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Civil Engineering Journal

Vol. 2, No. 11, November, 2016

Analytical and Laboratory Evaluation of the Solubility of Gypsiferous Soils

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Received 10 October 2016; Accepted 28 November 2016

Abstract

Gypsum soil is one of the problematic soils because of considerable solubility for Gypsum particles in contact with water. In this research the effects of three factors including; gypsum percent, hydraulic gradient and soil texture were studied on solubility of gypsum soils. To do this, samples of gypsum soils were provided artificially by adding various rates of natural gypsum rock including 0, 5, 10, 20 and 30 percent weight of 3 kinds of soil textures including clay, silty clay and sand. Totally, 15 types of gypsum soils were prepared. Then each of gypsum soils were leached under five hydraulic gradients levels 0.5, 1, 2, 5 and 10. The results of the test indicated that the rate of Gypsum in the soil had direct effect on the rate of soluble and by increasing the percent of Gypsum, the rate of solubility was increased. In addition, by increasing hydraulic gradient, the speed of water existing soil media in a specified time was increased and also higher rate of Gypsum was derived. Also the soil texture has a considerable effect on the rate of solubility of soil. In this study, rate of solubility of gypsum soils with sandy soils was determined as 1.5 to 2 times more than the rate of clay soils. The statistical results show the highest impact of gypsum percentage and lowest impact of hydraulic gradient soil on solubility of particles in different types of soils and it has no significant effect on the overall equation of the soil texture.

Keywords: Gypsum soil; Hydraulic Gradient; Solubility Speed; Statistical Analysis.

1. Introduction

Gypseous soils are found in arid and semi-arid areas. These soils are developed in vast areas of Asia such as Iran, Syria, Iraq, China, Uzbekistan and Kazakhstan. The increase of population and the necessity of execution of development plans have led to the development of Gypsum soil operation in recent years. Some of these plans are irrigation, conveyance canals and pipes, Roads and Highways, Railway, Airport bands; Establish Industrial cities and oil and gas fields, etc. The Gypsum soil is extended in most areas of Iran such as; Khozestan, Khorasan, Yazd, Isfahan, Ilam, Zanjan, Sistan etc. and it is of great importance because of the arid and semi-arid climate. Mahmoodi et al. [9] reported that the Gypsum soils of Iran are 28 million hectare, about 17 percent of all Iran fields. Based on a report of FAO, the Gypsum soil of Ilam with the same common border with Iraq are 14600 hectare and semi Gypsum soils are 629960 hectare. In this area, the construction of water structures on Gypsum soils is unavoidable and it is necessary to do some actions for safety and stability of the structures. For example, the path of main canal in Konjancham irrigation network is on Gypsum soils where the path of canals is changed and it is a costly alternative. So in most cases, Gypsum crystals with their special physicochemical properties are effective on some characteristics of soils such as strength, settlement, compaction, Atterberg limits, particle size, etc. In recent decades, the destruction of structures on Gypsum soil creates some problems namely in gypsum soil area. Based on the reports, various structures are destroyed

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all around the world due to gypsum and great financial and human costs [13]. For the first time, the problems of the structures founded on Gypsiferous soils were reported in Spain in 1927 in Spain as in many sections, the upper structure was settled and in some cases it led into to destruction or changing the form of canal lining. Breaking the dam of San Francis in California, America in March 1928 led into the death of many people [15]. This event was due to soluble materials in the dam bed. High seepage rate of water in Oklahoma and new Mexico dams in America, create some tunnels because of piping in Maximilian dam, settlement in the dam of Birrs near Basel, destruction and damage of Sahlabieh canals in the bank of Forat river in Syria, create continuous holes in canals in Ebro river of Madrid, Spain are the most important events due to the presence of Gypsum soil in their foundation [13]. Another dam that was confronted with some problems because of Gypsum soil is dam of Mosel in Iraq [17].The problems in Hydraulic structures due to Gypsum soil in Iran date back to a long time ago. Destruction and damage of main canal in Nekoabad and Mahyar projects in Zayande Rood of Isfahan is one of the best examples of canal damage due to Gypsum soil [1]. Another example of canal damage due to Gypsiferous soil is the main canal (canal A) of Bebahan network in Khozestan. In some sections of this canal being built on Gypsiferous soil due to seepage of water into canal bed and solution, large holes are created and finally concrete lining is destroyed [3].

