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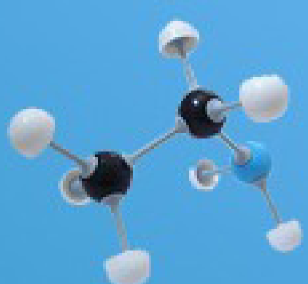

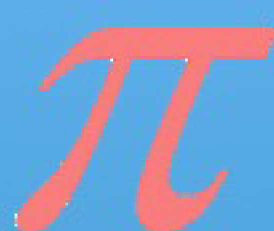

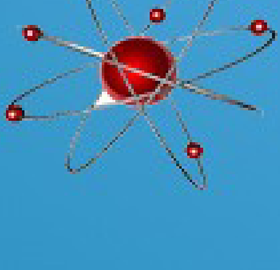

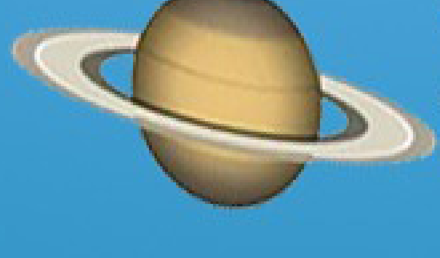

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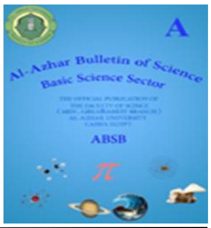

EFFECT OF ADDING LIME WASTE AND SODIUM CHLORIDE ON BENTONITE SWELLING BEHAVIOR AND INFILTRATION RATE

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ABSTRACT

Bentonite is artificial clayey soil that not only has the tendency to swell or increase in volume but also to shrink or decrease in volume due to variations in water content. In geotechnical engineering field, this soil causes severe damage to structures that are founded. The aim of this study is to investigate the effect of adding lime waste which is obtained from Abou Korkas sugarcane factory and sodium chloride on swelling properties of bentonite as a chemical stabilization process. In this regard, important techniques (SEM and EDX) were carried out to identify the mineralogy and microstructure variations before and after stabilization. Bentonite shows considerably different engineering behavior mainly depending on the mineralogical and chemical compositions. The results of the physical (geotechnical) tests indicated that lime waste and NaCl additives decreased the free swelling and increased the water infiltration of bentonite; the free swelling of the studied bentonite sample was 490% and free swelling for treated bentonite samples ranged between 250% and 370%, with an average of 297%. SEM and EDX analyses showed that all clay minerals are transformed to new flocculated cementitious compounds, such as calcium silicate hydrated (CSH) and calcium aluminate hydrated (CAH) so that bentonite texture is improved. The infiltration rate generally increases with either increase in salinity and electric conductivity; the values of infiltration rate were increased from 25 to 60 mm/h for the studied samples with an average value of 43.33 mm/h, due to reduction in clay content and a corresponding increase in the percentage of coarse particles. Utilization of solid wastes results in soil stabilization provides opportunity for cost savings in roadway construction, which will be of economic importance in developing countries.

Keywords: Bentonite, swelling, lime waste, chemical stabilization.

1. INTRODUCTION

Bentonite represents one of the problematic soils that face many geotechnical engineers in the field, the presence of montmorillonite clay in these soils imparts them high swell–shrink potentials **(Bell, 1988).** Montmorillonite is a type of clay minerals, this mineral is responsible for swell-shrink behavior of the soil; dry montmorillonite powder is major active constituent swells spontaneously when contacted with water **(Lew, 2010)**. The dry clay usually imbibes water and becomes a gel, and it can be stirred up with more water to yield a suspension. The variation in physical state from an anhydrous solid to a gel is called swelling **(Komine and Ogata, 1996).**

It well experienced that expansive bentonite have bad engineering properties and seriously considered to be problematic in geotechnical engineering, such soils have low strength and permeability **(Ismail and Ryden, 2014)**. Potentially expansive soils are being founded almost in many places in the world, in Egypt, are located at desert arid places outside the Nile valley like 6th of October City, Obour City, EL-Mokattem City, Badr City, EL-Shorok City, New Cairo City, Katamia City, Nasr City, El- Fayoum City, etc., these areas are surrounding with problematic expansive clayey soils which resulted in frequent notable damages to engineering structures. The differential movement caused by swell or dry of expansive soils can increase the probability of damage to foundation **(Zumrawi, 2015)**

In Egypt, a huge amount of buildings were built in regions encompassing problematic expansive soils, these soils were treated by using the soil replacement technique. It was observed that some of these buildings have some damages after the actual usage. These damages were identified as minor to major cracks in the structure members (Fig. 1). By studying these cases, it was clear that all cracks appeared in walls or concrete members were produced after using the buildings and consequently the leakage of water from any source, such as water and sewage pipelines, irrigation systems, and rains…. etc., and slowly percolated into the subsurface soil replacement material through any weak portion, and then reached to the underneath expansive soil **(Magdi *et al.*, 2017)**.

Fig. (1): Damage on a masonry wall due to soil swelling

1.1 Chemical Stabilization of Bentonite

Expansive soil is a highly expansive as it exhibits high swelling, shrinkage, compressibility and poor strength in contact with water, especially during rainy season leading to cracks in overlying road pavements **(Tilak *et al.*, 2014)**.

Bentonite stabilization is the modification of clay properties to improve one or more of their engineering properties by adding cementing material, or other chemical materials. The properties most often changed are salinity, pH, SiO_2 content, $CaCO_3$ content, SEM, EDX, swelling properties and infiltration rate.

Large areas of natural lands consist of soils with high clay contents which have low strengths and high swelling properties. This problem has an influence on construction of road and highway, if adequate support does not exist, the road will rapidly deteriorate. The solution to solve construction problems is by soil treatment with chemical additives; since the expansive soil has the same property of bentonite; bentonite was used as a substitute of the expansive soil.

1.2 Literature Review

The comprehensive review of literature showed that a considerable amount of work related to the improvement of characteristics of problematic swelling soil is done in the world as well as in Egypt by using industrial solid wastes as cement kiln dust and sodium chloride.

Hossain, (2001) had studied the effect of lime on engineering properties of swelling soil for use in road construction, the soil was stabilized with lime contents of 3%, 6%, 9%, 12% and 15%. Free swelling of the stabilized samples decreased with increasing lime content.

Al-Azzawi *et al.*, (2012) and Negi *et al.*, (2013) had investigated the effect of silica fume (up to 20%) on engineering properties of swelling soil; the results showed increase in unconfined compressive strength and reduction in free swelling from 50% to 7%.

