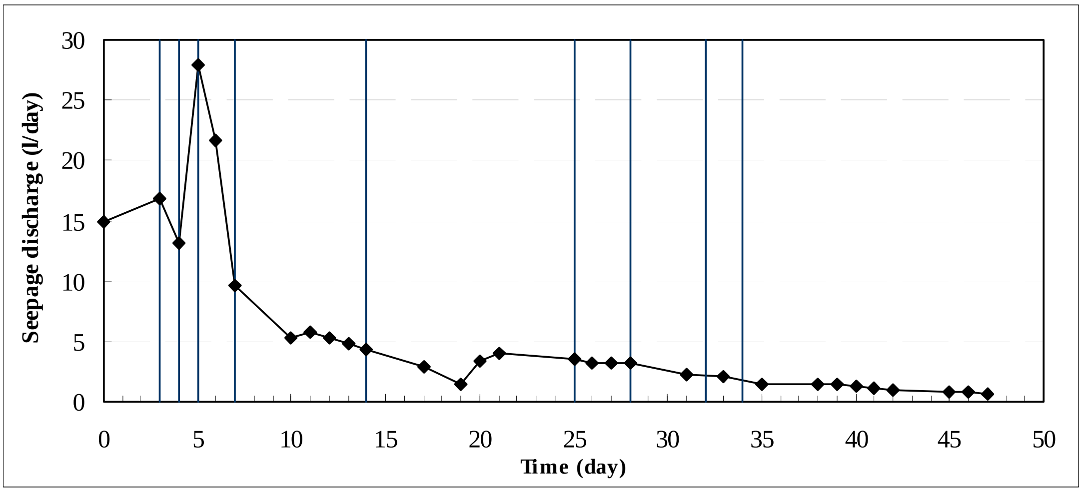
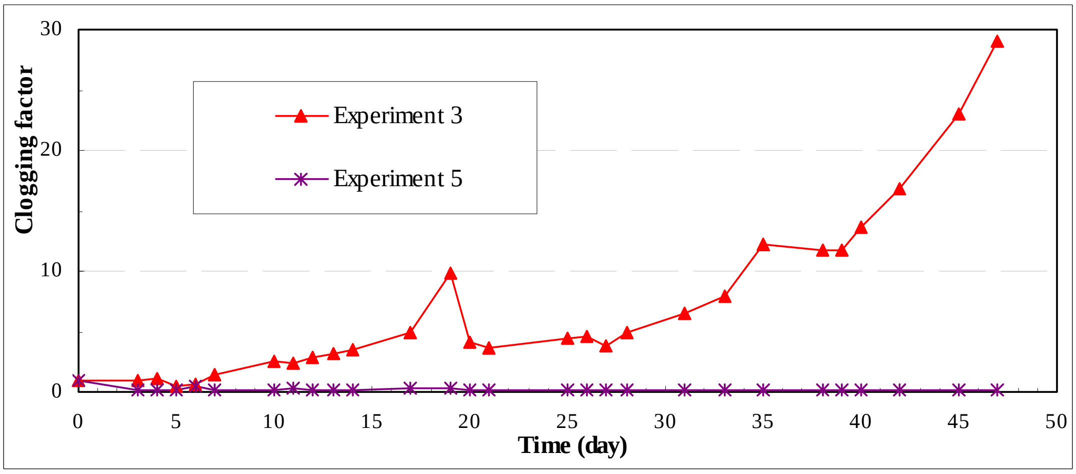
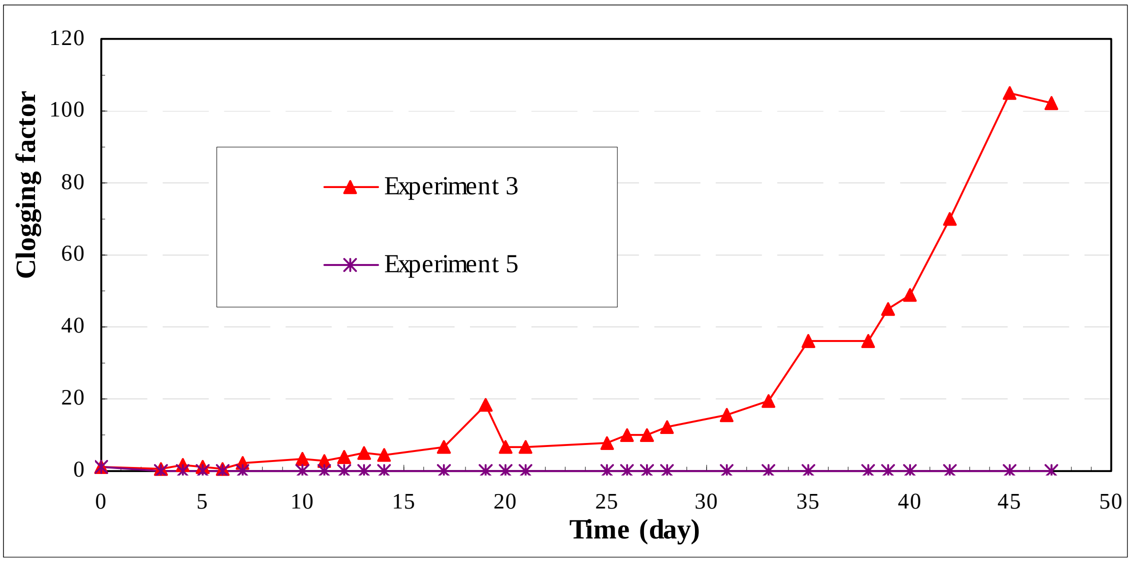


Figure 5 Seepage discharge of Column 3 (vertical lines represent the days of nutrition injection).



(a) Clogging factors p6-p1

Figure 6 Comparison of experiments 3 and 5 in clogging factor (p6-p1).



(b) Clogging factors p3-p2

Figure 7 Comparison of experiments 3 and 5 in clogging factor (p3-p2).

5 CONCLUSIONS AND RECOMMENDATIONS

According to the experimental results, BioSealing is proved to be an effective way to reduce the seepage discharge and to decrease the soil permeability for the four different situations studied: seepage appears under water and water flows out without sand; seepage appears under water and water flows out with sand; seepage appears at ground surface and water flows out with sand and seepage appears at ground surface and water flows out without sand. In the four experiments with nutrition injection (i.e. experiments 1, 2, 3 and 4), the clogging always occurred near the rubber tube in the column. The clogging factors C of the whole column increased from 1 to above 5 by adding nutrition for all the four experiments. The goal of these experiments was therefore successfully achieved.

BioSealing is an innovative technology with still no full comprehension. So far the relationship among the duration of the clogging, the degree of clogging and the volume of nutrition injection is unknown. More experimental study is required to gain a comprehensive understanding of the clogging durability. In addition, apart from the approved function of decreasing the soil permeability, BioSealing is also under consideration of its possible effect on soil strength improvement. It is therefore recommended to test the soil cohesion intercept c and the angle of friction ϕ by taking soil samples from the columns where the clogging occurs. For future field experiments on BioSealing, it is recommended to control the clogging degree to a certain suitable range, because the upward water pressure still exists and when the seepage passage is clogged completely at one position, seepage failure may occur at other places. The way to control the clogging degree and to reduce the risk of new crack occurrence in the field needs more study.

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