# Innovative Tecnology for Liners

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ABSTRACT: In this paper it is presented geotechnical results of bentonite—zeolite (BEZ) properties as potential liners for landfills. Literatur review has been pointing out that clayey soil liners are suitable as liners only when the temperature and moisture fluctuations are not high; otherwise, they can form cracks that cause the hydraulic conductivity to rise in the order of many folds. On the other hand, the use of geomembranes pointed out as the best alternatives for liners, are out of reach of most underdeveloped countries for their high price and the need for trained personnel for installation. Besides that, recent research have reported that geomembranes may lose their liner properties in four years, as well as, in case of GCL (geomembrane clay liner) the interface is susceptible of sliding and the shear strength of the interface is sensitive to moisture and density of the clay. Then, for most underdeveloped countries there is a need for a landfill liner that is natural, locally available, and that can be installed in an inexpensive way, and in compliance with the environmental regulations. In the studies performed, the low volumetric shrinkage of the BEZ indicate that it is not affected by moisture content fluctuations, and its hydraulic conductivity in the order of $10^{-10}$ cm/s meets regulatory agency requirements. The engineering proprieties of the studied BEZ liner show that it is a good alternative as landfill liner. Also, its inherent chemical properties (specially clinoptilolite zeolite) and its natural selectivity indicates that it will adsorb heavy metals such as $Pb^{2+}$, $Zn^{2+}$, $Cd^{2+}$, $Ni^{2+}$,$Fe^{2+}$, and $Mn^{2+}$ that may be present in the leachate. Therefore, their geotechnical and chemical properties make BEZ an innovative material for liners in landfills, in special, the presence of zeolites will add adsorption properties to the liner.

## 1- INTRODUCTION

Before 1950, landfills did not exist in developed countries, and before 1985 did not exist even in the big cities of most undeveloped countries. For instances, in China, the most populated country in this planet, the first landfills were constructed in the middle 1985's. According to Xiaobo et al (1990), in 2000, the total amount of waste collected in China, only in urban areas, were more than 102 million tons and it is expected to reach the astronomical amount of 12 billion tons in 2050 (approximately a 10% annual increase), due to an increase of urban populated areas – 18% in 1978 to 60% in 2050.

Traditionally, before 1950's, for all countries in this planet, garbage was dumped in flood plains and depressional areas, among other sites. Nothing was made to prevent leachate to contaminate ground and underground water. These garbage depositional sites were plagued by foul odors, rodents and represented a risk to human health.

By 1970, advancements in the field of geotechnics and the advent of geosynthetics, associated with growing environmental concern have enabled the switch from open dumps to landfills. Improvements in odor control, rodents control and many of the health hazards were made, by covering the waste quickly and carefully; however, no progress was done regarding the treatment of the two contaminants of environmental concern - leachage and gases. Later on, liners (and/or liner composites) were introduced to prevent leachage and soil-groundwater contamination, water infiltration in the landfill and gases release.

In the last three decades, substantial progress has been made in landfills politics, design and operation. In many countries the separation, re-use and recycling operations have been successfully implemented aiming specially to prolong the life span of a landfill. However, despite progress made in several countries towards recycling and incineration the tendency observed is that landfilling is a primary method of waste disposal and will remain at short and long terms.

Until recently, large landslides had not occurred in solid waste facilities. Among the landfill failures that occurred in 1990's are: (i) On March 19, 1988, there was a failure in Landfill at the Kettleman Hills Class I hazardous waste treatment, storage, disposal facility California. Approximately 443,000 cubic meters of waste and other material had been placed to a height of 27 m above the base at the time of the failure. The entire mass slid a horizontal distance of about 10 m toward the southeast, and vertical slumps of up to 4 m along the side slopes of the landfill were observed after the failure. Initial study of the failure indicated that it had most likely occurred within the liner system and identified both

geomembrane/ clay and their interfaces as candidate sliding surfaces.

Also, a 1.8 million tons landfill had failed in Colombia. The failure was attributed to miscalculations of the pore-pressure in this landfill that has used the recirculation technology (bioreactor).

Lessons on landfills failures have been pointed to some aspects of landfill design, construction and operation. Among them are the landfills liners (Kettleman) and the leachate recirculation, which uses the bioreactor technology (Colombia). This paper will not address the recirculation technology, although it will likely become an important technology in future, despite the Colombia failure. The recirculation technology (LRS – leachate recirculation system) re-introduces the leachate into the landfill. By doing this the amount of liquid is very large. However, the pH is maintained at a relatively neutral level and it speeds the rate of waste decomposition through the growth of microbial groups, and, consequently the rate of methane gas. Thus, the main advantages of LRS technology are: leachate management, production of gas methane, and rapid rate of decomposition. The disadvantages are lack of studies on geotechnical aspects on how re-circulation affect all elements of a landfill facility, specially the ones related to a more effective pore-pressure dissipation considerations and how to size the recirculation operation properly to each landfill.

This main focus of this paper is on liners (multi-layer composites). Also, the geotechnical studies that support the use of a combined liner – clay – zeolites are presented, among them: volumetric shrinkage, compaction and hydraulic conductivity. Chemical studies (performed elsewhere) highlight the high selectivity of zeolites towards heavy metals, providing an effective means of preventing contaminants from reaching the groundwater.