Kolaventi *et al.*, (2016) studied the effect of sodium chloride (NaCl) and calcium chloride ($CaCl_2$) salts as stabilizing agents for expansive soil. They added various amounts of each salt to the soil and found that the properties of soil are improved by the addition of NaCl and $CaCl_2$ at 8%.

Elmashad, (2017) studied the effect of ammonium chloride and lime on consistency limit, infiltration rate and swelling properties of bentonite, the results showed that by increasing additives concentration to 20% the liquid limit and swelling properties of bentonite were decreased while water infiltration was increased and the reduction in swelling is proportional to water infiltration rate of bentonite.

Marwa, (2016) and Sally, (2017) had studied treatment of expansive soil and bentonite using sodium chloride and Phosphogypsum (PG); Phosphogypsum is waste products produced from phosphate fertilizer factories, the results showed reduction in swelling potential, liquid limit and increased the infiltration rate, NaCl has a greater effect on swelling than PG.

1.3 Objective

This research work aims at eliminating the expansive engineering behavior of some Egyptian highly swelling soils using low-cost industrial solid waste as well as using NaCl, modification the engineering behavior of the stabilized bentonite through studying the chemical, microstructural and physical properties of studied expansive soil. In addition to the utilization of lime waste solves the problem of environmental pollution.

In this study an effort is taken to analyze the properties of bentonite using lime waste and sodium chloride. Various amounts of lime waste (5%, 10%, 15% and 20%) with and without NaCl were added to study the effect of these stabilizing agents on the chemical, microstructural properties, swelling characteristics and infiltration rate of bentonite.

2. MATERIALS AND METHODS

2.1 Materials

In this study, bentonite beside two materials are selected, to enhance the properties of expansive bentonite (Fig. 2), the selection of additives based on improvement the properties of expansive bentonite, using cheap and available material and trying to reduce the waste disposal damage on the environment.

2.1.1 Bentonite (B): Bentonite is a typical problematic swelling soil which loses its strength in presence of water resultant in swelling of the soil and in the absence of water it shows many cracks due to shrinkage, it has a high percentage of clay mineral, which is mostly montmorillonite in structure and brownish yellow in colour.

2.1.2 Chemical admixtures:-

2.1.2.1 Sodium chloride salt (NaCl): Commercial sodium chloride salt white in color and in the form of crystals was used for this study; the used quantity of NaCl was 1% by dry weight of soil.

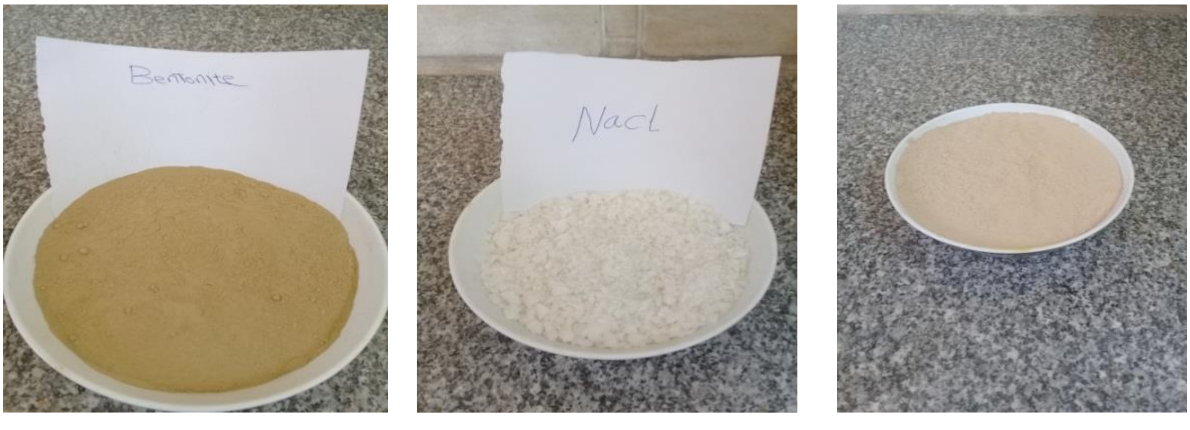
2.1.2.2 Lime waste (L.W.): Lime waste is solid waste material mostly composed of calcium carbonate**,** procured from Abou Korkas sugarcane mill that located in El Menia Governorate**.** In this study lime waste was mixed with bentonite in the different ratios (0, 5, 10, 15 & 20%) by weight of the dry bentonite; also (L.W.) was mixed with bentonite and (1% NaCl) in the same ratios. A chain of the laboratory tests were conducted on these samples. Chemical composition of (L.W.) was tested in laboratory and the main results are summarized in table (1).

2.1.3 Soaking Solution: Distilled water was used in all tests for mixing process.

2.2 Methods

2.2.1 Laboratory Tests

The experimental work was carried out in the laboratories of Construction Research Institute (CRI) of the National Water Research Center, Delta Barrage. The laboratory tests



Bentonite **NaCl Salt** **Lime waste**

Fig. (2): Views of materials used in the study included chemical, microstructural and engineering (physical) analysis, as shown in table (2) which represents the main testing program of this study.

2.2.2 Sample preparation for chemical, microstructural and engineering analysis

1. Bentonite is obtained and passing through sieve No.40 and a predetermined amount was weighed on a balance sensitive to 0.1gm and then placed in a mixing plates.

2. The weight of bentonite sample taken for test is replaced by percentage of weight of (L.W.) (5, 10, 15 & 20%) without NaCl in (group X).

3. The weight of bentonite sample is replaced by percentage of (L.W.) (5, 10, 15 & 20%) with 1% NaCl in (group Y).

4. After that (L.W.) and NaCl were initially mixed with distilled water making homogeneous reagent then bentonite is mixed with this solution, the mixed samples were closed and stored in a room for 24 hours before testing, then dried for 24 hours in oven at 70^0C and then the dry mixture was crushed and passed through No.40 sieve, samples then are ready for chemical and physical (engineering tests).

5. From the dried samples, small specimens with fractured surfaces were used for (SEM and EDX).

2.2.3 Laboratory Investigations on Chemical Analysis

The chemical analysis of materials and all mixtures were analyzed in the chemistry laboratory contribution with a chemist researcher. Chemical analyses are very important to determine the mechanism behind improvement process and also to know influence of various chemical parameters such as soil reaction (pH), electrical conductivity (EC), total dissolving solids (TDS), carbonates ($CaCO_3$) and silica content (SiO_2).

