Desiccation cracks behaviour of leachate in bentonite - zeolite composite liner

I W Wardhana 1, M A Budihardjo 1,2, T Istirokhatun 1, N Ikhlas 3

1 Department of Environmental Engineering, Diponegoro University, Semarang, Indonesia 50275
2 Environmental Sustainability Research Group, Department of Environmental Engineering, Diponegoro University, Semarang, Indonesia 50275
3 Department of Environmental Engineering, Institut Teknologi Pembangunan Surabaya, Surabaya, Indonesia 60186

irawanwisnuwardhana@lecturer.undip.ac.id

Abstract. This study tested desiccation crack potential and migration of metals through pure bentonite and bentonite-zeolite composites to determine the best composition of the composite liner. Pure bentonite (B) and bentonite-zeolite composites of 2% (B2), 5% (B5), and 8% (B8) were used as controlled variables. The results showed that the addition of zeolite could not minimize the desiccation behavior in the liner. The value of crack intensity factor (CIF) of each sample B, B2, B5, and B8 was 3.44%, 3.51%, 3.58%, and 3.64%, respectively, indicating a moisture content of 29.95%, 34.54%, 30.88%, and 28.21%, respectively.

1. Introduction
The percolation of rainwater and a small amount of anaerobic waste in landfills causes the formation of leachate, which has a high concentration of metal, organic materials, minerals, and microorganisms. Landfill leachate can cause environmental contamination through infiltration/migration mechanisms of the soil and groundwater. Preventing leachate migration to the environment is the focus of many engineers [1,2]. A landfill liner system prevents air, soil, and water contamination caused by leachate [3]. This layer consists of materials with low permeability that can avoid infiltration, gas leakage, and movement [4]. Many innovations regarding this liner ensure a reduction of the advective and diffusive transport of contaminants to the environment. The landfill liner acts as a barrier designed to retain the migration of the contaminants through several types of processes, including physical and chemical adsorption, ion exchange, precipitation, mechanical filtration, and biological degradation. Per leachate retention, landfill liners must have less than 1 x 10⁻⁷ m/s of permeability value [5].

Natural clays (often bentonite), geomembrane, and mixtures of both (Geosynthetic Clay Liner/GCL) are often used as liners because their low hydraulic conductivity is less than 10⁻⁹ m/s [6]. GCL performs well compared to compacted clay liner (CCL), especially during the installation and hydraulic conductivity. However, GCL is limited by the possibility of leakage during improper installation, shear strength after the hydration phase, and the potential for loss of bentonite during the placement process, especially bentonite powder [7]. The use of CCL is preferable in developing countries because the installation costs are cheaper. However, clay material is very susceptible to desiccation crack, so finding
the most effective and appropriate combination barriers [8]. Bentonite composite-zeolite/bentonite layer-embedded zeolite (BEZ) is recommended as a landfill liner because of its ability to absorb and prevent metals migration. BEZ also has lower hydraulic conductivity and volumetric shrinkage values than other materials [9].

Desiccation crack phenomena are essential parameters that must be understood whenever using clay material as a landfill liner. Rayhani et al. tested cracks in natural and artificial clay. They found that cracks and hydraulic conductivity of clays depend on the physic-mechanical properties of soil, especially the plasticity and swelling capacity. Cracks can cause an increase in the hydraulic conductivity value [10]. Desiccation cracks occur in three stages: the initial phase, the primary phase, and the steady phase. At the initial phase, cracks begin to appear gradually as the water content decreases. At the primary phase, the water content reaches critical values, and the cracks develop rapidly. At the steady phase, the water content approaches the soil shrinkage limit. The cracks develop slowly and near to a fixed condition [11]. The effectiveness of bentonite embedded zeolites (BEZ) compared to other materials, like sand [12] and polyacrylamide showed that BEZ has potential for use as a landfill liner. This study used the behavior of desiccation cracks to determine the effectiveness of BEZ material as landfill leachate retainers. Measurement of cracking was done by looking at crack behavior sequentially, which was not accommodated in previous studies by Kaya and Durukan. Bentonite and zeolite composite materials are expected to be a solution to minimize the desiccation cracks potential of the barrier layer.

2. Methodology
The nature of bentonite clay and zeolite used in this study is the same as in another study published elsewhere [5]. The study was conducted by varying the composition of zeolites, including pure bentonite (B) and bentonite-zeolite composites with zeolite content of 2% (B2), 5% (B5), and 8% (B8). A 1:1 ratio of bentonite to zeolite powder produced the bentonite embedded zeolite. The mixed powder was then weighed, to calculate the water content percentage. Each composite’s ability to absorb water was tested for 26 days using pure water, natural, and artificial leachate. The water absorbance test was conducted to see the response of each composite to crack and water loss.

The development of the crack was recorded and documented daily. On the last day, kerosene was injected between the cracks, and the volume of kerosene that seeped was calculated. The documentation results were made black and white to be analyzed using MATLAB so that the percentage and width of the cracked area of the artificial liner were known. Temperature and air humidity were also calculated to determine the relationship between the desiccation crack and these two parameters. The area of composite cracks was processed with the help of MATLAB software; after air-drying for 26 days and oven-drying for 24 hours, cracks occurred in the composites. MATLAB can calculate the area by identifying colors, making it easier for researchers to calculate the cracked area. In this experiment, the cracked sample area was marked in black, and the uncracked sample area was marked in white. The crack intensity factor (CIF) is used as a parameter to evaluate cracks of bentonite dryness. CIF is defined as follows:

\[ \text{CIF} = \frac{A_c}{A_t} \times 100\% \]  

While \( A_c \) is the drying crack area and \( A_t \) is the total surface area.