Total destroying of the channel and channel scour in SiminDasht to Garmsar path due to the fractures caused by cracks in the concrete canal bed, vertical and horizontal cracks and water penetration the dam of Gheysragh in Tabriz, severe cracking and water leading from underground water of Hengam Island in Persian Gulf are other cases of the effect of Gypsum on soil [12, 16]. Thus, it is necessary to carry out exact studies and researches on the damage of structures. In recent decades, some studies have been done about the identification of Gypsiferous soils and the relevant solutions. Yghmaeean and Givi [18] examined and compared the various methods of Gypsum measurement in soils of Isfahan. They stated that the main factor of difference in precision of methods was the type gypsum extract and among the existing extracts, Sodium Carbonate method was the most efficient method. Fauzia et al. [5] reported that the strength of soil was decreased because of derivation of Gypsum from the soil due to leaching. In another research in technology university of Baghdad on Gypsiferous soil samples, it was found that artificial samples of soil had high strength in dry mode, because the cement- Gypsum effect had high strength and after derivation of Gypsum this rate was decreased considerably. Hashemi et al. [6] investigated the relationship between clay minerals and different soil moisture regimes in gypsiferous soils of Fars Province in southern Iran. the results of soil and rock samples analyses showed that some palygorskite in all moisture regimes originated from parent materials and the smectite/(illite+chlorite) ratio increased with increase in moisture and the largest value (equal to 2.12) was observed in soils with xeric moisture regime. Abedi Kopai and et al. [2] investigated the effect of Micro Silica, Pumice and Perlite on Mechanical Properties of Gysiferous Soils and showed that silica had the most effect on shear, bearing and condensation parameters and Atterberg limits of Gypsiferous soil, and it improved these parameters of soil. Pumice improved shear, bearing and condensation properties of gypsiferous soil. Perlite reduced the shear, bearing and condensation properties of gypsiferous soil. Rahimi and Musavi jahromi [14] presented that the adding of 5 percent polyurethane mastic could improve the shear strength parameter of gypsiferous soil considerably.

Moutaz et al. [8] and Kifae [10] had performed some tests on the effect of leaching period on shear strength parameters and CBR in a clay-sand Gypsiferous soil using SC classification with 63% gypsum content and found that shear strength and CBR were decreased by increasing leaching period. Kargar [7] studied the effect of Gypsum on some physical characteristics of clay soil and found that existence of Gypsum decreased the liquid limit and plastic index. Nejadhashemi et al. [11] reported that permeability of Gypsiferous soil was different based on soil texture and the form of crystals and during leaching they had ascending, descending or constant forms. Also, permeability coefficients changes in Gypsiferous soil in primary stages are high because of particles move and Gypsum leaching, but it decreases gradually and finally it reaches a constant rate. Despite an extended area of Gypsiferous soils in Iran, there are not various studies on geotechnical properties and the presence of gypsum in water structures in Iran and this study attempts to have an analytic and laboratory evaluation of soil solubility with various textures..

2. Material and Methods

2.1. Soil Sample Preparation

The soil samples of the present study were provided from various areas of Ilam province (Iran). Based on field visits and the relevant problems in projects of Badreh and Mehran towns due to gypsum soil, some samples were provided from 10 regions and after preliminary tests, three soil samples were selected with clay texture (CH) from Salehabad in Mehran, Silty soil (CL) from Ilam and sand soil (SM) from Darreh shahr .

The Gypsum rock was added to natural soil samples after being crushed in various sizes and the Gypsiferous soil with the given percent was provided. Before being mixed with gypsum rock, the soil samples were tested for physical and chemical properties including: grain size distribution, Atterberg limit, compaction and chemical analysis (determine important Anions and cations, PH and EC). Gradation curve of soil and Gypsum for providing Gypsiferous soil samples are shown in Figure 1. and physical and chemical properties of soils are shown in Tables 1. , 2.