## 2- GEOMECHANICS OF LANDFILLS

The landfill stability is a very complex subject and it is influenced by many factors:

(i) Engineering properties- waste composition, hydraulic conductivity, volumetric change, settlement and stress-strain-strength;

(ii) the analysis, design and construction influences the landfill stability and are function of compaction control (landfill filling, operation equipments and construction placement); drainage systems (local site hidrology, climate conditions), slope stability analysis (waste filling slope and height, sub-base slopes, pore pressures, normal stresses, groundwater level, foundation geological profile), and seismic/dynamics effects.

(iii) The design factors in association with factors affecting stability and leachate are responsible for the cover systems choice.

Figure 1 describes in details the complexity of landfill geomechanics as proposed by Fang (1997).

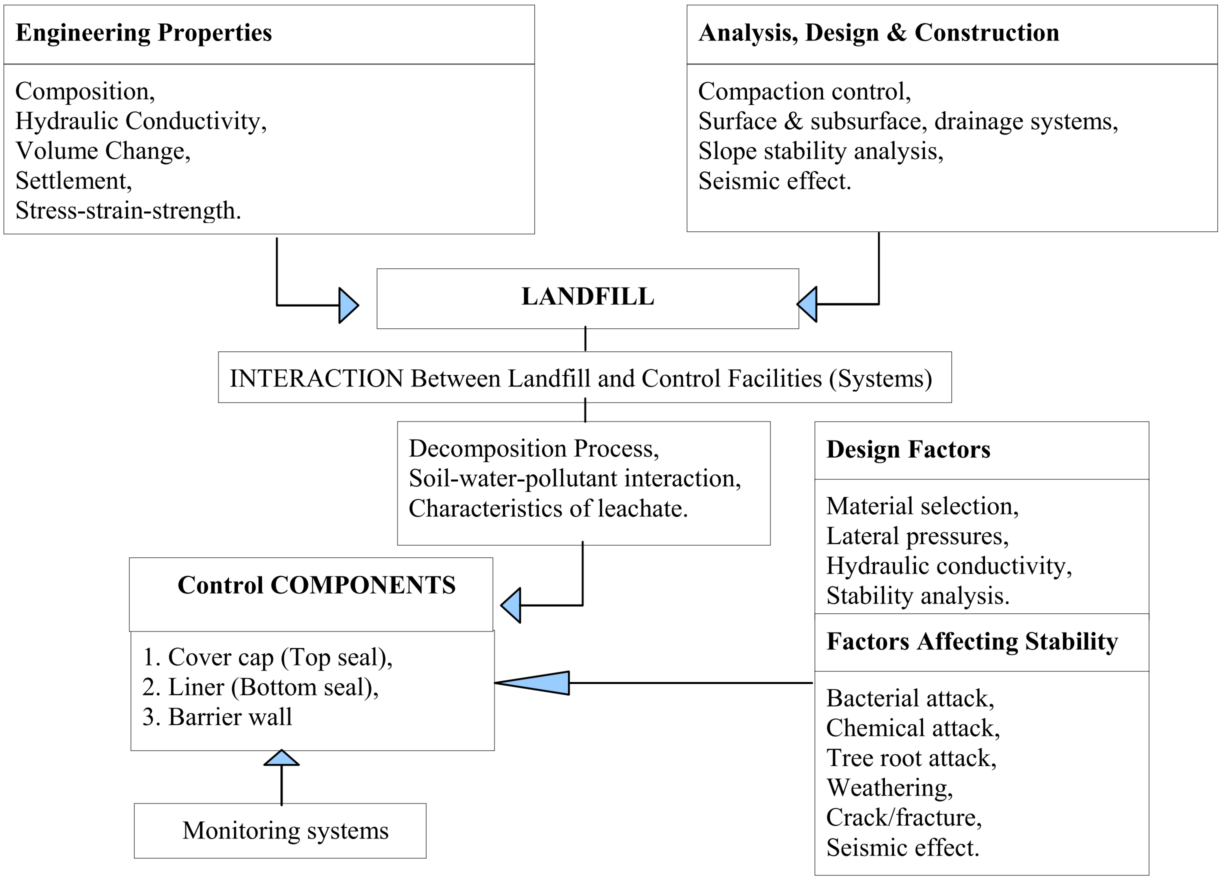


**Figure 1** Geomechanics of Landfill (Fang, 1997)

## 3. CHARACTERISTICS OF LEACHAGE AND GASES

Leachage and gases have a direct effect on the stability of landfills, in special in the cover systems – liners and covers. Increasing water increases the waste's unit weight, which means more driving force pushes on the liner system and foundation soils. Additional liquid could result in effective stress reductions. Thus, waste with higher moisture content may reduce shear strength. Also, a rising in water table can lift liners out of place (geomembranes). Therefore, periodic water table fluctuations must also be determined or estimated during design of the landfill.

Leachage is the product of waste decomposition, through chemical processes either oxidation (for metals), or broken down of organics by micro-organisms. It is a contaminated liquid of complex nature consisting of organic and inorganic salts, heavy metals, pesticides, toxic chemicals, acids, virus and pathogens. It is important to mention that most leachage are acidic and these acidic fluid can reach the liners, regardless the types of liners used.

For a closed landfill, the yield of leaching solution per day can be estimated by:

$$Q = CxIxAx10^{-3} \tag{1}$$

where, Q is the amount of the leaching solution; I is the precipitation; A is the area of precipitation; C is a coefficient which varies from 0.3 to 0.8. Usually, the value of C is adopted as 0.5.

According to Etalla (1987), the infiltration rate into landfills is mostly above 1mm/min.