3. Results and discussion
Cracks start from the surface to the lowest layer of the soil. At higher temperatures and relatively low humidity, drying-cracks begin faster in the surface layer. Only a small amount of water in the lower layers can be transported to the surface layer before cracks occur because of the generally low permeability of bentonite. This situation will cause a higher water content. If the clay stress decreases due to temperature rise and moisture decrease, cracks occur at the absorption of the higher water content. This result shows that a reduction of water content is also related to an increase in temperature [13].

Cracks in the liner layer are a significant concern in the performance of a landfill liner system. The liner layer consists of materials with low permeability to minimize infiltration and gas displacement. Liner layers are susceptible to cracks during the change between the dry and the rainy seasons over time.
The presence of cracks is a severe problem for long-term landfill performance [4]. Cracks usually occur in different widths that are problematic to analyze in an abbreviated time frame. Therefore, the crack intensity factor (CIF) is used to facilitate the measurement of cracks. CIF is calculated based on the crack surface area (Ac) ratio to the total dry land surface area (At). The measurement of the crack surface area is based on the width and length of the crack using a ruler or wire [14].

![Graph showing the relationship between Value and Day](image)

**Figure 1.** Humidity, daily temperature, and room temperature.

According to Nahlawi and Kodikara (2006), the bentonite used in this study has a higher water content than zeolite. Bentonite belongs to the montmorillonite group, which has an affinity for moisture. Therefore, bentonite has more water content than zeolite. The addition of zeolite in bentonite resulted in a significant increase in CIF. In this study, it was found that the rise in cracks was influenced by the addition of zeolite so that pure bentonite (B) was more suitable for use as a landfill liner compared to mixing zeolite (B2, B5, B8) because bentonite tends to have more water content and does not cause crack formation overall. Regarding the landfill liner, bentonite can be used as an alternative geomembrane replacement liner because bentonite has a lower CIF value and can expand again after going through the drying stage [15].

Temperature and humidity are factors influencing crack conditions in the sample. Air humidity is one element affecting the condition of the sample. The temperature and humidity of the air are very closely related because if the air humidity changes, and the temperature will also change. Air humidity is inversely proportional to air temperature. The higher the air temperature, the lower the air humidity. The elevated temperatures cause precipitation (condensation) of water molecules contained in the air. Thus the water content in the air decreases. The higher the air temperature, the lower the humidity, meaning humidity is inversely proportional to temperature; therefore, when the temperature rises, the humidity will decrease and vice versa. In the measurement process, heat transfer generally occurs from a measured place. What is read on the measuring device is the temperature after equality occurs. The results showed an increase in air temperature along with a decrease in humidity and vice versa. This situation happens because when elevated temperatures occur, condensation of water molecules in the air condenses, decreasing air water content. The average daily temperature ranges from 26°C to 30°C, while the average room temperature ranges from 24°C to 30.5°C. Increasing temperatures can increase the potential for crack formation because the level of soil moisture loss is high [14].
Desiccation crack testing includes water content and crack surface area testing. Testing of the water content showed that water content fluctuated, with the highest levels in the B2 sample and the lowest in the B8 sample. Increasing bentonite content in the zeolite bentonite mixture increases optimum water content, while the dry unit weight decreases [12]. If the bentonite content in the mixture increases, the optimum moisture content should also increase due to the bentonite's water-holding capability. Zeolite has considerable water content in bentonite-zeolite mixtures. This result can be seen from the increase in zeolite water content little by little until it reaches the optimum water content and then begins to decline rapidly. The limit of saturated levels of water for zeolite is 28%. The decrease in the water content of zeolite in a bentonite-zeolite mixture is relatively high. It is related to the capillarity of zeolite and chemical and electrical bonding with bentonite.

The crack intensity factor (CIF) results showed an increase in the percentage of crack intensity factors and the percentage of the zeolite mixture. The lowest crack intensity factor is in sample B, which is pure bentonite. The highest crack intensity factor is in the B8 sample. Based on this research, the sample suitable for landfill liner usage was pure bentonite because the cracks occurred less than when mixing zeolites, as the nature of zeolite being able to release H₂O faster results in composite materials drying faster, thus that more cracks arise. Consequently, leachate seeps into and contaminates the soil, so that the bentonite sample is chosen for this consideration.

![Figure 2. Crack intensity factors per day.](image)

The percentage of CIF per day showed fluctuations in the four samples, but, overall, the percentage of CIF is highest in sample B and lowest in sample B2. Based on Tang et al.'s research, the water content during cracks ranged from 38% to 48%, and an increase in crack intensity factor (CIF) occurred with decreasing water content and pore volume. This result is consistent with the research data; the water content decreases along with the increase in CIF. Based on the research, the smallest CIF was produced in pure bentonite samples of 3.44% [16].

4. Conclusion
Composite-pure bentonite and bentonite-zeolite showed exciting results, indicating that the potential for drying cracks and migrating leachate concentrations was reversed between the two types of composites. Pure bentonite has a better performance keeping the liner layer from cracking while adding zeolite increases cracking. Bentonite embedded zeolite (BEZ) has the potential to be material for landfill liners, although new materials must be added to reduce the possibility for cracks in this mixture.
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