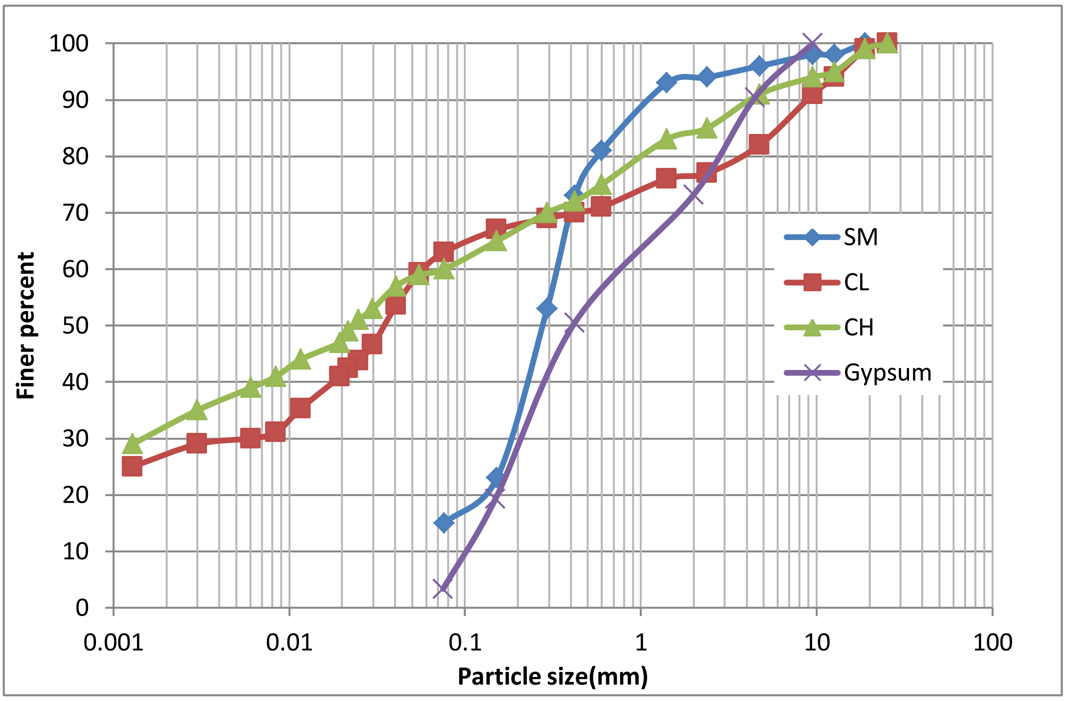


Figure 1. Gradation curves of the studied samples

Table 1. Physical charactistices of studied soils

Classification (unified)	Atterberg limits		Compaction (standard practor test)		Texture (%)			Sampling Location
	Plastic limit	Liquid limit	Maximum dry density (gr/cm^3)	Optimum water content	Sand	Silt	Clay	
CH	33	60	1.68	17	44	26	30	Mehran
CL	18	39	1.78	14.5	45	27	28	Ilam
SM	NP	NP	1.82	11.9	85	5	10	Darreh shahr

Table 2. Results of chemical analysis of studied samples

Sum of Cations	Cations (meq/lit)			Sum of Anions	Anions (meq/lit)				EC dS/m	pH	Sampling Location
	K^+	Na^+	Mg^{+2}+Ca^{+2}		SO_4^{-2}	Cl^-	HCO_3	CO_3^{-2}			
234.8	35	177	22.8	249.5	62.5	185	2	-	3.84	7.75	Mehran
5.6	--	--	5.6	4.6	4.6	-	-	-	0.78	7.24	Ilam
11.89	-	0.89	11	13.3	3.2	1.85	8.25	-	0.86	7.31	Darreh Shahr

2.2. Treatments

Based on the research purpose to evaluate the effect of solubility of gypsum soils, samples of Gypsiferous soil were provided artificially by adding various amounts of natural Gypsum including 0, 5, 10, 20 and 30 percent weight of 3 kinds of soil textures including clay, silty clay and sand. Totally, 15 types of gypsum soils were prepared. Each artificial gypsum soil was tested in 5 levels of hydraulic gradient of 0.5, 1, 2, 5 and 10. Thus, 75 treatments were provided and each treatment was performed in three replications and totally, 225 leaching tests were performed.

2.3. Compaction test

The compaction of soil samples in leaching cell needs optimum water content and maximum dry density, so the standard compaction test was done on various combinations to determine the compaction characteristics of soils with various rates of Gypsum. So, the standard Compaction test was performed on all studied treatments based on the standard of ASTM D 644-05.

2.4. Leaching Apparatus

In the present research, regarding the nature and the number of required tests of leaching, a specific laboratory leaching test Apparatus was designed. This device has three parts including: leaching cell, hydraulic gradient generator and a feeding tank.

2.5. Leaching cell

The early idea for making leaching cell was form of standard Compaction. But regarding the small volume of this form and high precision, a decision was made to use a similar form with larger volume. This form had a cylinder shape with total length of 34 cm and effective length of 20 cm for soil sample and inner diameter of 13 cm. In upper and lower parts of sample cell, thickness equal to 7 cm, a galvanize plate and a geotextile layer were designed to prevent moving of solid particles. The material of cell was polyethylene with high pressure (10 atmosphere) with pressure of 10 bar and rubber sealing were used to and also the flinches were controlled by 4 bolds with length of 43 cm and some beads in up and down of flinch (Figure 2).

