BIS HEALTH AND ENVIRONMENTAL SCIENCE
Volume 1 2024 | DOI: 10.31603/bishes.15
5th Borobudur International Symposium on Science and Technology (BIS-STE) 2023
UNIMMA PRESS
UNIVERSITAS MUHAMMADIYAH MAGELANG

The influence of cementation solution on the permeability of waste sludge stabilized with bacteria as a temporary landfill cover

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Abstract

Piles of rubbish can produce liquid waste called leachate. Leachate from landfills can have negative impacts on the environment and humans. To minimize the impact of leachate on the surrounding environment, the waste is covered with a material that can isolate it from the surrounding environment. Previous research has reported that waste sludge as a by-product of water system processing can be used as a temporary landfill cover after being compacted and reinforced using the MICP method to reduce water flow. Therefore, this research was carried out with the aim of determining the effect of the molarity of the cementation solution on the deposition process of calcite which is concentrated in the soil pores, thereby reducing the permeability coefficient value of the Temporary Landfill Cover. In this study, sludge waste was processed by adding 6% Bacillus Subtilis bacterial culture for 6 days with variations in the molarity of the cementation solution (CS), namely 0.25 M, 0.5 M and 0.75 M. The results showed that the cementation solution was 0.25 M gave the best results in the deposition of calcite that marked with a smaller permeability value compared to the 0.5 M and 0.75 M solutions after curing period for 28 days.

Keyword

Leachate, Landfill cover, Sludge waste

Published:
October 20, 2024

Selection and Peer-review under the responsibility of the 5th BIS-STE 2023 Committee

Introduction

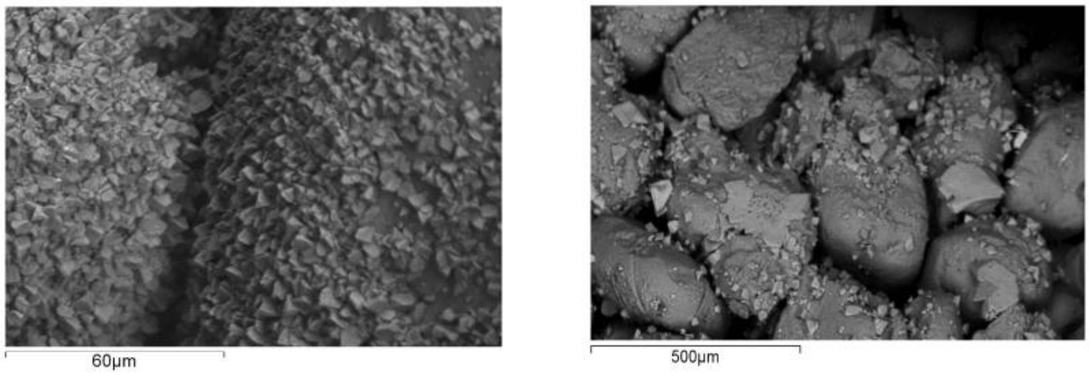
Piles of rubbish can produce liquid waste called leachate. Leachate from landfills can have negative impacts on the environment and humans. At the Manggar landfill in Balikpapan, the volume of waste in 2023 will increase significantly, even reaching 30 to 50 tons per day. Previously it was only around 380 to 420 tons, but now it reaches 400 to 450 tons. Piles of rubbish can produce liquid waste called leachate. Leachate is a liquid that originates from the infiltration of external rainwater and the results of the decomposition of solid waste [1] [2]. Leachate from landfills can affect human health, pollute the environment and aquatic biota because the leachate contains various organic and inorganic chemical compounds as well as a number of pathogenic bacteria.

Apart from that, it also contains ammonia, lead and parasitic microbes such as water fleas which can cause itching on the skin [3][4].

Trash from landfills is covered with materials that can keep it isolated from the environment to reduce the impact on the surrounding ecosystem [5]. In addition to the waterproof layer, foundation layer, protective layer, soil erosion control layer, and others, the cover system has to be precisely planned [5][6]. Temporary landfill cover can be used to minimize liquid infiltration into waste to minimize the generation of leachate [7]. Currently, experts have provided several suggestions regarding the permeability of temporary cover soil, for example ranging between 10-4 cm/s and 10-5 cm/s [5][8]. The Sanitary Landfill system or method is a system for managing or destroying waste by throwing and piling up waste in a sunken location, compacting it, and then filling it with soil. This closure will be able to reduce odors and lots of flies at the landfill site. This will also speed up the decay process.