1) **Determination Of pH, EC and TDS**

The pH of the samples were determined using the method of **(Eades *et al.*, 1962)**, which involves mixing the solids with pure water

Table (1): Chemical Composition of Lime waste

Properties	TDS ppm	SiO_2 (%)	Fe_2O_3 (%)	Al_2O_3 (%)	$CaSO_4$ (%)	CaO (%)	$CaCO_3$ (%)	MgO (%)	L.O.I (%)
Element Content	2880	6	2.25	0.75	0	46	82	1.5	42

TDS: total dissolved salts, SiO_2: silica, Al_2O_3: aluminum oxide, Fe_2O_3: ferric oxide, CaO: calcium oxide, $CaCO_3$: calcium carbonate, MgO: magnesium oxide, $CaSO_3$: calcium sulfates, L.O.I: loss on ignition.

Table (2): Series of testing program (mix. scheme of bentonite and additives)

Group Name	Test Series	Samples (Mixtures Name)	Mixture of Materials			Experimental test type (Laboratory analysis)
			Bentonite clay %	Lime waste %	NaCl %	
control	B (Bentonite)	B	100	0	0	**(A) (Chemical Analysis)** 1. Soil Reaction (pH-value) 2.Total Dissolved Solids (TDS) 3. Oxides and $CaCO_3$ 4. Electrical Conductivity (EC) **(B) (Microstructural Analysis)** 1. Scanning Electron Microscopy (SEM) Test 2. Energy Dispersive X- ray Spectroscopy (EDX) Test **(C) Physical Properties Tests** 1. Free swelling (FS) 2. water infiltration rate test
X	BL (Bentonite + Lime waste)	BL5	95	5	0	
		BL10	90	10	0	
		BL15	85	15	0	
		BL20	80	20	0	
Y	BLNa (Bentonite + Lime waste + NaCl)	BLNa1	94	5	1	
		BLNa2	89	10	1	
		BLNa3	84	15	1	
		BLNa4	79	20	1	

(1solid : 5water), shaking samples, and then testing with a pH meter after 1 hour and after 24 hour.

The total dissolved solids test (TDS) is a measure of all dissolved solid particles in water or soil solution. TDS is measured in a laboratory and expressed in mg/L or ppm. 1 ppm indicates 1 milligram of dissolved solids per litter of solution. It is determined by means of an electrical conductivity meter (EC meter).

EC is a measure of the concentrations of dissolved ions in water, and is reported in micromhos per centimeter (µmhos/cm) or microsiemens per centimeter (µS/cm) **(Aboukila and Norton, 2017).**

1) Determination Of Silicon Dioxide and $CaCo_3$ Content

Determination of the oxides of main components for mixtures samples conducted chemical tests according to (**Egyptian Code, 2009).**

2.2.4 Laboratory Investigations on Microstructural Analysis

Scanning electron microscopy (SEM) test has been extensively used to study the morphology of bentonite, also SEM with energy dispersive x-ray spectrometer (EDX) has been used to identify the composition and nature of minerals after improvement. This test was carried out in laboratories of National Research Center (NRC); the test was performed according to **(Erica, 2013)**.

Table (3): Samples used for SEM/EDX analysis

Sample number	Proportions of mixtures
B	Control sample of pure bentonite
BLNa4	20 % L.W. + 1% NaCl + 79% Bentonite

2.2.5 Laboratory Investigations on Engineering Properties

To study the effect of different concentrations of mixtures on bentonite, a group of physical soil tests has been carried out. The tests plan to start with free swell for all samples and infiltration test for the best samples (B and BLNa4). The mixtures were analyzed in Soil Mechanics and Foundation Laboratory in the Construction Research Institute (CRI), National Water Research Center (NWRC).

1) Determination of Free Swell Test

The free swell test is one of the most commonly used simple tests in the field of geotechnical engineering for getting an estimate of soil expansion potential, it is very important property of bentonite and mixtures, the procedure of this test was carried as follows **(Egyptian Code Practice of Soil Mechanics /ECP 202/22001)**.

Fig. (3): Free swell test determination of samples

2) Determination of Bentonite Water Infiltration Rate

The most common method to measure the infiltration rate is by a field test using a cylinder or ring infiltrometer. In an attempt to correlate the swelling of clays to the rate of water infiltration, a new easy laboratory apparatus is presented. The idea is to measure the swelling and infiltration in one simple test ‘‘the swelling infiltrometer’’ **(Elmashad & Ata, 2016)**.

Fig. (4): Cylinder or ring infiltrometer

3. RESULTS AND DISCUSSION

Laboratory tests were conducted on samples prepared by adding different ratios of lime waste and sodium chloride to bentonite. Chemical and physical tests were done to investigate the effect of additives on bentonite properties. The test results are presented as following.

3.1 Bentonite Characterization

Physico-chemical properties of bentonite are shown in table (4), The total dissolved salts of the used bentonite are about 5600 parts per million (ppm), chlorides are about 855 (ppm) and no sulfates, from chemical analysis, the main mineralogical constituents of bentonite is silica (63%), free swelling is about 590%. The results of mineralogical composition are summarized in table (5).

3.2 Laboratory Test Results on Chemical Stabilization

3.2.1 Variations in TDS with the Addition of Chemical Admixtures

Total dissolved solids increases with addition of (L.W.). The increased soluble solid content with addition of (L.W.) and NaCl indicates that the amount of additives available for cementing actions. This gives a positive result, which shows in Figs. (5 & 6).

The practical reasons for the addition of lime waste to bentonite are to improve characteristics and reduce swelling by saturating the clay with Ca ions that in (L.W.) or with Na ions that in NaCl. However, the chemical interaction of (L.W.) and NaCl with clays must also be considered an important part of a permanent improvement due to the formation of cementitious materials which decreases the swelling of bentonite L.W./NaCl mixtures.

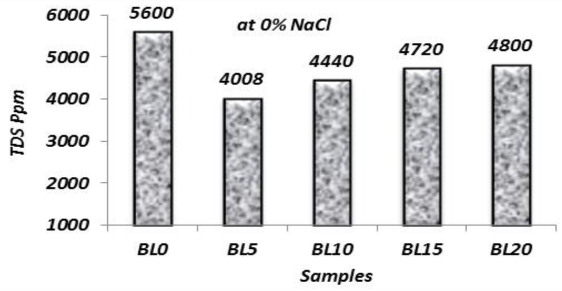


Fig. (5): Variations of bentonite TDS by addition of different ratios of L.W. (5, 10, 15& 20%) for group (X) mixtures

It was observed that the salinity of expansive bentonite decreases as the lime waste content increases in Fig. (5); Salinity of bentonite only was 5600 ppm when different ratios of lime waste were added salinity was decreased due to cation exchange and started to increase again to 4800 ppm.