2.6. Hydraulic gradient generator system

To provide required hydraulic load for flow in the cell and providing water leaching conditions, a closed system including a storage tank, a small pump and a vertical pipe containing several output valves in various heights were used. Thus, water was pumped form storage tank by a steel pipe with the length of 2.5 meter and diameter of 1.5 inch. So depending on the considered hydraulic gradient, outer valve was selected in pipe body and its upper valves were opened and their water was directed to feed tank. So in each experiment, the hydraulic gradient was constant.

2.7. Feed Tank

Regarding the high number of leaching tests and time -consuming tests, it was impossible to do tests by one leaching cell, so to provide several tests in the same time, a feed tank of hydraulic gradient was used in the distance between hydraulic gradient generator pipe and leaching cells. This tank was built by steel plates with thickness of 2 mm in a cubic shape in dimensions of 20×50×60. This tank contains 5 valves (1.5 inch) for water outlet in the distance of 10 cm from each other. By this tank, it was possible to use 5 leaching cells under the same hydraulic gradient at the same time. The details of various parts of this device are shown in Figures 2., 3. Also the image of the apparatus and its accessories are illustrated in Figure 4.

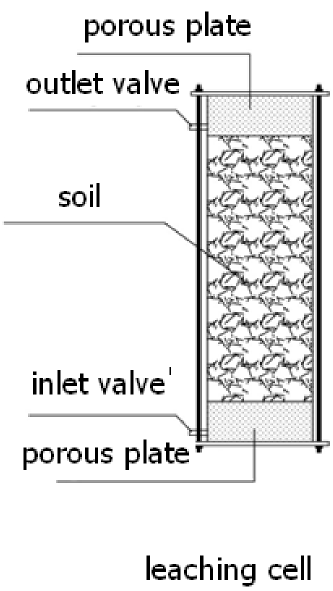


Figure 2. Schematic figure of leaching cell

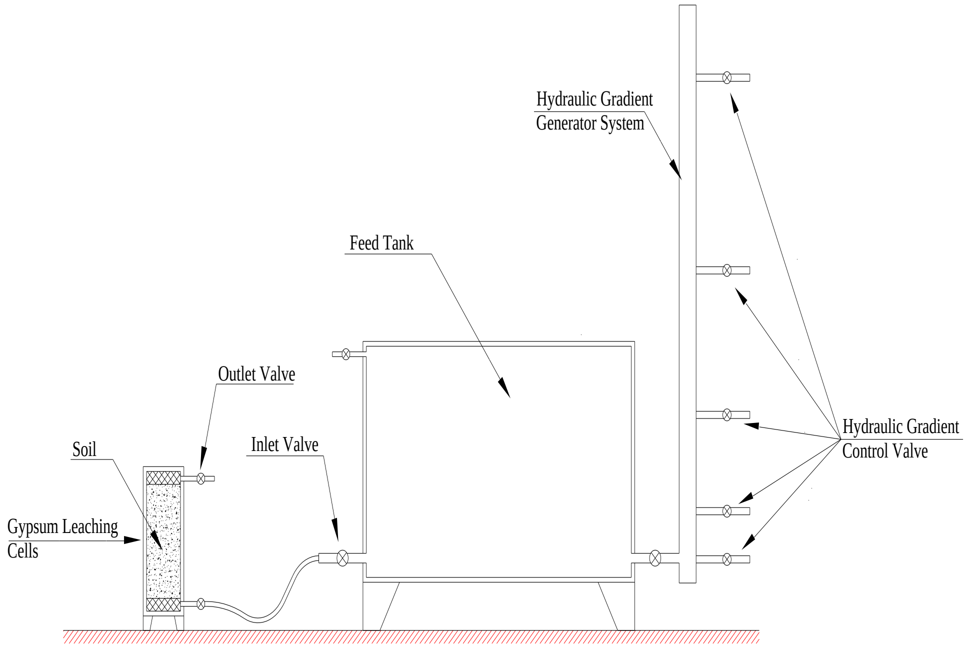


Figure 3. Schematic view of leaching device

a) leaching cell

C) complete collection of the device

b) leaching cells and feeding tank

Figure 4. Leaching test apparatus and its accessories

2.8. Preparation of the specimens

As it was referred, the aim of the present research is investigating the effect of soil texture and hydraulic gradient on the rate of gypsum solution. Specimens were provided artificially by adding determined amount of natural gypsum. Then, the soil sample was compacted by optimum water content and a density of 90 percent of laboratory maximum dry density in the leaching cell of the apparatus. To do this, at first, based on the volume of sample and the determined compaction percent as 90 percent for all tested samples, the weight of soil, Gypsum and the rate of required water to reaching optimum water content were computed and after adding water to it, the total humid mixture was inserted in 5 layers and each layer was heated by 30 impact of a steel device with diameter of 16 mm and weight of 850 gr. Figure 5. show the procedure of specimen the preparation. In the present research, the numbers of layers and required blow were determined based on trial and error.

