

Assessment of Dissolution Rate Constant for Kербala Gypseous Soil

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Abstract:

The stability of many soil foundations which are constructed on gypseous soils may depend upon rate of dissolution caused by water seeping through this type of soil. Aggressive degree of water for Kербalaa gypseous soil with high gypsum content of (27%) can be assessed on basis of the relation which was established by authors and collaborators to define the rate of gypsum dissolution constant(K).

The laboratory model tests were achieved by preparing recompacted soil samples at field unit weight (13.51 kN/m³) and susceptible to four values of solutions flow velocities of distilled water and (calcium sulphate , sodium chloride)salts .

The results showed that the gypsum solubility enhancement is a consequence of increasing flow rate of solutions and sodium chloride presence, thus the dissolution rate constant K(m/sec) values were ranged from (1.36-4.2)*10⁻⁵ for sodium chloride solution,(1.14-3.14)*10⁻⁵ for calcium sulphate solution and(1.24-3.59)*10⁻⁵for distilled water for flow velocity ranging between (0.0093-0.0266) (m/sec) .

الخلاصة:

ثبوتية العديد من أسس التربة المنشأة على التربة الجبسية تعتمد على معدل الذوبانية المتسببة بواسطة نضوح الماء خلال هذا النوع من التربة .درجة هجومية الماء لتربة كربلاء الجبسية بمحتوى جبسي عال(27%) يمكن أن تقيم بالاعتماد على العلاقة الموضوعية من قبل المؤلفين لتعريف ثابت معدل ذوبانية الجبس (k) . الفحوصات المختبرية أنجزت عن طريق تحضير عينات معاد رصها حسب الكثافة الحقلية(13.51) كيلونيوتن/م³ومن ثم تعريضها لأربع سرع مختلفة من محاليل (الماء المقطر , وأملاح) كبريتات الكالسيوم وكوريد الصوديوم)).

النتائج أظهرت انه زيادة ذوبانية الجبس هي نتيجة لزيادة معدل الجريان للمحاليل ووجود ملح كلوريد الصوديوم لذلك قيم ثابت معدل الذوبانية (k) م/ثا كانت تتراوح من(1.36-4.2) * 10⁻⁵ لمحلول كلوريد الصوديوم (1.14-3.14) * 10⁻⁵ ، لمحلول كبريتات الكالسيوم و (1.24-3.59)*10⁻⁵ للماء المقطر لمعدلات جريان تراوحت (0.0093-0.0266) م/ثا.

1. Introduction

Collapsible soil is defined as soil that is susceptible to a large and sudden reduction in volume upon wetting. Collapsible soil deposits share two main features:

- They are loose, cemented deposits.
- They are naturally quite dry.

Collapse behavior could also happen in fill material as a result of decrease in negative pore water pressure (capillary tension), when the fill become wet the process of their collapsing is often called any of hydroconsolidation, hydrocompression or hydrocollapse. Another type of collapsing could occur in saturated soil bearing soluble mineral upon subjected to continuous leaching resulted from infiltration of rainfall or fluctuation of water table [Mansour,et.al.,2008].The principle source of ground water is meteoric water that is precipitation (rain, sleet, snow and hail), part of this water enters the ground by infiltration whilst the reminder is lost either as runoff on the surface or by evaporation and transpiration to the atmosphere [Bell,et.al.,1986].

The effect of ground water on the engineering behavior of soils and rocks has a fundamental importance, according to the phrase of Tergazhi "without water there would be no soil mechanics" [Bell,et.al.,1986]. Seepage through the soil foundations containing soluble rocks may produce settlements and redistribution of pore pressures which threaten stability of the structures [James and Edwarthy,1985]. Gypsum, anhydrite, calcite, dolomite, and variety of other simple minerals are water soluble

and common in the foundation soil. When these soluble minerals present in the foundations of structures are dissolved by seepage water, the void space that form can lead to create permeability and flows along established flow paths, or the development of new seepage flow paths. If the seepage progresses, excessive flows may develop that lead to erosion and piping and eventual structure failure, [Seepage chemistry manual, 2005].