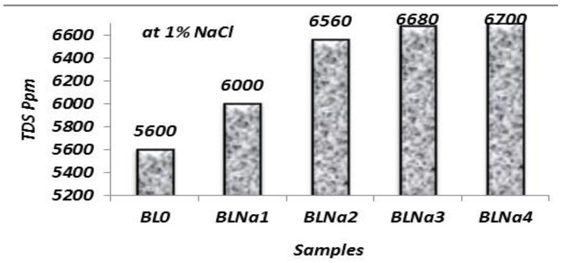


Fig. (6): Variations of bentonite TDS with lime waste + 1% NaCl for group (Y) mixtures

In Fig. (6) salinity increased as lime waste content increase and NaCl concentration was 1%. The reaction will be stronger in the case of high silicate content in the swelling clay.

By determination of silicate content

Table (4): Physico-Chemical analysis of bentonite

TDS ppm	Cl^- ppm	pH	O.M. %	SiO_2 (%)	R_2O_3 (%)	SO_3 (%)	CaO (%)	MgO (%)	L.O.I (%)	Free swelling (%)
5600	855	9.12	0	63	11.5	0	4	0.7	18	590

TDS: total dissolved salts, Cl^-: Chlorides content, pH: hydrogen ion concentration O.M.: organic matter, L.O.I: loss on ignition.

Table (5): Mineralogical analysis of Egyptian bentonite

Soil type	**clay mineral**		**Non clay mineral**
Bentonite	**Montmorillonite**	**Kaolinite**	**Quartz**
Percent	50%	37.5%	93.75%

(SiO_2%) as following in Figs. (7 and 8) found that; SiO_2% decreased with increase of lime waste content due to consumption of silica in pozzolanic reaction and formation of calcium and sodium silicate hydrated.

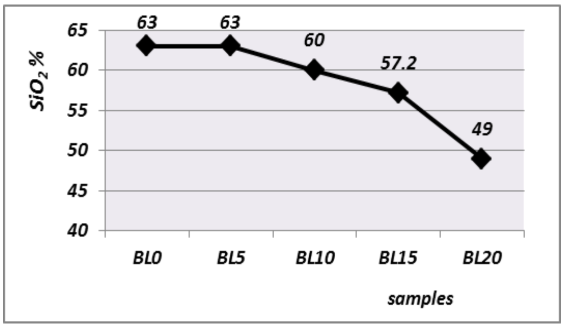


Fig. (7): Variations of SiO_2% by addition of different ratios of L.W. (5, 10, 15& 20%) for group (X) mixtures

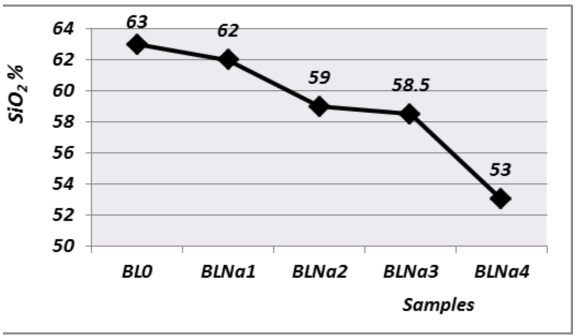


Fig. (8): Variations of bentonite SiO_2% with lime waste content + 1% NaCl for group (Y) mixtures

3.2.2 Effect of Chemical Admixtures on pH of Bentonite

The pH of bentonite is an indirect measure of clay reaction; pH is directly proportional to physical properties in alkaline state. In high pH environment the clay surface mineralogy is changed due to reaction with calcium and sodium ions to form cementitious products. The results of reaction mechanisms are reduction in moisture content and swelling and improved stability and the water infiltration rate.

Variations of pH of the lime waste and sodium chloride stabilized expansive bentonite with a curing period (1h and 24h), is shown in the following Figures.

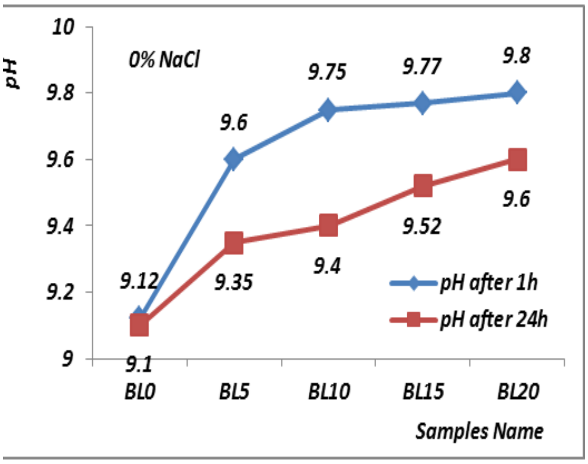


Fig. (9): Variation of bentonite pH with addition of lime waste in different ratios (5, 10, 15 & 20 %) for 1h and 1day curing

The immediate effect (after one hour) of mixing (L.W.) on soil pH value is presented in Fig. (9); the pH of bentonite was increased from 9.12 to 9.6 in mix BL5, 9.75 in BL10, 9.77 in BL15 and 9.8 in BL20.

The highly alkaline environment produced by the addition of lime waste causes dissolution of silica and alumina of the clay minerals and combination with the calcium produce new cementitious compounds (CSH and CAH). So that soil texture improved, the strength increased; swell characteristics reduced (**Zaman *et al*., 1992**).The variations are shown in Figs. (9 and 10).

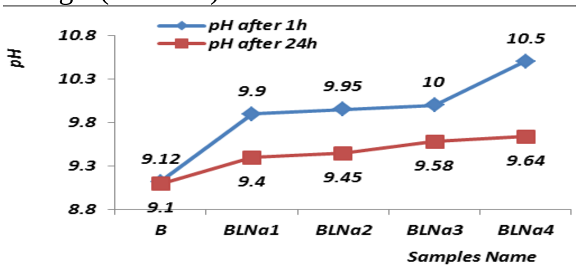


Fig. (10): Variation of bentonite pH by addition of different ratios of (LS & 1% NaCl)

Fig. (10) shows the effect of curing time on pH value of treated bentonite; when (L.W.) and 1% NaCl was mixed with bentonite, the pH of the bentonite was increased from 9.12 to 9.9 in mix BLNa1, 9.95 in BLNa2, 10 in BLNa3 and 10.5 in BLNa4. pH value gradually reduced with increasing curing times.

