

## Design of Landfill Liner for Boron Mine Waste Water

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### Abstract

The purpose of this study is to form the impermeable layer as landfill liner to store boron mine waste water. Boron mine waste water was supplied from Emet (district of Kutahya city, Turkey) Boron Factory. In this study, five different mixtures were used. These mixtures were natural soil, natural soil mixed with Na-bentonite (10%, 20%, 30% and 40%). A miniature landfill tank (240 cm × 120 cm × 60 cm) with six sections was constructed and mixtures were compacted in the container according to the optimum water content. After curing period, 120 liter boron mine waste water was poured into each section and impermeability of mixtures was observed. As a result of observations, it was seen that natural soil was totally inefficient material. Natural soil started leaking on the fifth day and waste water was completely leaked within 27 days. Natural soil mixed Na-bentonite (40%) mixture gave the best result among them. The thickness of impermeable layer formed with natural soil mixed Na-bentonite (40%) can be offered between 40 and 60 cm for the *in-situ* application.

**Keywords:** Na-bentonite; Landfill liner; Boron mine waste water; Natural soil

### Introduction

Waste landfill areas are the potential source of soil and groundwater contamination in most countries. Leachate from waste water is the major carrier of soluble and suspended contaminants in the bottom impermeable liner. Design and construction of proper lining system are important to protect the surrounding environment. Typically, hydraulic conductivity must be less than or equal to  $1 \times 10^{-7}$  cm/sec for soil liners and covers used to contain hazardous waste, industrial waste and municipal waste [1]. In the presence of leachate from waste water, the permeability of a bentonite with natural soil can be used as a composite lining system. One important aspect of hydraulic barriers is the Cation Exchange Capacity (CEC) of the liner material. The most common clay minerals, such as kaolinite, illite and chlorite have CEC values from 5 to 40 meq/100 g [2], whereas bentonite has CEC values from 77 to 120 meq/100 g [3] and from 75 to 110 meq/100 g [4].

Tong [5] studied on permeability of compacted mixture of sand with a low percentage of sodium bentonite (less than 15% by dry weight). Standard test procedures were used to determine the permeability of compacted sand-bentonite mixtures. Permeability values of mixtures decreased with increasing the percentage of bentonite. Li et al. [6] considered PerFluorinated Compounds (PFCs) as a leaching material and Na-bentonite as a common barrier material. It was found that the PFCs did not bind substantially to the bentonite. Hydraulic permeability of bentonite liner were not affected by the PFCs. The sand-bentonite mixture partially retained the PFCs. Benson et al. [7] investigated the hydraulic conductivity (permeability) of compacted clay liners. Hydraulic conductivity measurements were conducted on a wide variety of soils from 67 landfills in North America. They found that the hydraulic conductivity values were less than  $1 \times 10^{-7}$  cm/sec.

Simon and Muller [8] refer to standards for alternative cover lining materials and design criteria in Germany. They show necessity of the creating new liner methods and mixtures for real site conditions. Jain et al. [9] investigated heavy metal concentrations of old and new sanitary landfill liner systems. They found that heavy metal concentration has great influence on the old landfill liner systems. Tuncan et al. [10] studied using natural zeolite as a landfill liner. Different ratios of bentonite and zeolite mixtures were compacted with an optimum water content. Shear strength parameters, permeability, pH, heavy metal content and other properties of compacted mixtures were determined. They conclude that Bentonite/Zeolite = 0.10 ratio is the ideal mixture for sanitary land fill liner material. Mishra et al. [11] investigated the effects of NaCl and CaCl<sub>2</sub> by varying concentrations on bentonite. Results indicated that liquid limit, plasticity, swell potential and swell pressure decrease and hydraulic conductivity increases with salt concentration. Samples compacted on the dry side of optimum water content showed a higher swelling pressure in comparison to the samples compacted at optimum water content.

Hoeks et al. [12] investigated the applicability of bentonite as a lining material for isolation of waste disposal sites on laboratory and field scale. The permeability of sand-bentonite mixtures depends on the type of bentonite, the bentonite content in the mixture and dry bulk density. The sand-bentonite mixtures were 10-100 times more permeable for landfill leachate than for clean water. Bottom liners should contain considerably more bentonite to prevent infiltration of leachate in the subsoil. Field experiments showed that there was no leakage at all through bentonite liners over a two-year period.