The amount of leaching solution that can flow through the floor barrier can be estimated by:

$$Q = kxAxH/L \tag{2}$$

Where, Q is the amount of leaching solution ($cm^3/s$); k is the permeability coefficient (cm/s); H is the water head loss (cm); L is the thickness of the floor barrier (cm).

In the last decades several water balances models have been developed for landfill water balance, in different countries. For instances, LCAM (Landfill Cover Approximation Model) had been developed for the Finnish Institute of Environment, and have presented reliable results for their landfills (Saarela & Karvonen, 1999).

The predominant gas in a landfill, in the first years, is carbon dioxide, while in the later years is a mixture of methane-carbon dioxide in almost equal proportions. Steady gas generation continuous for 10-15 years. The rate of gas production is function of many factors, among them, pH, waste composition, depth and moisture content are found to be the most important. Methane is explosive and asphyxiant. It is liable for its effect in the global warming as well as to its potential to migrate and accumulate in homes and buildings. The gas generated by a landfill may also contain concentrations of vinyl chloride and hydrogen sulfide. Vinyl chloride is a human carcinogen, and hydrogen sulfide damages lungs and blood circulation. These health hazards must be considered during pre-design, design, construction operations and maintenance.

## 4. LINERS

Landfills are lined on the bottom and sides with natural and synthetic barrier to contain and collect liquids (leachate) and prevent waste to escape to the environment. Natural liner is composed by compacted clay. The synthetic liner includes high density polyethylene (HPDE), geosynthetic/ clay (GCL), and polyvinyl chloride (PVC).

According to USEPA's 1982 Interim Regulations, a synthetic membrane liner is considered best to "prevent", whereas a clay liner will "minimize" migration of wastes.

A double composite landfill liner system as proposed by Daniel & Koerner, (1991), and presented in Figure 2, consists of four parts and 10 layers: leachate collection system (layers 1, 2 and 3; primary layer (layers 4, 5, and 6), leak detection system (layer 7), and secondary line (layers 8 and 9). The tenth layer is the soil and/or rock subgrade.

Stress cracking and environmental stress cracking have been responsible for premature failure in some of these systems (Peggs, 1990). In most cases, failures do not occur due to misuse of material properties or miscalculation of service life. Stresses can be imposed on a geomembrane by tension, shear, torsion, bending, and compression (Soong, 1995). A small number of geomembrane liner failures have occurred by simple overloading as consequence of shear failures on the adjacent lining system interfaces. Significant loss of the strength on geomembrane can occur during installation and unexpected local service conditions could initiate a crack in the material, which can grow until failure. In short, they are caused by some unknown material performance characteristic or unexpected local service condition that initiates a crack at a flaw in the material. The amount of strength loss can be a function of gradation, angularity, and maximum size of the backfill particles, weight, type of construction, and compaction equipment (Allen, 1991). Therefore, the predominant mode of premature failure is a quasi-brittle fracture initiated at stress concentrating geometries. Strength losses reported vary from 10% to 70% (Elias, 1990).

According to Harper et al. (1993) the key point in a GCL design is that the shear strength of this interface needs to be thoroughly evaluated by the designer during the design phase and verified by conformance testing on the actual materials to be used in construction for the specific site conditions. The shear strength of the interface should not be taken from assumed or published values, nor should it be left up to the contractor to choose materials based on manufacturer's representations.

A composite barrier should not be used on slopes unless the designer fully considers the above factors (Peggs, 1990): (i) the general stability of a composite barrier on side slopes can be compromised by relatively small excess water and gas pressures of magnitudes that are common to typical operational conditions in municipal waste landfills; (ii) the shear strength of the interface between a smooth geomembrane, and the slit-film side of a geotextile-based GCL can be affected by hydration of the bentonite, and extrusion of bentonite through the slit film; (iii) the combination of a smooth geomembrane and a geotextile-based GCL should be avoided on side slope covers; (iv) interface strength testing should be performed on the specific material combinations for each cover design at the normal stress and hydration conditions appropriate to site conditions; (v) the test method and equipment should be calibrated and appropriate for the low normal loads and shear stresses for cover designs. Use of generic or published data for interface shear strength, or dependence on others not familiar with the design to provide the required testing, can lead to expensive failures; (vi) due to low normal loads of landfill covers, especially during construction, the stability of these systems is extremely sensitive to pore pressures above and below the geomembrane. Pressures that might normally be considered rather small can provide an uplift force that is a significant percentage of the normal force provided by the overlying materials;(v) gas and pore water pressures should be anticipated in the design of landfill covers, and relieved to the extent necessary to obtain the required factor of safety.