Sludge waste is a by-product produced from water treatment plants originating from surface water. This mud is formed due to the accumulation of colloidal particle deposits which are forced to settle more quickly using chemicals [9], [10]. Many studies have been carried out regarding the effect of using sludge as a material for making temporary landfill covers and to determine the quality of temporary landfill covers which are reinforced using the MICP (Microbially Induction Calcite Precipitation) method and have shown positive results [11][5]. MICP is a soil stabilization improvement technique using microorganisms that can change and improve the physical and mechanical properties of soil [12][13][14]. The MICP microbial induced calcite precipitation method is a sustainable and environmentally friendly technique for soil stabilization [15][16].

The results of previous research using waste sludge treated with the MICP method with variations in bacterial concentration (BC) were able to reduce permeability [17]. With the addition of 6% bacteria the permeability value is 1.98x10-4 cm/s, with the addition of 8% it is 1.62x10-4 cm/s and with the addition of 10% the permeability value becomes smaller to 1.29x10-4 cm/s, meaning the concentration of bacteria added will affect the volume of calcite deposited [18]. To precipitate calcite by bacteria, it is also influenced by a good growth environment, the mixing method and also the cementation solution (CS) added to the MICP process. An environment with a neutral pH and rich in nutrients will increase bacterial growth [19]. Injecting bacteria into the soil layer will cause calcite deposition to only occur in areas close to the injection site. According to Al Qabani. 2012 the molarity of the cementation solution will affect the type of calcite crystals that settle in the soil pores [20]. The high molarity of the cementation solution injected into the soil will prevent it from entering small pores so that calcite deposition only occurs on the surface, show in Figure 1.



(a) 0.25 M (b) 1 M

Figure 1. Scanning electron microscopy images of samples going through different chemical treatments: (a) 0.25 M (b) 1 M

Based on previous research conducted by Authors [21] shows that by adding cementation solution with a concentration of 2% and bacillus subtilis bacteria in the exponential phase of culture age of 3 days with a concentration of 6% shows that this mixture can reduce the permeability value. Therefore, the author wants to conduct research with a different bacterial culture age, namely 6 days, where the bacteria are in the death phase [21]. The aim of this research is to determine the effect of cementation solution (CS) on calcite deposition patterns. It is important to carry out a series of tests on waste sludge mixed with bacterial solutions and cementation solution with different molarities characterized by changes in permeability values. It is hypothesized that the calcite deposition pattern is different observed on a micro scale will have an impact on overall mechanical and hydraulic properties of cement sample

Methods

Materials

The initial step in the research design involves preparing the necessary materials, which comprise sludge from IPAM Perumda Tirta Manuntung Km. 8 in Balikpapan City and Bacillus Subtilis bacteria for the mixer. In this study, additive stabilization was accomplished by blending 2% of 0.25M, 0.5M, and 0.75M cementation solutions with 6% of the IPAM Perumda Tirta Manuntung Km.8 Balikpapan sludge and Bacillus Subtilis bacteria with a culture age of 6 days. Various instruments, including sieve analysis tests, water content determination, specific gravity measurements using picnometer experiments, Atterberg limits testing, and standard Proctor tests, are utilized to facilitate the completion of this research on temporary landfill cover. The laboratory at Balikpapan University supplied the equipment for this research.

Bacterial culture

According to Indriani [22] the formula utilized for cultivating Bacillus Subtilis bacteria comprises 20 grams of Urea, 3 grams of Nutrient Broth (NB), 2.12 grams of $NaHCO_3$, 4.14 grams of $CaCl_2$ $2H_2O$, and 10 grams of NH_4Cl. These components are combined in an Erlenmeyer flask and dissolved in 1000 ml of distilled water (aquades). Subsequently, the solution is sterilized in an autoclave at 121°C. After sterilization, it is mixed with Bacillus Subtilis bacteria and B4 media. Initially, 500 ml of distilled water is prepared and combined with 3 grams of Nutrient Broth in a separate Erlenmeyer flask without stirring. Both Erlenmeyer flasks are then autoclaved at 121°C and 1 atm pressure for 15 minutes. Once cooled, the bacterial inoculation process is conducted by introducing the bacterial isolate into the prepared B4 medium under laminar airflow conditions to ensure stability, control, and sterility. A 2% bacterial suspension of the total B4 medium is then transferred to an Erlenmeyer tube and mixed thoroughly using a vibrator. The bacteria are cultured for 6 days before application to stabilize the soil.

Cementation solution

After Based on Rajiv T [23], the process of making a cementation solution requires a mixture of urea with $CaCl_2$ $2H_2O$ with the composition shown in Table 1.