Amadi [13] studied the swelling parameters of soil-bentonite mixtures for use as barrier in municipal waste landfill. Swelling potential and pressure tests were performed using variable content of bentonite (0-10%) at optimum water content. Experimental results showed that swell pressures of compacted soil mixtures increased with increasing amount of bentonite with processed tap water and three leachate solutions. Shoung [14] investigated of the sealing performance of bentonite and bentonite/crushed rock plugs under diverse

conditions. American colloid granular bentonite and Apache Leap tuff have been mixed to prepare samples for laboratory flow testing. Injection pressure flow tests, polyaxial flow tests, high temperature flow tests and piping tests were performed. The results indicate that a suitable mixture would have at least 25% bentonite by weight mixed with well graded crushed rock.

Bradshaw et al. [15] investigated the hydraulic conductivity of bentonite liner for using municipal waste leachates. They also tested geosynthetics with bentonite as a liner, and they found that the system was working highly effective under the stress with low hydraulic conductivity. Morandini and Leite [16] determined the hydraulic conductivity performance of natural soils and bentonite mixtures for waste disposal facilities. Their results showed that the percentage of the bentonite directly affects the hydraulic conductivity performance and the content of the mixtures should be carefully chosen due to best performance and cost relationship.

The purpose of this study is to present a mixture of natural soil and Na-bentonite as a material for use in composite lining system [17]. Bentonite serves as a pore sealant yielding low hydraulic conductivity. Various ratios of bentonite percentages were tested to obtain the most desirable mixture ratio of ideal liner mixture. Waste water used in this study is formed as a result of ore enrichment in the Espey Concentrator of Emet Boron Factory, Turkey. Landfill is constructed to store this waste water near the factory. Results of the experiments were checked according to the Turkish Solid Waste Regulations [18].

## Materials

### Natural soil

Natural soil used in this study was obtained near the factory and excavated between -1.50 meters and -2.00 meters from the ground surface. Boron Factory is located at the Emet (district of Kutahya city, Turkey). The properties of the natural soil were found by conducting the index experiments in the laboratory. Some properties of natural soil were given in Table 1.

Optimum Water Content (%)	21
Dry Unit Weight (gr/cm <sup>3</sup> )	1.58
Specific Gravity	2.53
Natural Water Content (%)	9
Liquid Limit (%)	42
Plastic Limit	22
Classification	ML
Grain Size Distribution	Gravel (8%), Sand (35%), Silt (39%), Clay (18%)

**Table 1:** Some properties of natural soil.

### Na-bentonite clay

Commercial powdered Na-bentonite clay was used to improve the physical and chemical characteristics of natural soil mixed bentonite mixtures. It is a highly colloidal, plastic and potentially low permeability material. X-ray diffraction analyses of bentonite give the following components: 59.49% Si, 18.06% Al, 0.91% K, 2.42% Mg,

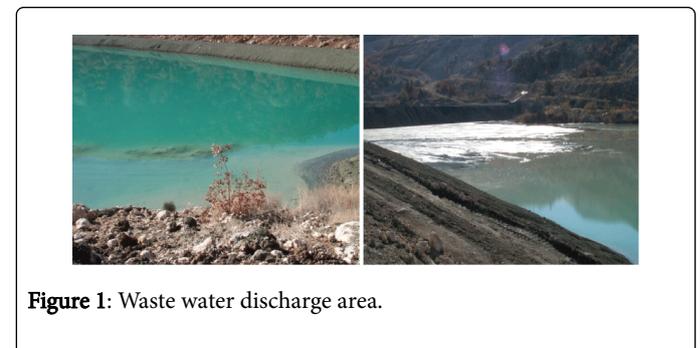
4.14% Fe, 3.72% Ca, 2.50% Na and 0.10% S. Na-bentonite is a highly cohesive material with a small angle of internal friction of 5°. Some physico-chemical properties are given in Table 2. All of the properties were found by performing the experiments in the laboratory.