Figure 5. Compaction of soil in leaching cell

After compaction of samples in the leaching cell, steel lattice plates and geotextile layers as filters were inserted in up and down of the samples. Then flinches of forms were controlled by related bolds. This test was done for soil sample with various percent of gypsum and then 5 leaching cells were prepared and determined under a given and constant hydraulic gradient.

2.9. Leaching test procedure

After preparing testing samples in leaching cell and connecting them to a hydraulic constant head, outlet valve of leaching cell was closed for 24 hours for saturation of the samples. Later, the outlet valve was opened and in various periods including; 5, 30, 120, 360, 720, 1440 and 2880 minutes, after opening the valve, water samples were collected and tested for determining gypsum content. To determine the rate of gypsum in samples of outlet water, the method of determining the rate of calcium Ion was used. Also after the end of test, the rate of gypsum sample was determined using sulfate Ion.

2.10. Measuring the rate of Gypsum in soil

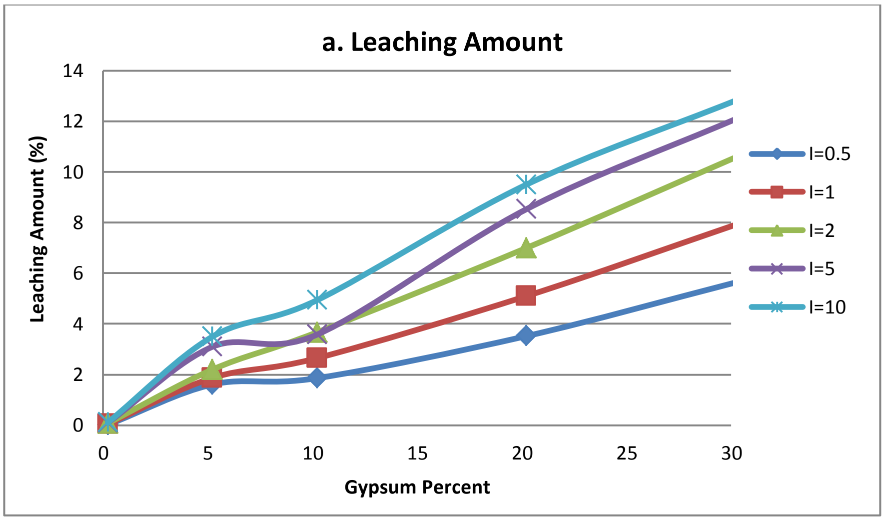
After the end of tests, soil samples were extracted from various layers and for uniformity, the samples were mixed again and the samples were tested using total Sulfate. To determine gypsum percent using total sulfate, 200 gr of dried sample was passed from 2mm sift, then it was milled until it could pass from 1 mm sift. Then a sample of 100 gr was provided and it was milled until it could pass from 150 µ sift. The obtained sample in this stage was used as test sample. Then 5 gr of soil with 10 cc of water and 20 cc of ammonium carbonate (%25) were boiled for 15 minutes and then it was washed 8 to 10 times with distilled water. Then, the obtained factor was weighted (M1) again and its sediments were put on to changing its color to white. This sediment was kept in 1000 degree temperature and then it was dried in a desiccator and then was weighted with sample (M2). The following equation was obtained with significant level of two weights of M1 and M2 in coefficient of 1.7 and 6.86 percent of Gypsum [4].

$$GP = (M_2 - M_1) * 6.86 * 1.7 \tag{1}$$

3. Results and Discussion

3.1. Investigating the effect of Gypsum percent on solution of Gypsum soil

As it was referred, in the present research the sample of soil was saturated for 24 hours and then it was under leaching for 48 hours. After this period, the remaining rate of Gypsum was determined in the soil. Then extracted gypsum of each treatment was computed due to leaching and the rate of leaching. Obtained Results of these studies were indicated based on Figure 6 for various rates of hydraulic gradient. As it is shown in Figure 6, by increasing gypsum percent, soil solution is increased and leaching is reduced by the increase of soil gypsum percent, (Figure 6a).