Table 1. Cementation solution mix to be used in 1000 ml of water

Molarity	Urea (g)	Cacl2 2H2O (g)
0.25	7.5	13.875
0.5	15	27.75
0.75	22.5	41.625

The process for making a cementation solution is to mix water with Urea and CaCl2 2H2O according to the concentration in Table 1, stir until the ingredients are completely dissolved with concentrations of 0.25M, 0.5M and 0.75M. Then pour the solution into an Erlenmeyer tube and close tightly. After that, leave the cementation solution at room temperature for 6 days.

Soil testing

The three steps involved in implementing test results and soil analysis in the laboratory are: testing for chemical characteristics using an XRF (X-Ray Fluorescence Spectrometer), testing for physical characteristics, and testing for mechanical properties of the soil [24]. Based on Tao Sun, currently 2023, experts have provided several suggestions regarding the permeability of temporary cover soil, for example ranging between 10-4 cm/s and 10-5 cm/s [5]. Research design for permeability test specimens with the addition of cementation solution with variations of 0.25M, 0.5M, and 0.75M as much as 2% as shown in Table 2.

Table 2. Design of permeability test objects

Testing	Culture Age and Bacterial Percentage	Cementation Molarity 2%	Number Of Samples Curing Period 7	14	21	28
PERMEABILITY	6 Days 6%	0.25M	3	3	3	3
		0.5M	3	3	3	3
		0.75M	3	3	3	3

Results and Discussion

The results of testing the soil's chemical, physical, and mechanical properties in a laboratory setting to determine any changes that occurred in the samples stabilized by adjusting the amount of cementation solution and Bacillus Subtilis bacteria added, using material from the sludge of IPAM Perumda Tirta Manuntung km 8 Balikpapan, are presented in the following chapter.

Chemical characteristics testing

Based on the results of XRF (X Ray Fluorescence Spectometer) testing on sludge samples which were carried out in a chemical laboratory with Horiba Scientific [25], the test results show the Ca content is 4.0651%. This Ca element is expected to react with Bacillus Subtilis bacteria to form calcium (CaCO3) [26][27]. Calcium carbonate production via bacterial hydrolysis of urea is the most easily controlled MICP mechanism and has the potential to produce large amounts of calcium carbonate in a short time.

Physical Characteristics Testing

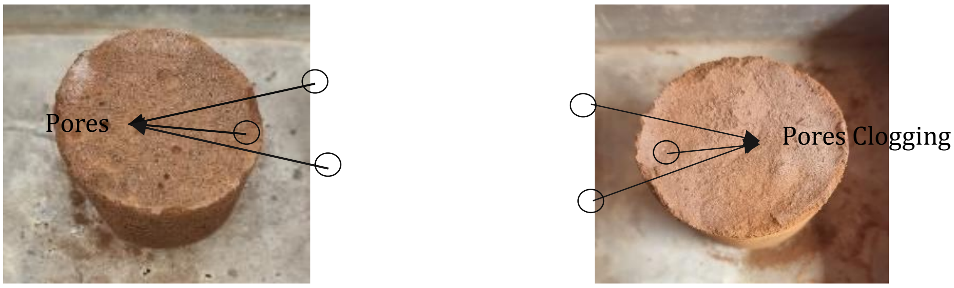
To determine the physical characteristics, the sludge was tested for water content, sieve analysis, specific gravity, plastic limit, liquid limit and plasticity index. From the hydrometer test results, it is known that 39.8% of the sample is silt and 25% of the sample is clay. The specific gravity test results show a value of 2.62 g/cm^3. The water content test shows a value of 42.54%. the liquid limit test results show a value of 45.65%. the plastic limit test results show a value of 32.32%. the plasticity index test results show a value of 13.33% and sieve analyses 63%.

Mechanical Characteristics Testing

Standard proctor tests and permeability tests were used to evaluate the sludge's mechanical characteristics. The test results for the standard proctor yielded an optimum water content (OMC) of 33.65% and a maximum dry volume weight (MDD) of 1.099 g/cc. In order to get coefficient values, permeability is tested. In this permeability test, the high energy fall method (Falling Head) is employed due to the presence of fine-grained soil in the sample [28]. The results obtained is 5.04×10^{-4} cm/s.

Results and Analysis of Material Samples After Stabilization

After obtaining the value of the maximum dry volume of soil (maximum dry density) and determining the value of optimum water content (optimum moisture content), after obtaining the test results of the proctor test, we will continue making samples for permeability testing with variations in the addition of cementation solution and Bacillus Subtilis bacteria. Research shows that samples that are not stabilized have large surface pores and after stabilization using the MICP method the surface of the sample pores looks smaller, this occurs because of the deposition of calcite in the surface pores of the sample. The difference between samples before and after stabilization for curing 28 days can be seen in the Figure 2.