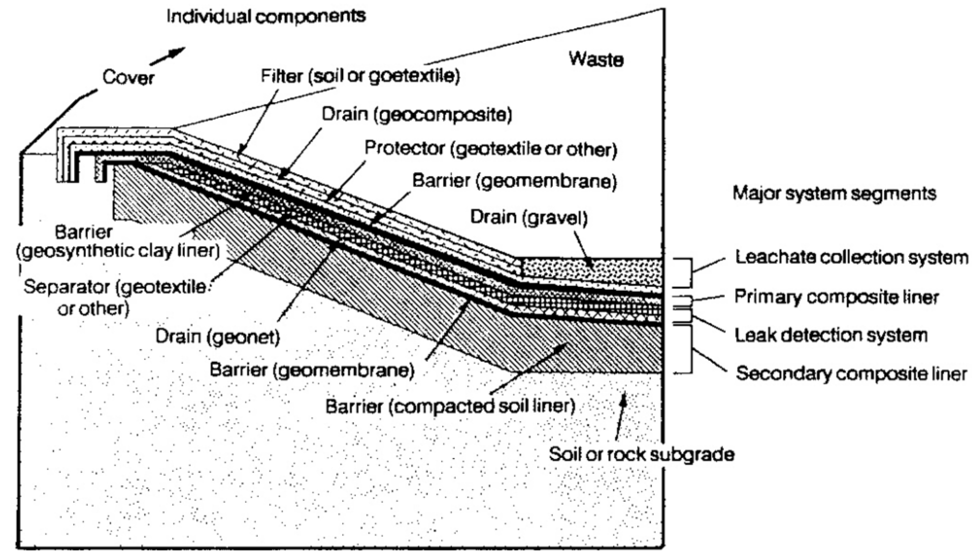


**Figure 2** A double composite landfill liner system (after Daniel, D. E. and Koerner, R. M; [1991], Civil Engineering, ASCE, NY, pp. 46-49)

*4.1. Geomembranes*

Geomembranes as liners were used in the 1950's by the Departament of Agriculture and the Bureau of Reclamation. The major geomembranes types are as follows: (i) plastics category: polyvinychloride (PVC), polyethylene (LDPE, MDPE, HDPE), chlorinated polyethylene (CPE), elasticized polyolefin (3110), polyamide (PA); (ii) rubbers: isoprene- isobytylene (butyl), epichlorohydrin rubber, ethylene propylene diene monomer (EPT), polychloroprene (neoprene), ethylene propylene terpolymer (EPT), ethylene vinylacetate (EVA), ethylene propylene rubber (EPDM); (iii) combinations: PVC-nitrile rubber, PE-EPDM, PVC-ethyl vinyl acetate, crosslinked CPE, chlorosulfonated polyethylene (CSPE).

There are an estimated one-quarter million liquid impoundments and solid waste landfills with geosynthetic lining systems in the U.S. and Canada (Kanninen, et al, 1993).

In general, the greater the polymer crystallinity, the lower is the gas permeability. They also show that the permeability varies with type of gas and temperature.

The main design issues for the geomembrane include differential settlement, wrinkle management, punctures, gas migration, low-temperature behavior for landfills subjected to sub-freezing temperatures, and susceptibility to rats and rodents.

*4.2 – Clay Liners*

Compacted clays soils have traditionally been used as liners. Waste disposal regulations commonly stipulate maximum values of hydraulic conductivity, typically in the range of $10^{-6}$-$10^{-7}$ cm/s. Failures in clay liners have been attributed to construction quality and to the appearance of dessication/cracks, which have increased the hydraulic conductivity. Clayey soil liners are suitable when temperature and moisture fluctuations are minimal, however; when temperature and moisture fluctuations are high, they form cracks that causes an increase the hydraulic conductivity in the order of many folds (Wong and Haug, 1991; Shan and Daniel, 1991; Villar and Rivas, 1994; Kraus et al., 1997; Stewart et al., 1999; Sivapullaiah et al., 2000; Tay et al., 2001).

*4.3 Innovative materials in clay liners*

Even though geomembranes have been point out as the best alternative for liners, they are out of reach of most underdeveloped countries for their high price and the need for trained personnel for installation. Besides that: (i) researches have been reporting the lost of their liner properties in four years (Rowe et al., 2003); (ii) the geomembrane/ clay interface is susceptible of sliding; (iii) clay/geomembrane interface indicated that the shear strength is sensitive to moisture and density conditions of the clay.

Then, for most underdeveloped countries there is a need for a landfill liner that is natural, locally available and that can be installed in an inexpensive way. An alternative for that has been used in southeastern countries is to mixture clay, bentonite and zeolites. In this case, the zeolites will add adsorption properties to the liner.

*4.3.1 Zeolites in the clay liner*

Zeolites were discovered in 1756 by the Swedish mineralogist Crinstedt who named them from the Greek word zein and lithos, meaning “boiling stones”. Since then, more than 50 species have been recognized, and at least 150 have been synthesized in the laboratory.

In recent years, several researches have been made with zeolites as clay barriers. Minato et al (1994) have reported successful cases of using zeolites, in the patented technique “sealingsoil”. This technique has included a combination of ion-exchange minerals, natural clay, clay minerals, and calcium carbonate. It is based on adsorption, ion-exchange, and crystallization mechanisms along time. The heavy metals became trapped inside zeolites structure and a new inert substance is formed along time.

Zeolites are hydrous aluminosilicate minerals, and belongs to the tectosilicate group in the silicate class. It has been identified more than 40 diferent types of zeolites, the most known are: clinoptilolite, mordenite, phillipsite, analcime, chabazite, faujasite, ferrierite, heulandite, laumontite.

Clinoptilolite has received extensive attention due to its selectivity to heavy metals such as $Pb^{2+}$, $Zn^{2+}$, $Cd^{2+}$, $Ni^{2+}$,$Fe^{2+}$, and $Mn^{2+}$.

Zeolites are formed in veins of altered volcanic rocks and granitic rocks and present very beautiful crystals forms due to hydrothermal reactions. The main composition of natural zeolite is tetrahedral silicates and gibbsite with alkalis of Na, K, Ca and Mg. Today, their unique cation-exchange, adsorption, hydration-dehydration, and catalytic properties prompted their use in: slow-release fertilizers, dietary supplements in animal nutrition, carriers of insecticides, herbicides and fungicides, and deotorizes (Pond & Mumpton, 1984). Crystalline zeolites are unique adsorbent materials, characterized by void volumes of 20% to 50% and internal surface areas of several hundred thousand square meters per kilogram.