2. Gypsum dissolution as a hazard to civil engineering

The interaction of gypsum and water in engineering projects can cause sever problems and catastrophic ground and structural failures .Intensely loaded foundations on soluble soils are vulnerable when only very small settlements can be tolerated, such problems have been met in Iraq especially in shallow gypsiferous soil with a fluctuating water table [James and Edwarthy,1985]. Subsidence caused by gypsum dissolution produces difficult conditions for building constructions and in many cases the collapses are so sever that little can be done to mitigate the problems. Good site investigation and hazard avoidance are the best approaches followed by construction that can cope with any expected subsidence. In Ripon area of north Yorkshire,UK there is especial planning control and buildings are now constructed on reinforced raft foundations, additional protection could be offered by extending foundations with supporting beams outside the main footprint of the property .In subsidence-prone karstic areas it is important to use flexible service pipe materials and to guard against water loss and infiltration that itself could trigger subsidence. In some places, services trenches have been lined with waterproof membranes to stop this happening [Cooper, 2006].

3. Theoretical considerations:

Gypsum is a hydrated calcium sulphate $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$, it has low specific gravity of 2.32, and has large influence on the physical and mechanical properties of soils containing large a mount of gypsum. It is one of the rock forming minerals which tend to dissolve in water [Bell,et.al.,1986]. It is a sparingly soluble salt, its solubility is 2 gram per liter but it varies with presence of other salts and temperature[Nashat,1990],[Netterberg,1970].Although solubility is an important factor in solution behavior. [James and Kikpatrick, 1980] pointed out that solution rate is a more significant parameter. These authors were defined the solubility of substance "the amount which can be dissolved in a given quantity of solvent at equilibrium" and the rate of solution as "the speed which it achieves this equilibrium concentration". James and Lupton,1978 have noted a material dissolves at a rate and in a manner which is influenced by its solubility (C_s) and a specific solution rate constant (K)

Experiments have achieved by James and Lupton, 1978 and they proved that solution of gypsum can be expressed by the equation:

$$\frac{dm}{dt} = KA(C_s - C)^\theta \quad \text{.....} \quad \boxed{1}$$

Where:

m: the amount of gypsum dissolved at time t.

K: the dissolution rate constant m/sec.

A: the area of gypsum exposed to solution, m^2 .

C_s : the saturation concentration of gypsum g/l.

C: the concentration of gypsum dissolved in solution, g/l.

θ : has a value of 2 for anhydrite and 1 for calcareous rock, gypsum, and halite.

4. Material Used

4.1 Soil

The soil used in this paper was a gypseous soil (secondary gypsum), which was brought from zone 10 km south of Al-Razaza lake behind the strategical way near Kerbala Thermstone Factory , Fig.(1).The soil was taken from (2 - 2.5)m depth with a gypsum content of 27%, which represents highly gypseous soil [Al Barzanji,1973] .

4.2 Leaching solutions

1. Distilled water: Distilled water was used in all tests.

2. Salty solutions: The concentration of gypsum and halite salts were obtained from Al Rzaza region after Al Bidaree and Al Bassam,2000 results which were represented the maximum concentrations of all salts for this region where the gypsum salt concentration was taken equal to the actual value of halite salt (1700 ppm) since it is the higher value and for comparison.

5. Soil Testing

5.1 Physical and Chemical Tests

These tests were performed for Kerbala gypseous soil, see Fig.(2) and tables (1)&(2) .