(a) Before Stabilization (b) After Stabilization Using the MICP Method

Figure 2. Soil Sample: a) Before Stabilization; b) After Stabilization Using the MICP Method

After testing the permeability by adding cementation solution and Bacillus Subtilis bacteria at a culture age of 6 days, it can be seen in Table 3. After testing the permeability with the addition of cementation solution and Bacillus Subtilis bacteria, it can be seen in Figure 3.

Table 3. Results of permeability test values

Test	Concentration	Curing Time (Days)			
		7	14	21	28
Permeability (cm/s)	0,25M	$3{,}70\times10^{-4}$	$3{,}18\times10^{-4}$	$1{,}75\times10^{-4}$	$0{,}91\times10^{-5}$
	0,5 M	$4{,}12\times10^{-4}$	$3{,}44\times10^{-4}$	$2{,}04\times10^{-4}$	$1{,}58\times10^{-4}$
	0,75 M	$4{,}20\times10^{-4}$	$3{,}79\times10^{-4}$	$2{,}69\times10^{-4}$	$2{,}04\times10^{-4}$

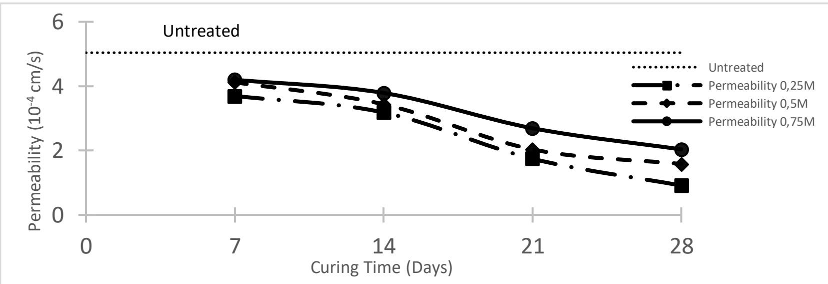


Figure 3. Comparison graph of permeability test results on mixed cementation solutions

Figure 3 shows that there are differences in permeability reduction with differences in each cementation solution mixture. The result shows that the samples optimized with cementation solution and bacillus subtilis bacteria have lower permeability compared to untreated samples. The sample with the lowest graph is found in the sample with a cementation solution mixture of 0.25M. This means that the samples that have been tested are in line with research conducted by Mujah and show that effective CaCO3 crystals can be produced through a combination of low concentration cementation solutions (0.25 M) [29]. The presence of biomass accumulation near the plug resulted in a decrease in pore volume, leading to sample clogging in certain areas, while some flow channels remained unclogged within the samples [20]. When employing a low-concentration solution for the MICP treatment, precipitation occurred primarily at pore throats where bacteria and nutrients were abundant, as noted by DeJong et al. This observation is further supported by the widespread distribution of precipitation throughout most of the samples, with no abrupt clogging reported [19]. The sample with the highest permeability was identified as the 0.75M variation with a 7-day curing period, exhibiting a permeability of 4.20×10-4 cm/s, while the lowest permeability was recorded at 9.1×10-5 cm/s for the 0.25M cementation solution with a 28-day curing period. Across all variations of cementation solution, permeability decreased with an increase in the sample's curing period. Specifically, the 0.25M variation reduced soil permeability by up to 65.36%, the 0.5M variation by up to 68.6%, and the 0.75M variation by up to 59.59%.

Conclusion

The study's findings show that the sample's permeability satisfies the requirements for a temporary cover landfill, where the acceptable range for permeability is 10-4 to 10-5 cm/s. The permeability value of the sample may decrease with the addition of bacteria and cementation solution. The test findings indicate that a low concentration cementation solution—specifically, a 0.25 M concentration cementation solution—can be combined to generate the most effective $CaCO_3$ crystals. This demonstrates how the partial filling action of the crystals reduces the pore space, which lowers porosity and permeability. Based on the test results, it can be inferred that adding the cementation solution can lower the sludge's permeability value. Additionally, a longer curing period and a lower cementation solution concentration will also help to reduce the permeability coefficient value, which indicates that the soil's pores are getting smaller. The test findings demonstrate that utilizing the MICP method to increase soil stability through the addition of cementation solution can lower permeability values and, thus, lower the likelihood of environmental harm from leachate water.

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