Figure 3 shows the circular arrangement of the silica tetrahedra, and the resulting high surface area. This group, also receives the name of “molecular sieve”, due to their selective properties on cation exchange capacity the tetrahedra structure is rigid and the pore size is also fixed, therefore, the cations of lower radius can move freely inside the zeolite pores, while the biggest ones are excluded.

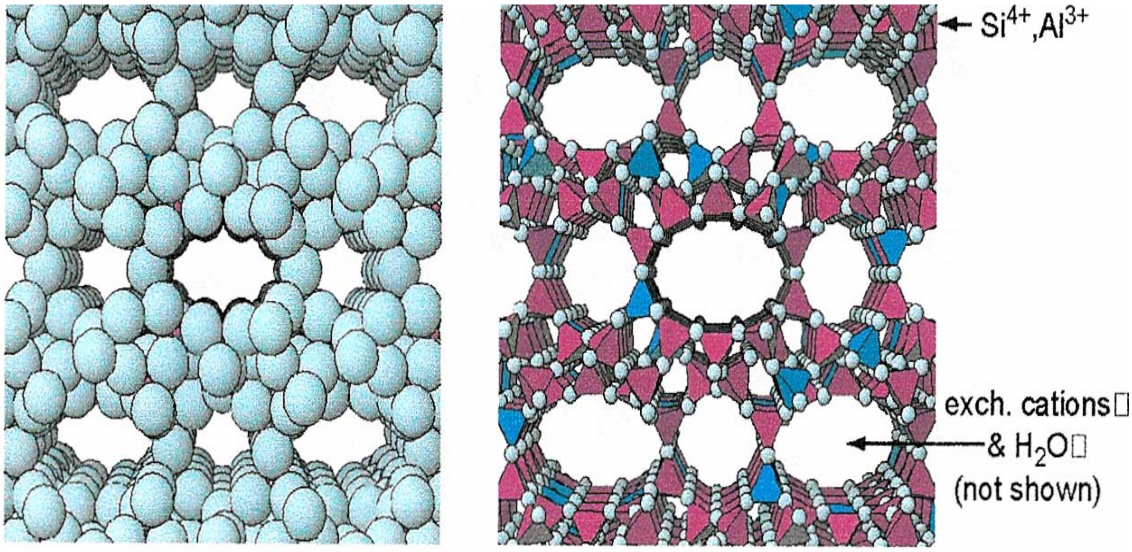


**Figure 3** Zeolites structure

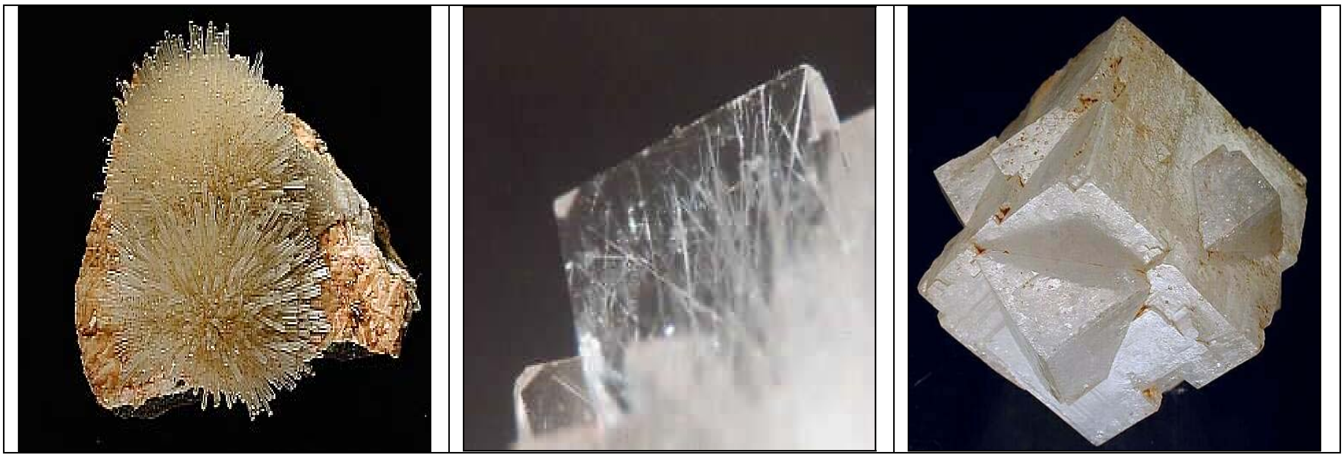

**Figure 4** Phillipsite rods, clinoptilolite plates and analcime crystals - beautiful forms of zeolites

*4.3.2 Chemical Properties of Zeolites*

Table 2 shows the chemical properties of Gordes zeolites in comparison to Na-bentonite (Güney and Koyuncu, 2002).

*Table 2 – Chemical Properties of Gordes Zeolites and Na-bentonite*

| | **Na- bentonite** | **Gordes Zeolites** |
|---|---|---|
| Specific Gravity | 2.60 | 2.63 |
| Specific Surface Area ($m^2/g$) | 400 | 29.9 |
| pH | 9.5 | 8.2 |
| Cation Exchange Capacity (meq/100g) | 90 | 165 |

*4.3.3 Engineering Properties of Zeolites*

Two potential liners materials will be studied - samples of bentonite embebbed zeolites (BEZ) and bentonite embebed sand (BES) were tested for engineering properties to evaluate its potential as liner and the following engineering properties of both Gordes zeolites and Na-bentonites were studied: hydraulic conductivity, volumetric shrinkage and compaction.