NaCl react with the $Ca(OH)_2$ in (L.W.) at early ages to reduce its content forming NaOH, which can raise the alkalinity that help the Si-O and Al-O bonds to break, pH decreased with time for the treated bentonite due to more production of calcium silicate hydrated (CSH) gel or calcium aluminate hydrated (CAH) as a result from pozzolanic reactions.

3.2.3 Variations in Calcium Carbonate Content

Calcium carbonate acts as a binding material, it increases with the increase in lime waste content due to carbonation reaction as showed in table (6). This content may vary with respect to time since cementation process is a long time chemical reaction; by increase curing time increase the cementation of clays.

Table (6): Variation of calcium carbonate content with the addition of lime waste for groups (X & Y) mixtures

Group Name	Mixtures	$CaCO_3$ %
control	B	7
X	BL5	13
	BL10	14
	BL15	17
	BL20	32
Y	BLNa1	1
	BLNa2	7
	BLNa3	8
	BLNa4	21

3.3 Effect of Chemical Admixtures on Microstructural Properties

Microstructure analysis refers to the size, shape and arrangement of soil aggregates and pores. The EDX spectra obtained at different points of interests on the test samples to obtain the elemental composition.

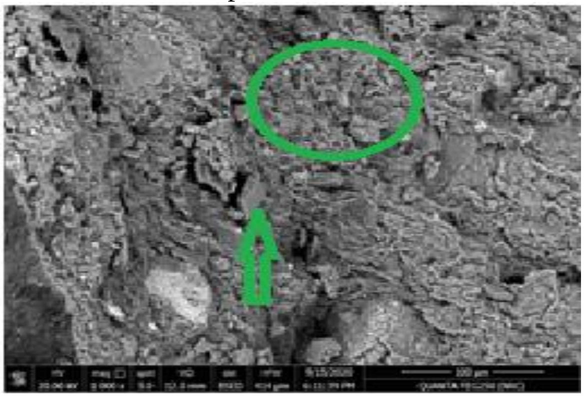


Fig. (11): SEM micrograph of bentonite

The results of SEM analysis of bentonite showed that the shape of bentonite is rough surface contains small porous. The texture consists of many sheet-like particles. Bentonite seems to be covered by homogenous layers, Fig. (11) showed that the main clay mineral in bentonite is montmorillonite.

The EDX results of bentonite showed the concentration of elements present in bentonite. EDX results indicated presence of Si, Al, Mg, Fe, Ca and K elements. The greatest dominant peak in line spectrum is for oxygen then silicon followed by aluminum. The results indicated the presence of montmorillonite series for bentonite.

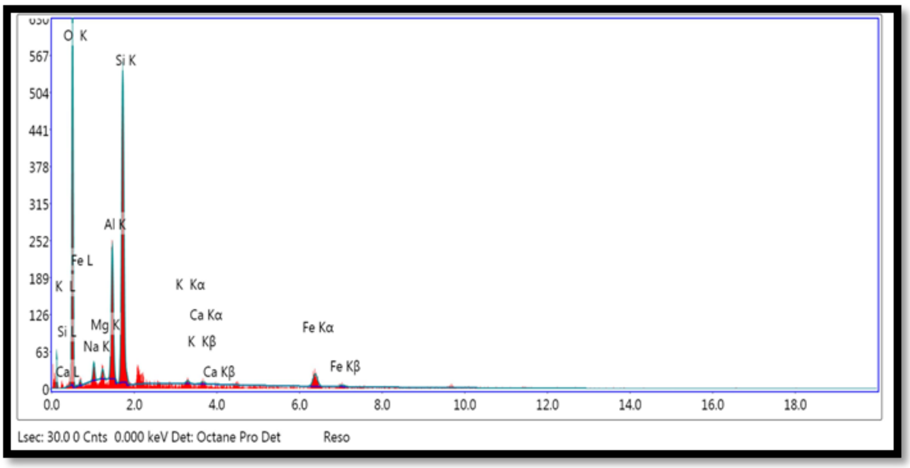


Fig. (12): Bentonite EDX diagram before stabilization

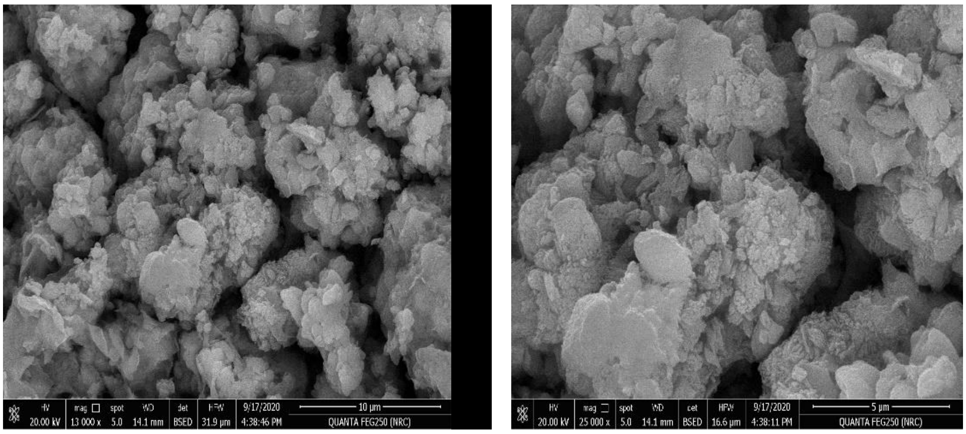
The results of quantitative analysis of bentonite clay particles are shown in table (7). Element content % depends on atomic mass but atomic weight % depends on numbers of atoms.

Table (7): Quantitative chemical composition of bentonite clay

Element	Element content by EXD %	Atomic weight %	Formula
Quantitative Data for Fig. (12)			
O	51.28	65.74	SiO_2
Na	3.44	3.07	Na_2O
Mg	1.25	1.05	MgO
Al	10.9	8.29	Al_2O_3
Si	26.29	19.2	SiO_2
K	0.43	0.23	K_2O
Ca	0.47	0.24	CaO
Fe	5.94	2.18	Fe_2O_3
Totals	100	100.00	

SEM analysis done for the tested sample BLNa4 (20% L.W.+1% NaCl) showed that there was improvement of soil structure morphology. The micrograph showed that small pores of bentonite are transformed into large pores of aggregates, and it showed crumbs of floccules with porous nature and cementitious compounds, calcium silicate hydrated (CSH) and calcium aluminum hydrated (CAH) are coating and joined the clay particles in stable aggregates. The cementation contributed to the strong inter-particles bonds that can offer greater strength of the stabilized soil **(Wong *et al.*, 2013).** This aggregation leads to improvement in infiltration rate and free swelling of expansive clays.