pH	9.50
Electrical Conductivity (milliSiemens/cm)	2.69
Cation Exchange Capacity (meq/100g)	90
Specific Gravity	2.60
Silt (%)	12
Clay (%)	88
Liquid Limit (%)	447
Plastic Limit (%)	60
Shrinkage Limit (%)	32

**Table 2:** Some physico-chemical and index properties of Na-bentonite used in the experiments.

### Boron mine waste water

Waste water was obtained from effluent of Boron factory shown in Figure 1. Waste water used in this study is formed as a result of ore enrichment in the Espey Concentrator of Emet Boron Factory. The contents of the waste water were determined after performing some experiments in the laboratory. Some properties of waste water are given in Table 3. The limits according to the Turkish Solid Waste Regulations of boron and arsenic are given in Table 4 [18].



**Figure 1:** Waste water discharge area.

Waste Water (tons/year)	30.000-35.000
Boron (B <sub>2</sub> O <sub>3</sub> ) (ppm)	3265
Iron (Fe) (%)	0.02-0.05
Arsenic (As) (ppm)	15.6
Moisture Content (%)	95.75
Density (gr/cm <sup>3</sup> )	1.028

**Table 3:** Some properties of waste water.

	Boron	Arsenic
Discharge to environment	500 ppm	0.5 ppm

Tap water	2 ppm	0.05 ppm
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**Table 4:** The maximum allowable levels of boron and arsenic according to the turkish solid waste regulations.

### Testing Method

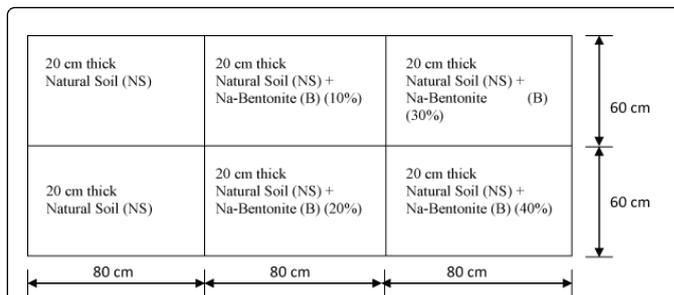
A miniature landfill tank (240 cm × 120 cm × 60 cm) was used to obtain the closest results in-situ applications. The tank was divided into six sections shown in Figures 2 and 3. The first and the second sections consist of a 20 cm thick natural soil. Natural soil was obtained from near the factory. Natural soil was compacted with optimum water content in the tank with a thickness of 20 cm. After 28 day curing period, waste water (obtained from landfill area shown in Figure 1) was poured into the tank with a height of 25 cm. Volume of the waste water was 120 liter for each section. Waste water leaked totally after waiting 27 days. This soil cannot be used by itself. Therefore, it is decided to use with some percentages of bentonite (10%, 20%, 30%, 40%). Some properties of these mixtures are given in Table 5. The third, fourth, fifth and sixth sections consist of a 20 cm thick compacted bentonite (10%, 20%, 30%, 40%) mixed natural soil mixtures shown in Figures 4 and 5. These mixtures were prepared on the basis of dry weight. A standard compaction test was employed to prepare specimens. After waiting 28 day curing period, waste water was poured with a 25 cm thick above the compacted impermeable liner shown in Figure 6. Tank was observed for 9 months (from September to May). Leakage did not occur in the tank through the natural soil mixed bentonite mixtures.



**Figure 2:** Miniature landfill tank with 6 divisions.



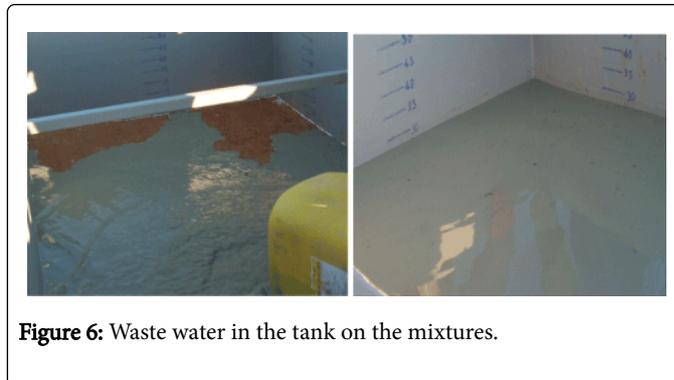
**Figure 3:** General view of miniature landfill tank.