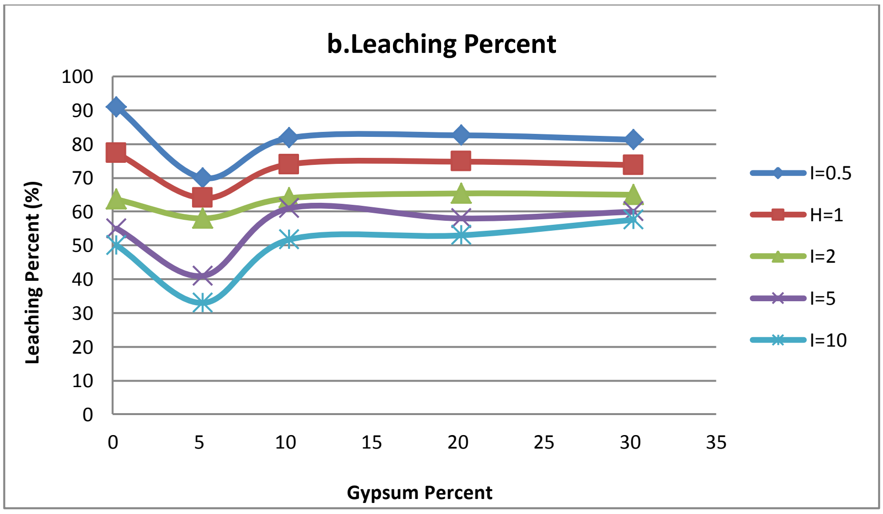


Figure 6. The effect of gypsum rate and hydraulic gradient on the rate of solution of gypsum in clay soil.

3.2. The effect of hydraulic gradient on the rate of solution of Gypsum soil

The effect of hydraulic gradient of water in soil on the rate of Gypsum soluble in samples of Gypsum soils with various rates of Gypsum with Silty sand is shown in Figure 7. With investigating the effect of hydraulic gradient of water flow in soil on the rate of Gypsum solution, the minimum rate of solubility of hydraulic gradient is 0.5 and maximum value is related to hydraulic gradient 8. So it can be concluded that the rate of soluble has direct relationship with hydraulic gradient.

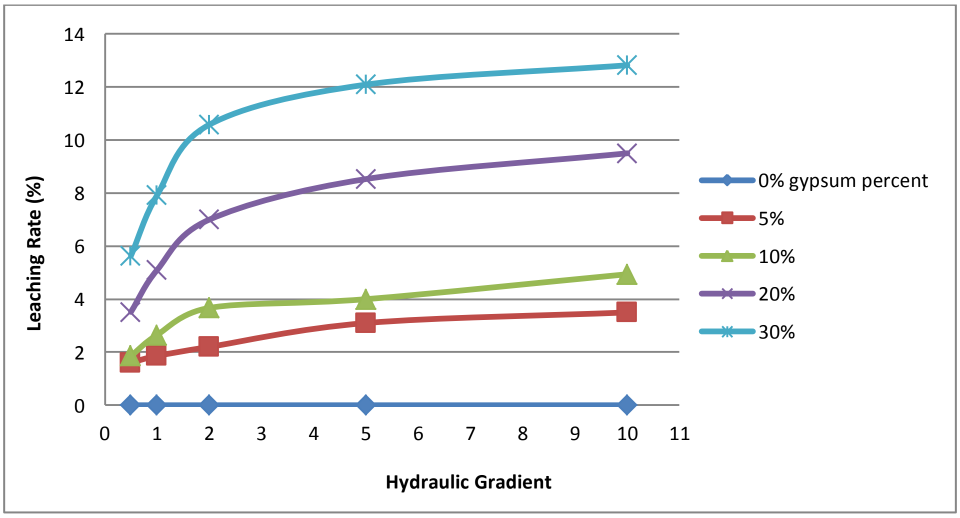


Figure 7. The effect of Gypsum rate and hydraulic gradient on the rate of Gypsum solution in a silty clay soil

3.3. The effect of soil texture on the rate of solution of gypsum soil

The results of leaching tests on soil samples with various textures and under different hydraulic gradient for samples contain 20 percent of gypsum are shown in Figure 8. Also, the rate of solution of gypsum samples for each rate of gypsum and under constant hydraulic gradient is 10 for three types of soil as shown in Figure 9. As shown, the rate of leaching in sand soils is more than two other soils, clay and silty clay. It means that in soils with coarse grained, the gypsum solubility is more than that of other soils. This is because of high permeability of soils with coarse grained texture, limited solution of gypsum in water. It means that gypsum solution in water is 2 gr/liter. So a determined volume of water has limited potential for solution and carrying gypsum. In the samples of gypsum soils with the same rate of gypsum, hydraulic gradient and soluble time with different textures, in the soils with high permeability, the volume of outlet water will be higher than the others, so the extracted rate of gypsum is more. It can be said that the solubility rate of gypsum has direct relationship with water flow, so each factor such as hydraulic gradient and soil texture leading to increase of the rate flow and outflow from soil environment can increase the rate of solubility of the soil. Also, based on Figures 8. and 9. it is found that there is a considerable difference between sand (coarse grained) and two clayey fine grained soils. Furthermore, there are no considerable differences between the two clayey soils as their permeability is approximately as the same.