EDX test on treated bentonite has been presented in micrograph illustrated in Fig. (14). EDX results showed variation in Si, Al and Ca elements peaks than bentonite EDX that showed in Fig. (13), due to consumption of silica and aluminum in hydration reaction and formation of cementitious compounds, which has a more complex crystalline structure**.**



(a) at magnification factor=13000 **(b) at magnification factor=25000**

Fig. (13): SEM micrographs of BLNa4 mixture

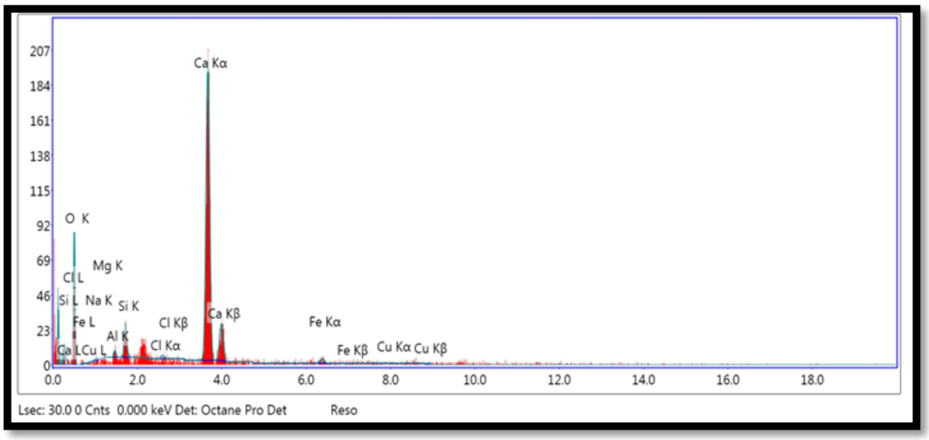


Fig. (14): bentonite EDX Diagram after stabilization

The formed cementitious compounds (as a result of the chemical reactions between silica and alumina and the additives) reduced the volume of the void spaces and joined the soil particles (**Ismael, 2006).** Hydration reaction equations are given as following equations:

$$Ca^{2+} + 2OH^{-} + SiO_2 \rightarrow CSH \quad \text{Calcium silicate hydrated (1)}$$
(Silica) (Gel)

$$Ca^{2+} + 2OH^{-} + Al_2O_3 \rightarrow CAH \quad \text{Calcium aluminum hydrated (2)}$$
(Alumina) (Fibrous)

The quantitative data presented in table (8) showed variation in Si, Al and Ca atomic weight ratios in the treated bentonite. Calcium was observed to be the most dominant element that enters in hydration reaction, followed by oxygen. Other elements included sodium, iron; cupper, magnesium, and potassium were also found.

Table (8): Quantitative chemical composition of treated bentonite

Element	Element content by EXD %	Atomic weight %	Formula
Quantitative Data for Fig. (14)			
O	49.01	70.12	SiO_2
Na	0.64	0.63	Na_2O
Mg	0.46	0.43	MgO
Al	0.57	0.49	Al_2O_3
Si	2.38	1.94	SiO_2
Cl	0.29	0.19	NaCl
Ca	44.14	25.21	CaO
Fe	1.66	0.68	Fe_2O_3
Cu	0.86	0.31	CuO
Totals	100	100.00	

3.4 Effect of Chemical Admixtures on Physical Properties

The reaction of (L.W.) and NaCl with bentonite can be described as a chain of chemical reactions. The results of some of these reactions are expressed as a change in the free swell and water infiltration rate of bentonite.

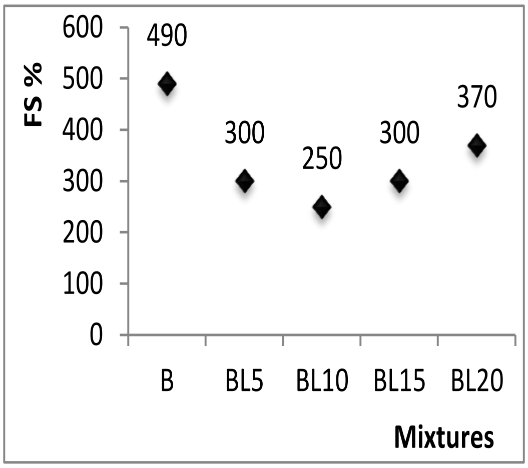
3.4.1 Variation in Bentonite Swelling Properties

The free swell test (FS) results of bentonite clay are given in Fig. (15). The applications of (L.W.) alone or (L.W.) with NaCl resulted in reduction in the free swell of this soil.

It is observed that for all additives used in the tests, the free swelling generally decreased when the additive content increased this reduction in free swelling explained due to change in pH, TDS, carbonate content and hydration reaction.

3.4.2 Effect of Additives on Bentonite Infiltration Rate

Infiltration rate is an important variable for understanding of bentonite properties. Due to the longtime used for infiltration test, only three carefully selected samples were analyzed, the control specimen of pure bentonite only and two of the samples which showed the most marked changes in free swelling [(bentonite + 20% binder (lime waste) and (bentonite + 20% lime waste + 1% NaCl)].