**Figure 4:** General view of mixtures in the miniature landfill tank.



**Figure 5:** Compacted mixture in the tank.



**Figure 6:** Waste water in the tank on the mixtures.

Mixtures	Specific Gravity	Liquid Limit (%)	Plastic Limit (%)	Max. Dry Unit Weight (g/cm <sup>3</sup> )	Optimum Water Content (%)
NS	2.53	42	22	1.58	21
NS+B (10%)	2.61	74	24	1.69	21.3
NS+B (20%)	2.63	107	27	1.69	22.2
NS+B (30%)	2.64	140	29	1.53	23.5
NS+B (40%)	2.66	157	31	1.53	24.5

NS: Natural Soil, B: Na-bentonite

**Table 5:** Some properties of mixtures.

## Experimental Results

Natural soil mixed bentonite mixtures was prepared by using standard compaction test in the tank. The Tank was divided into 6 sections. Two sections have only natural soil and the others have bentonite (10%, 20%, 30%, 40%) mixed samples. Mixtures were compacted with a thickness of 20 cm. Waste water was added with a height of 25 cm.

Waste water leaked totally through the natural soil within 27 day period shown in Figure 7. Boron and arsenic contents in the leachate are found as 245 ppm and 0.10 ppm, respectively. Dumping limits of boron and arsenic to the environment are 500 ppm and 0.5 ppm, respectively according to the Turkish Solid Waste Regulations [18]. Waste water did not leak through the natural soil mixed bentonite mixtures. It leaked 18 cm, 16 cm, 14 cm and 13 cm through bentonite (10%, 20%, 30%, 40%) mixed natural soil, respectively shown in Figures 8-11. Hoeks et al. [12] presented that there was no leakage at all through sand mixed bentonite (5%) mixtures over a two-year period. There is an agreement with the results of this study.

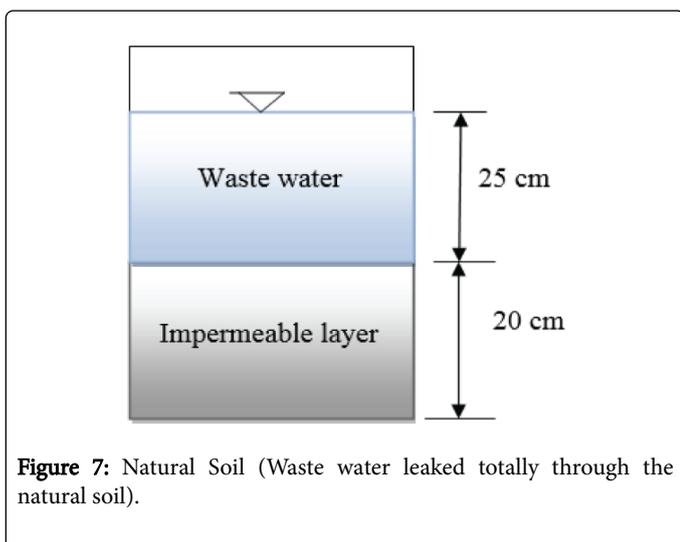


Figure 7: Natural Soil (Waste water leaked totally through the natural soil).

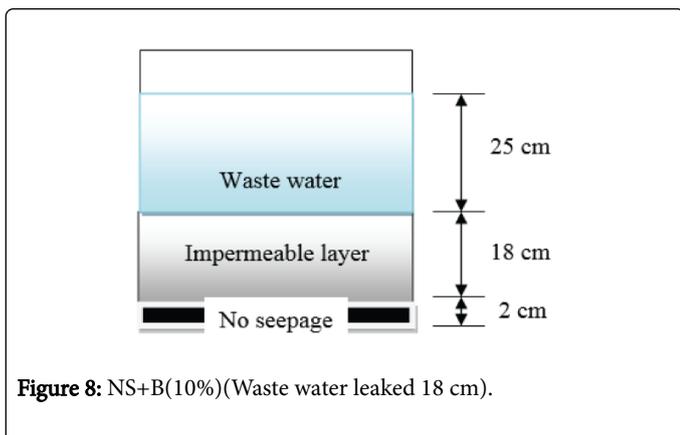


Figure 8: NS+B(10%)(Waste water leaked 18 cm).