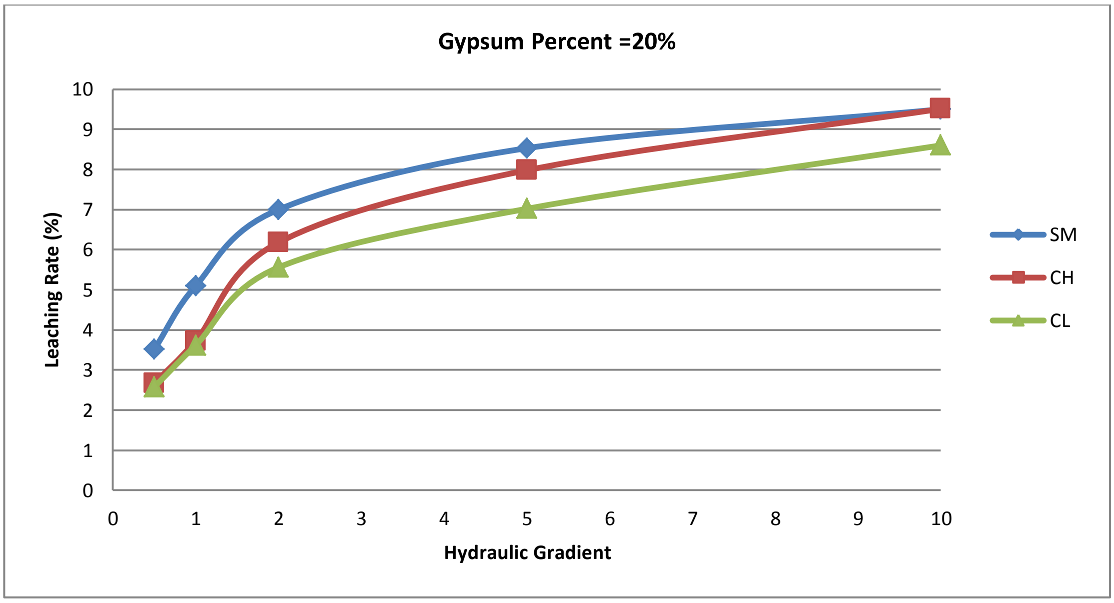


Figure 8. Variation of gypsum solubility rate with different hydraulic gradient and same gypsum percent for various soils

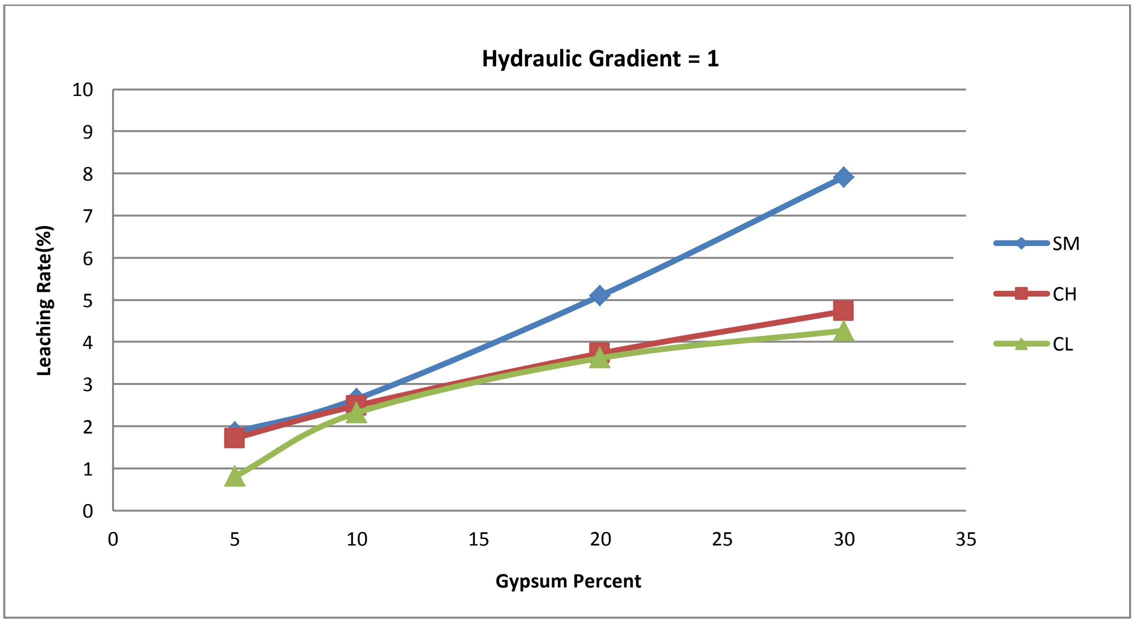


Figure 9. Variation in the rate of gypsum solubility for a constant hydraulic gradient for various soils