*4.3.3.1 Hydraulic Conductivity*

It was used 1-D consolidation apparatus to determine the hydraulic conductivity, according to ASTM 2435. Figure 5 shows the hydraulic conductivity of BEZ with 10% and 20% bentonite meet the most common regulatory requirements. The hydraulic conductivity of BEZ is in the order of $1x10^{-10}$ m/s, which is required by many regulatory agencies.

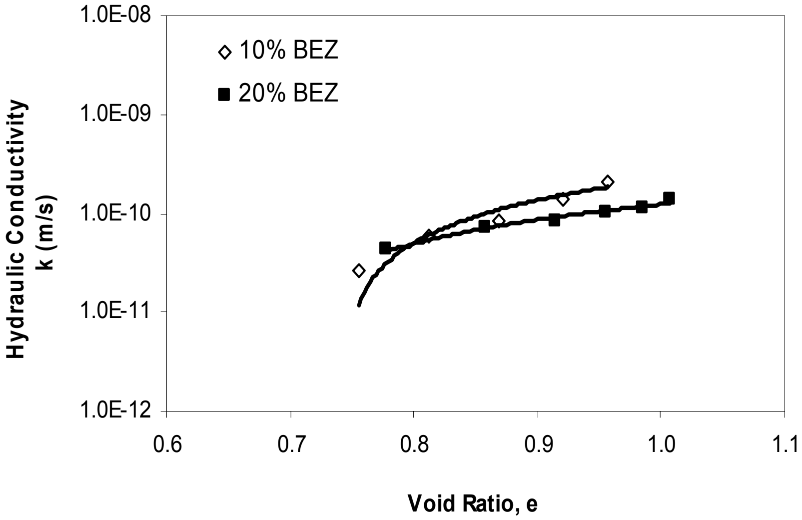


**Figure 5.** Hydraulic conductivity of BEZ with 10% and 20% bentonite as a function of void ratio.

The test results showed that the setting pressure did not affect the overall hydraulic conductivity of soils for any practical purposes, Figure 6. The reported hydraulic conductivities of BEZ are in good agreement with those reported by Tuncan et al., (2003) and Kayabali (1997) using triaxial permeameter. Although it shows variations with bentonite content, the reported hydraulic conductivities of BESs are in the order of $1x10^{-10}$ m/s (Chapuis, 2002). Based on obtained test results with 1-D consolidation apparatus and triaxial permeability apparatus, BEZ can be used as a liner material without further problems.

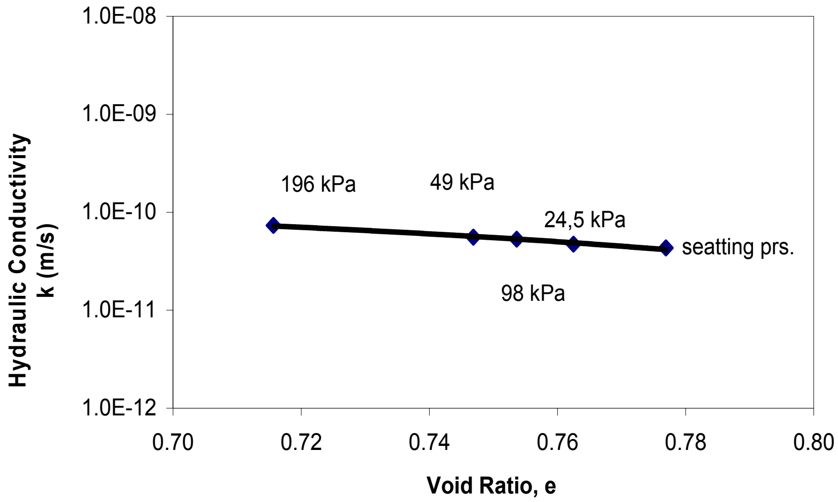


**Figure 6.** Variation of hydraulic conductivity with respect to void ratio of 20% BEZ samples for different initial seating pressures (after Kaya and Durukan, 2004)

*4.3.3.2 Compaction*

Compaction characteristics of Na-bentonite embedded Bigadic zeolite is presented in Figure 7 (Kaya and Durunkan, 2004) for 100% bentonite, 3% BEZ, 5% BEZ, 10 BEZ and 20% BEZ. Maximum dry unit weight varies from 1.2 g/cm$^3$ to 1.3 g/cm$^3$ and the corresponding optimum moisture content varies from 14% to 17%. Saturation lines were drawn by using specific gravity, Gs, of zeolite (2.39) and that of 20 % of BEZ mixture (2.45) to show the importance of saturation on compaction of the mixtures. An increase in the bentonite content increases the optimum moisture content, while it decreases the dry unit weight. The varying percentage of zeolite (3% to 100%) neither imparts a great variation in the maximum dry unit weight nor in the optimum moisture content. The compaction characteristics of BEZ could be improved by choosing a well graded soil. In this experiment, it was used uniform soil prepared with the zeolite grains passing #40 (0.475 mm). The high optimum moisture content and the low dry unit weight of BEZ are not obstacles for its use as a liner material as long as other engineering properties are meet the regulatory agency requirements.

Typical compaction characteristics of BES, at proportions 3%, 5%, 10% and 20% are presented in Figure 8. Dry maximum unit weight varies from 1.67 to 1.82 g/cm$^3$, and the corresponding optimum moisture content varies from 14 to 17%.