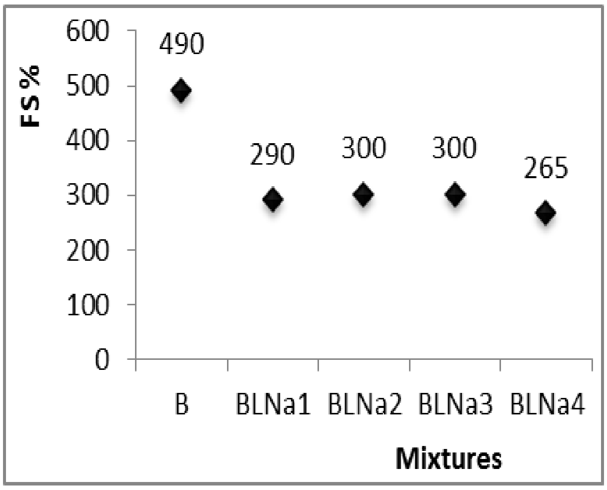


Fig. (15): Effect of additives on free swelling of bentonite

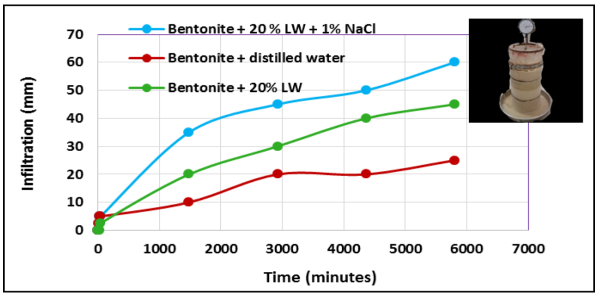


Fig. (16): Infiltration rate analysis curve for selected samples

The graphical plot of infiltration rate vs. time showed that the infiltration rate after 5805 min (96 h) of measurement of bentonite and bentonite mixtures, the final infiltration rates were in the range of (25 - 60 mm/h) for the studied samples with an average value of 43.33 mm/h (fig. 16). Increase in infiltration rate due to decrease in clay content and a corresponding increase in the percentage of coarse particles and this is accepted with the results of the SEM/EDX tests.

The electric conductivity (EC) of water chemistry significantly affects the infiltration rate of the soils; the infiltration rate generally increases with increasing in electric conductivity. The electric conductivity of applied additives solutions (EC) significantly affects the infiltration rate of bentonite as following Fig..

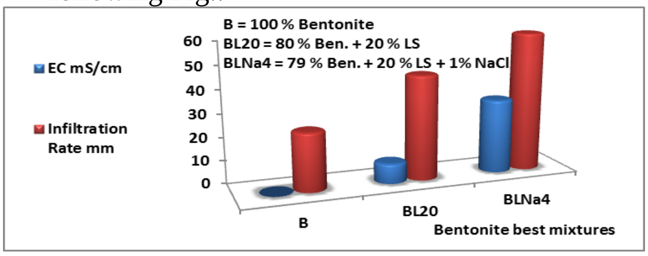


Fig. (17): Relationship between additives (EC) and bentonite infiltration rate

By determining (EC) under laboratory conditions we concluded that the electrical conductivity of distilled water and lime waste with salt solutions significantly affects the infiltration rate of the bentonite; the (EC) value of added solutions varied from 8.550 to 32.000 ms/cm with an average value of 20.28 ms/cm.

Bentonite changed from highly swelled material to aggregates in high salinity and electric conductivity leading to increase infiltration and decrease swelling of clays containing high ratios of montmorillonite mineral. Due to aggregates formation the movement of water into stabilized bentonite become easy leading to decrease in moisture content and enhance engineering properties.

4. CONCLUSION

Based on the above laboratory investigation conducted on bentonite, lime waste and sodium chloride mixtures, the following conclusions can be drawn.

1. One of the unique physical properties of montmorillonite is that it exhibits hydrophilic properties and swells with water.
2. The first increase in TDS and SiO_2 content with the increase in the additives contents is recognized to the possible formation of some hydration products, after that, the consumption of cations for pozzolanic reaction is the reason for the decrease of TDS and SiO_2 content, thereby reduction of pH after 24h with pH still higher than (7) indicates usually a good reactivity to L.W./NaCl treatment.
3. The free swelling of bentonite is reduced with the increase of lime waste concentrations.
4. The free swelling of bentonite is reduced dramatically with, the increase in lime waste content activated by NaCl.
5. The infiltration rate increased with either increase in salinity or electric conductivity.
6. Adding the chemical additives to the bentonite is considered an effective way to solve the problems of water infiltration and expansion of bentonite.
7. NaCl allows forming ionic bonds with bentonite molecules, reaction products decrease the repulsive forces between the clay particles forming cementitious or binding particles resulting in reducing free swelling.
8. The SEM photographs observations agreed well with results from chemical and geotechnical analysis.
9. Lime waste and NaCl have a potential to modify the engineering behavior of bentonite clay and to make it suitable for many of the geotechnical applications.
10. Utilization of solid wastes results in soil stabilization provides opportunity for cost savings in roadway construction, which will be

of economic importance in developing countries.

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5. REFERENCES

[1] Aboukila, E. F., & Norton, J. B., (2017). Estimation of saturated soil paste salinity from soil-water extracts. Journal of soil science. Vol. 182, No.3, Pp.107-113.

[2] Al-Azzawi, A., Khalida, A., Daud, Muhammed, A., & Abdul, S., (2012). Effect of silica fume addition on the behavior of silty-clayey soils. Journal of engineering and development, Vol. 16, No.1. Pp.92-105.

[3] Bell, F. G., (1988). Stabilization and treatment of clay soils with lime, part 1of basic principles. International journal of ground engineering. Vol.21, No.1, Pp.10-15.

[4] Eades, J. L., Nicholas, F. P., & Grim, R. E., (1962). Formation of new minerals with lime stabilization as proven by field experiments in Virginia. Highway research board, bulletin, Vol.26. No. 335, Pp. 31-39.

[5] Egyptian Code Practice of Soil Mechanics (ECP): Part 2, (2001). Standard test method for free swell test. Vol. 202, Pp. 142-152.

[6] Egyptian Code of Soil Mechanics and Foundation Design and Construction (EC/Part 202/2-2001), (2009). Laboratory tests. National Center for Housing and Construction Research. Cairo. Egypt.

[7] Elmashad, M., & Ata, A., (2016). Effect of seawater on consistency, infiltration rate and swelling characteristics of Montmorillonite clay. Journal of Housing and Building National Research Center, Vol. 12, Pp. 175 -180.

[8] Elmashad, M. A., (2017). Effect of chemical additives on consistency, infiltration rate and swelling characteristics of bentonite. National water research center journal. No.13, Pp. 177-188.

[9] Erica, V., (2013). Scanning electron microscope image as a mean to determine dispersibility. M.Sc. thesis. Department of civil engineering. Lowa State University. Ames, Lowa.

[10] Hossain, M. A. (2001). Geotechnical behaviour of a lime treated expansive soil. M.Sc. thesis, Department of civil engineering, Dhaka, Bangladesh.

[11] Ismael, A., (2006). Treatment and improvement of the geotechnical properties of soft fine-grained soils using chemical stabilization. Ph.D. thesis. Department of geotechnical engineering. Halle Wittenberg University. Germany.