3.4. Results statistical analysis

In this section, based on the different hypotheses, the effects of three factors of Gypsum, Soil hydraulic gradient texture are examined. As the main hypotheses it was supposed that there is a significant relationship between the hydraulic gradient, Gypsum, leaching and types soil. Then statistical analysis was done SPSS software which the results are presented in Table 3, 4. and 5. As shown in Table 3, to test the comparison of hydraulic gradient, Gypsum Percent , leaching by the type of soil, a one-way variance analysis is used and degree of freedom 74 = DF is not significant at the level (0.05<Sig). Therefore, H0 is supported and study hypothesis is rejected with confidence interval 95%. In other words, there is no significant difference between hydraulic gradient, Gypsum, leaching by the type of soil.

Table 3. Significant difference hydraulic gradient, Gypsum percent, leaching by the type of soil

Variable	Source change	Sum of squares	Df	Root mean	F	Sig
Hydraulic gradient	Between group With the group Sum	0.00 150 150	2.0 72 74	0.000 2.083	0.000	1.000
Gypsum percent	Between group With the group Sum	0.00 150 150	2.0 72 74	0.000 2.083	0.000	1.000
Leaching	Between group With the group Sum	20.932 758.775 779.707	2.0 72 74	10.466 0.073 10.539	0.993	0.375

Table 4. Results relationship between hydraulic gradient, Gypsum percent, leaching and soil types

	Soil	Hydraulic gradient	Gypsum percent	Leaching
Soil	------	-		
Hydraulic gradient	0.000	----------------------------------		
Gypsum percent	0.000 0.000	0.000 1.000	---------------------	
Leaching	0.000 0.000	**0.382 0.091	**0.878 0.000	--------------------

Table 5. Predication of the soluble rate soil types through hydraulic gradient and gypsum percent

Variable	R	R^2	F	P	β	T	P
Constant					-5.09	-8.42	0.000
Hydraulic Gradient	0.91	0.84	127.72	0.000	0.924	8.64	0.000
Gypsum Percent					1.872	17.49	0.000
Soil					0.291	1.57	0.12

As shown in Table 4, based on the estimated significance level regarding the relationship between leaching, hydraulic gradient and Gypsum percent as lower than the alpha level (0.01) less, it can be said that there is a significant positive relationship between the leaching and rate of Gypsum percent. H0 is rejected and H1 is supported. Then according to the statistical analysis made for gypsum leaching relationship in Table 5. a correlation was developed as Equation 2.

$$L = -5.09 + 0.924H + 1.872G \tag{1}$$

Where L is the leaching rate, H is Hydraulic gradient and G is Gypsum percent.

4. Conclusion

In the present study, the effect of gypsum percent, hydraulic gradient and soil texture on solution rate of gypsum was investigated. To do this, samples of gypsum soils were provided artificially by adding various rates of natural gypsum rock including 0, 5, 10, 20 and 30 percent weight of 3 kinds of soil textures .Then each of gypsum soils were leached under five hydraulic gradients levels 0.5, 1, 2, 5 and 10. The results of the test indicated that the rate of Gypsum in the soil had direct effect on the rate of Solubility and by increasing the percent of gypsum, the rate of soil solubility was increased. Thus, leaching, the ratio of gypsum exiting soil to the initial gypsum in soil is reduced by increasing the percent of gypsum percent in soil. In addition, by increasing hydraulic gradient, the speed of water existing soil media in a specified time was increased and also higher rate of Gypsum was derived. Also the soil texture has a considerable effect on the rate of solution and this depends upon the difference of their permeability.

In the present research, the rate of solubility in gypsum soils with sand soils was determined as 1.5 to 2 times more than that of clay soils. The statistical results show the highest impact of gypsum percentage and lowest impact of hydraulic gradient soil on solubility of particles in different types of soils and it has no significant effect on the overall equation of the soil texture. 84% of the variance in the rate of Solubility of soil can be explained by hydraulic gradient.

5. Acknowledgement

Given that, these experiments of this study are performed in Laboratories of oil Mechanics and Technical and Saze Azma of Parsian in Ilam Province, we would like to express our appreciation to the management and employees of these two institutes.

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