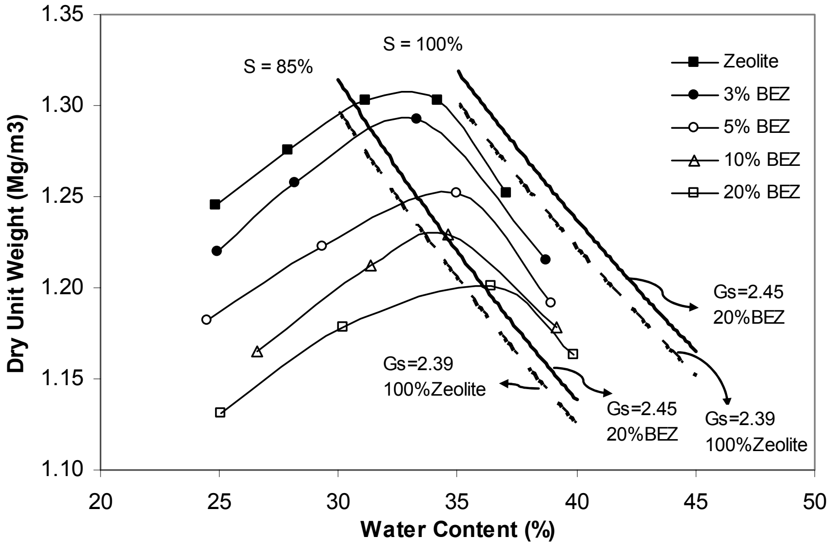


***Figure 7.*** *Comparison characteristics of bentonite embedded zeolite with various content of bentonite (Kaya and Durukan, 2004).*

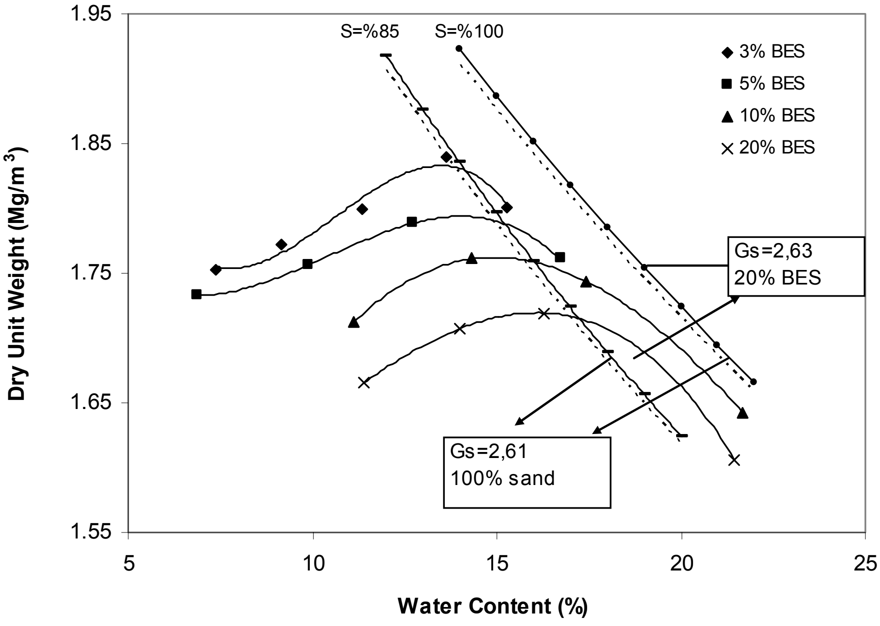


***Figure 8****. Compaction characteristics of bentonite embedded sand with various bentonite contents.*

Figure 9 shows the effect of compaction energy on BEZ with 10% bentonite. Note that as the compaction energy increases the optimum moisture content decreases whereas the dry unit of the mixture increases, similar to natural soils. For example, the optimum moisture content and the dry unit weight of BEZ with 10% bentonite is about 37%

and 1.25 g/cm$^3$ for modified compaction whereas they are 50% and 1.05 g/cm$^3$ for reduced standard compaction, respectively. The observed optimum moisture content and dry unit weight BEZ mixture are comparable with those reported by earlier results (Guney and Koyuncu, 2002; Kayabali, 1997).

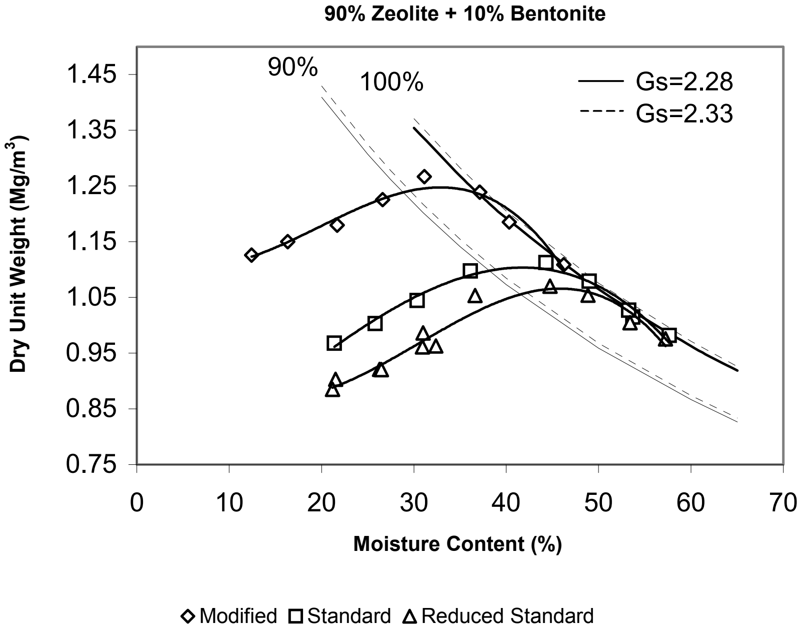


***Figure 9.*** *The effect of compaction energy of BEZ with 10%bentonite and 90% Gordes zeolite.*

The effect of the grain size is showed in Figure 10.