[12] Ismail, A., & Ryden, N., (2014). The quality control of engineering properties for stabilizing silty Nile Delta clay soil, Egypt. Journal of geotechnical engineering. Vol.32, No.9, Pp.773-781.

[13] Kolaventi, S.S., Venigalla, S.G., & Rakesh, D., (2016). Stabilization of black cotton soil using salts and their comparative analysis. International journal of engineering development and research, Vol. 4, No. 2, Pp.797-800

[14] Komine, H., & Ogata, N., (1996). Prediction for swelling characteristics of compacted bentonite. Canadian geotechnical journal. Vol.33, No.1, Pp.11-22.

[15] Lew, B., (2010). Structure damage due to expansive soils: A case study. Journal of environmental geotechnical engineering. Vol.15, No.12, Pp.1317-1324.

[16] Magdi, M., Asmi, O., Abdelmarouf, Abubakr, E., Gameil & Zumrawi, (2017). Damages of buildings on expansive soils, diagnosis and avoidance. International journal of scientific emerging research. Vol.6, No.2, Pp.108-116.

17] Marwa, H. S., (2016). Improvement of swelling soil for constructions by industrial chemical wastes. M.Sc. thesis in applied chemistry. Department of environmental basic science. Ain Shams University, Cairo, Egypt.

18] Negi, C., Yadav, R.K. & Singhai, A.K., (2013). Effect of silica fume on index properties of black cotton soil. International journal of scientific and engineering research. Vol.4, No.8, Pp.828-832.

[19] Sally, M.A., (2017). Treatment of swelling soil using salt and phosphogypsum. M.Sc. thesis. Department of civil engineering. Ain shams university. Cairo, Egypt.

[20] Tilak, B., Dutt, R.K., & Mohanty. B., (2014). Engineering properties of bentonite modified with lime and gypsum. Jordan journal of civil engineering. Vol.8, No.2, Pp.39-45.

[21] Wong, L.S., Hashim, R., & Ali, F. (2013). Improved strength and reduced permeability of stabilized peat focus on application of Kaolin as a pozzolanic additive. Construction and building materials journal, Vol.40, Pp.783-792.

[22] Zaman, M., Laguros, J.G., & Sayah, A., (1992). Soil stabilization using cement kiln dust. Proceeding of the 7th international conference on expansive soils, Dallas, USA, Pp. 347-351.

[23] Zumrawi, M. E., (2015). Construction Problems of light structures founded on expansive soils in Sudan. Vol.4, No.8, Pp.896-902.

تأثير إضافة مخلفات الجير وكلوريد الصوديوم على خصائص إنتفاش ومعدل تسريب البنتونايت

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الملخص العربى

يعتبر البنتونات نوع من أنواع المواد الطينية التى تنتفش عند خلطها بالماء حيث يتكون بشكل أساسي من مجموعة من المعادن الطينية الإنتفاشية وأهمها معدن المونتموريلونايت حيث أن التربة التى تحتوى على نسبة عالية من معدن المونتموريلونايت لا يصلح التاسيس عليها بسبب انتفاشها المرتفع . يهدف هذا البحث إلى دراسة تأثير إضافة بعض المواد الكيميائية مثل مخلفات الجير التى نحصل عليها من مصنع سكر أبوقرقاص بمحافظة المنيا وملح كلوريد الصوديوم على خصائص البنتونايت الإنتفاشية كعملية تثبيت كيميائى للبنتونايت حتى يصلح للأغراض الهندسية, وخاصة عندما ظهرت الحاجة إلى تحسين خواص هذه التربة وبأقل تكلفة ممكنة. ولدراسة تأثير مخلف الجير وملح كلوريد الصوديوم على خصائص البنتونايت فقد تم خلط البنتونايت معهما فى مجموعتين (X & Y) المجموعة الأولى (X) هى تربة البنتونايت مع نسب صغيرة من مخلف الجير وهى (5، 10، 15و 20%) بدون ملح كلوريد الصوديوم والمجموعة الثانية (Y) وهى أربعة نسب مختلفه من مخلف الجير (5، 10، 15 و20%) مع نسبه صغيرة ثابته من كلوريد الصوديوم (1%). في هذه الدراسه تم إجراء الإختبارات الكيميائية وإستخدام تقنيات عالية مثل التصوير الإلكتروني للتعرف علي تركيزات بعض العناصر وأيضاً التركيب النسيجي الدقيق الداخلي للخلطات قبل وبعد المعالجه بالإضافه إلي الإختبارات الهندسية مثل إختبار الإنتفاش الحر ومعدل تسريب المياه فى البنتونايت. ومن خلال هذه الدراسة تم التوصل إلى أن إضافة مخلفات الجير مع زيادة نسبتها في التربة تؤدي إلى حدوث سلسلة من التفاعلات الكيميائية بين البنتونايت ومحلول من المواد المضافة وأهم هذه التفاعلات هو تجمع الحبيبات, التفاعل البوزولاني والتكربن , ينتج عنها عدة أنواع من الأملاح التي بدورها تعمل على زيادة عملية تثبيت خصائص البنتونايت, حيث يعتبر الجير مصدراً للكالسيوم الذى يربط الجزيئات معاً مما يعطى ثباتاً للتربة. كما أن البنتونايت حساس جدًا للكلوريدات والأملاح الذائبة ويحدث تجمع للجزيئات عند تعرضه للبيئات المالحة. ايضاً تحليلات التصوير الالكتروني بعد المعالجه أظهرت أن معظم معادن البنتونايت المسببة للإنتفاش قد تحولت إلي مركبات ذات خصائص أسمنتيه مثل سليكات الكالسيوم وألومينات الكالسيوم المتهدرته وهى مركبات ذات تركيب بللورى أكثر تعقيدا وأكثر ثباتاً. كما أظهرت الدراسة أن المخلفات الصناعية ومع زيادة تركيزاتها في التربة تعمل على رفع قاعدية التربة إلى الدرجة المطلوبة لتثبيتها وتقلل من خاصية إنتفاش البنتونايت. كما لوحظ بأن مخلفات الجير بتركيزاتها المختلفة مع كلوريد الصوديوم لها تأثير أفضل من إستخدام مخلفات الجير بدون الملح فى خفض نسبة الإنتفاش وزيادة معدل تسريب الماء داخل البنتونايت, وأن نسبة الإنتفاش تتناسب عكسياً مع معدل التسريب. وبهذا يمكن استخدام مخلفات الجيرمع كلوريد الصوديوم فى تحسين التربة وحماية البيئه من هذه الملوثات.