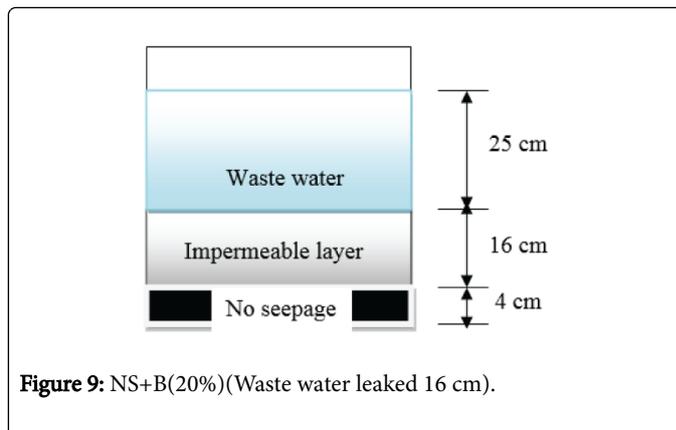


Figure 9: NS+B(20%)(Waste water leaked 16 cm).

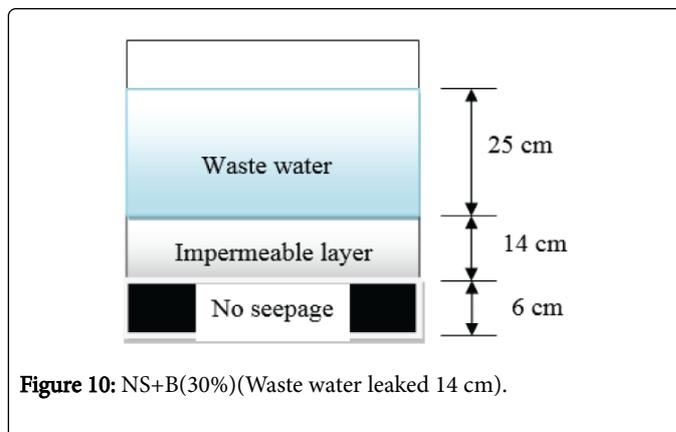


Figure 10: NS+B(30%)(Waste water leaked 14 cm).

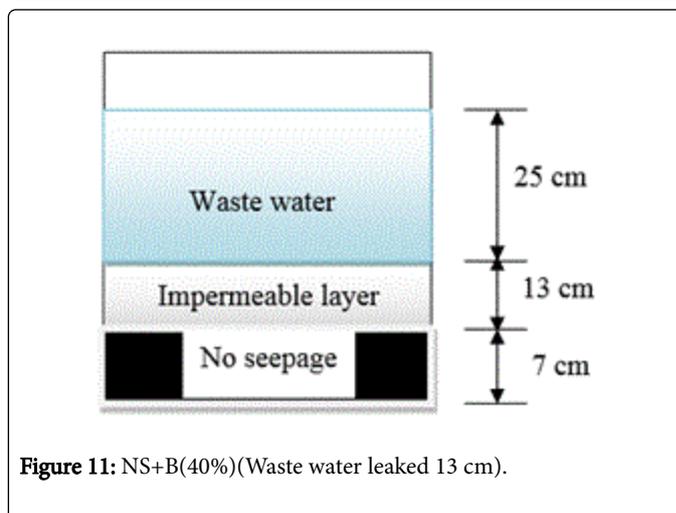


Figure 11: NS+B(40%)(Waste water leaked 13 cm).

## Conclusions

It was observed that natural soil by itself can not be effectively used in bottom lining system for waste water. After 9 months observation of the tank, waste water leaked 18 cm, 16 cm, 14 cm and 13 cm through the bentonite (10%, 20%, 30%, 40%) mixed natural soil mixtures, respectively. Bentonite (40%) mixed natural soil gave the best result among them. If factor of safety is considered between 2 and 3, *in-situ* thickness of impermeable layer can be chosen between 40 cm and 60 cm according to the experimental results.

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