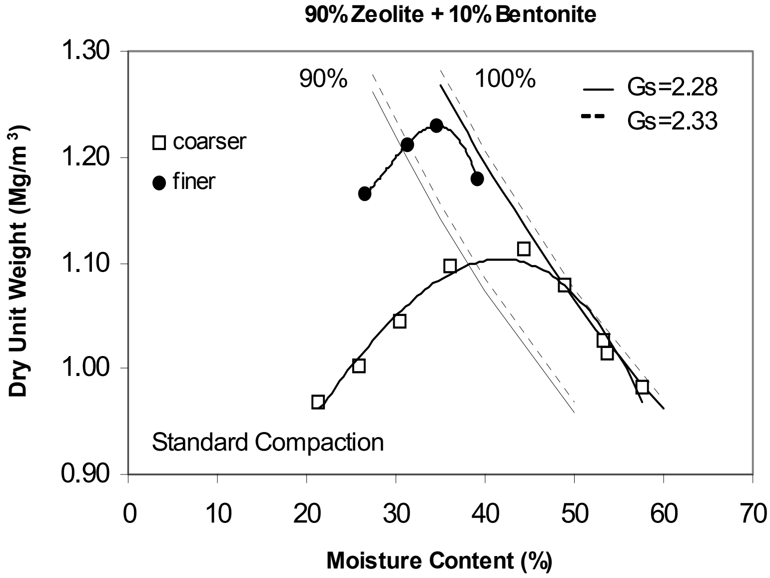


***Figure 10.*** *The effect of grain size on the compaction characteristics of BEZ.*

4.3.3.3 ***Volumetric Shrinkage***

Figure 11 compares the volumetric shrinkage and BEZ and BES. Note that BES shrinks more than BEZ at any given molding moisture content for both 10% and 20% bentonite content of the mixtures. Tay et al., (2001) indicated that volumetric shrinkage of compacted BES containing 10% and 20% bentonite are less than 4% of volumetric shrinkage criterion that set by Kleppe and Olson (1985). Figure 11 shows that the volumetric shrinkage of BEZ is far from 4% criterion and performs much better than BES. The practical implication of volumetric shrinkage results is that BEZ will not be affected from moisture content changes due to freezing/thawing cycles and groundwater level fluctuations. In other words, no serious cracks will develop in the structure of BEZ that will affect the overall performance of BEZ liner.

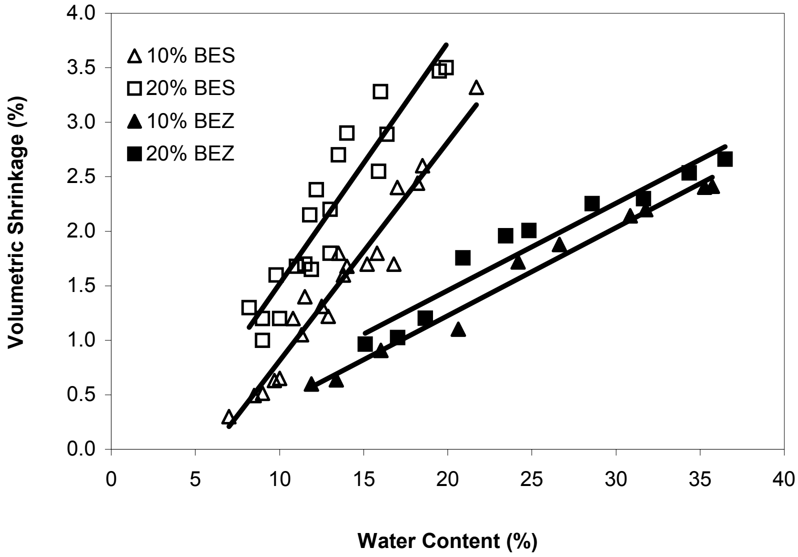


***Figure 11.*** *Comparison of volumetric shrinkage of BES (open signs) with those of BEZ (filled signs), (BES data from Kraus et al., 1997). Lines on the data show the linear regression lines.*

5- CONCLUSIONS

Based on the obtained laboratory test results the followings can be concluded:

1. The compaction characteristics of BEZ are different from those of BES. The optimum moisture content of BEZ is much higher than that of BES whereas the maximum dry density BEZ is lower than that of BES.
2. The compaction characteristics of BEZ also show variations with the grain size of zeolite. The optimum moisture content of BEZ with coarse zeolite particles is higher than that of BEZ with fine zeolite whereas the dry density of BEZ with coarse zeolite particles is lower than that of BEZ with fine zeolite particles.
3. Volumetric shrinkage of BEZ is significantly lower than that of BES. The low volumetric shrinkage indicates that BEZ will not be affected from moisture content fluctuations.
4. The hydraulic conductivity of BEZ in the order of $1x10^{-10}$ cm/s, which meets regulatory agency requirements.
5. From engineering point of view, BEZ is a good alternative candidate as landfill liner material.

6-ACKNOWLEDGMENTS

The engineering properties of zeolites tests were conducted by Seda Durukan and Ali Hakan Oren of Dokuz Eylul University, Izmir-Turkey

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