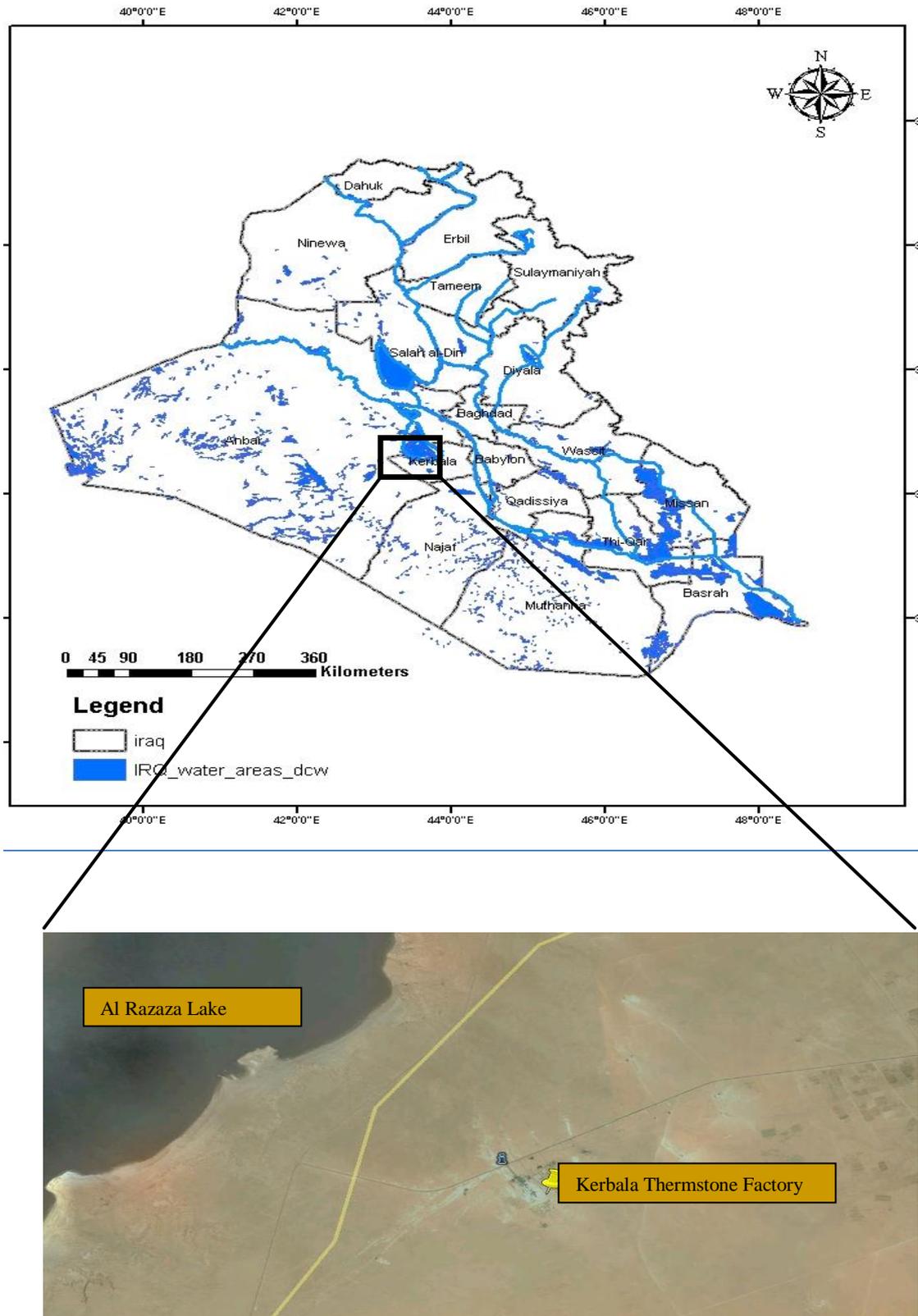


Fig.(1) Map of Iraq and satellite image for location of study soil

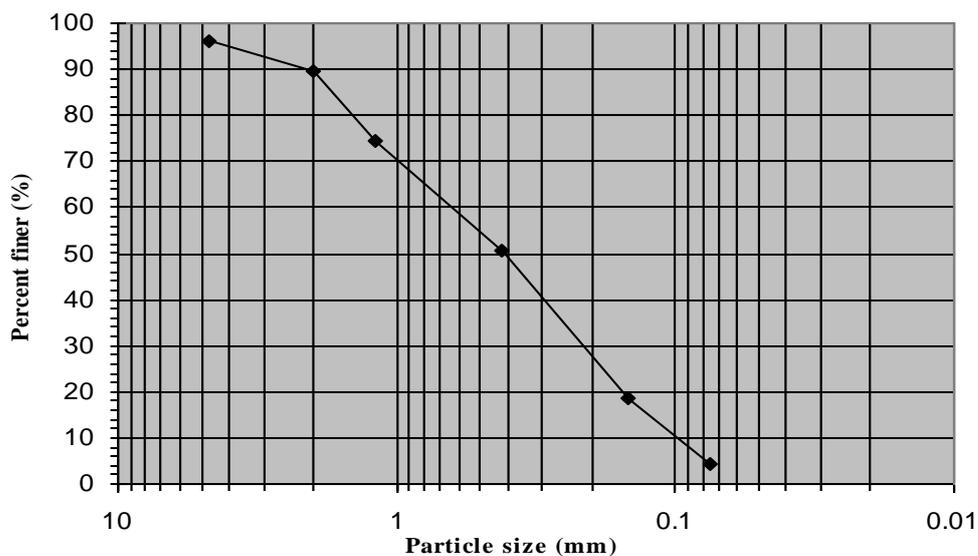


Fig.(2) Grain size distribution by kerosine method

Table(1) Chemical analysis of gypseous soil sample
(After Geological survey and mining company)
(Atomic Absorption)

CaO %	MgO%	SO ₃ %	Na ₂ O%	CO ₃ %
9.53	0.62	13.76	0.54	0.12

Table (2) Physical properties of gypseous soil sample

Test Type	Value	Specification
Particle size distribution (Kerosine treated method)	Classified SP	BS 1377:1975, test No.7(A), Head,1980
Specific gravity (Kerosine method)	2.45	BS 1377:1975, test No.6(B), Head,1980
Field unit weight(kN/m³)	13.51	-----
Maximum dry unit weight(kN/m³)	18.8	BS 1377:1975, section 3.7.3, Head,1980
Minimum dry unit weight(kN/m³)	11.3	BS 1377:1975, section 3.7.4, Head,1980
Relative Density (%)	41	-----
Initial voids ratio (e₀)	0.853	-----
Moisture content (%)	2.2	ASTM (D2216-80)

5.2 Model preparation:

The laboratory model tests were carried out inside a plastic cylindrical container with dimensions of (18.5 cm diameter and 30 cm height), see Fig.(3). A 2 cm layer of graded sand was spread on the bottom of the container to act as a lower free draining layer. The required pre-weighted amount of air dried natural soil was mixed with specific amount of water depending on the field density. The prepared soil was spread in five layers with thickness of 5 cm and compacted uniformly to achieve the required density. The model soil was left 48 hrs before testing to lessen the initial water content and to achieve accurate testing procedure.

5.3 Model test

The previously prepared solutions were let to pass through transparent pipes with a specific hydraulic gradient by lifting the water level to give a specific head and keep it constant through constant solution level. The different values of velocities were achieved by using manually controlled valves and volumetric flowmeters, Fig(3). The dissolved gypsum concentrations in solutions for each value of flow velocity were measured as follow:

After completion of the time required for raising solution from soil sample bottom and drained from top of it (represent zero time), immediately the solution sample was drained and kept in a labeled container. After that there was a specific accumulative volume of solution during 20 minutes where the solution sample was drained and kept in a labeled container also to determine concentrations of gypsum dissolved in water in (ppm) and mass of it in (gm) by Titration with (Na_2EDTA) solution method and Mercuric diet which used as indicator for reaching balance point [APHA,AWWA,WPCF,1985], then the graduated tank must be draining with washing quickly by distilled water and let solution to accumulate in graduated cylinder during next 20 minutes. This test procedure would be repeated each specific time of 20 minutes continuously to obtain the total mass of gypsum dissolved up to the end of 160 minutes.

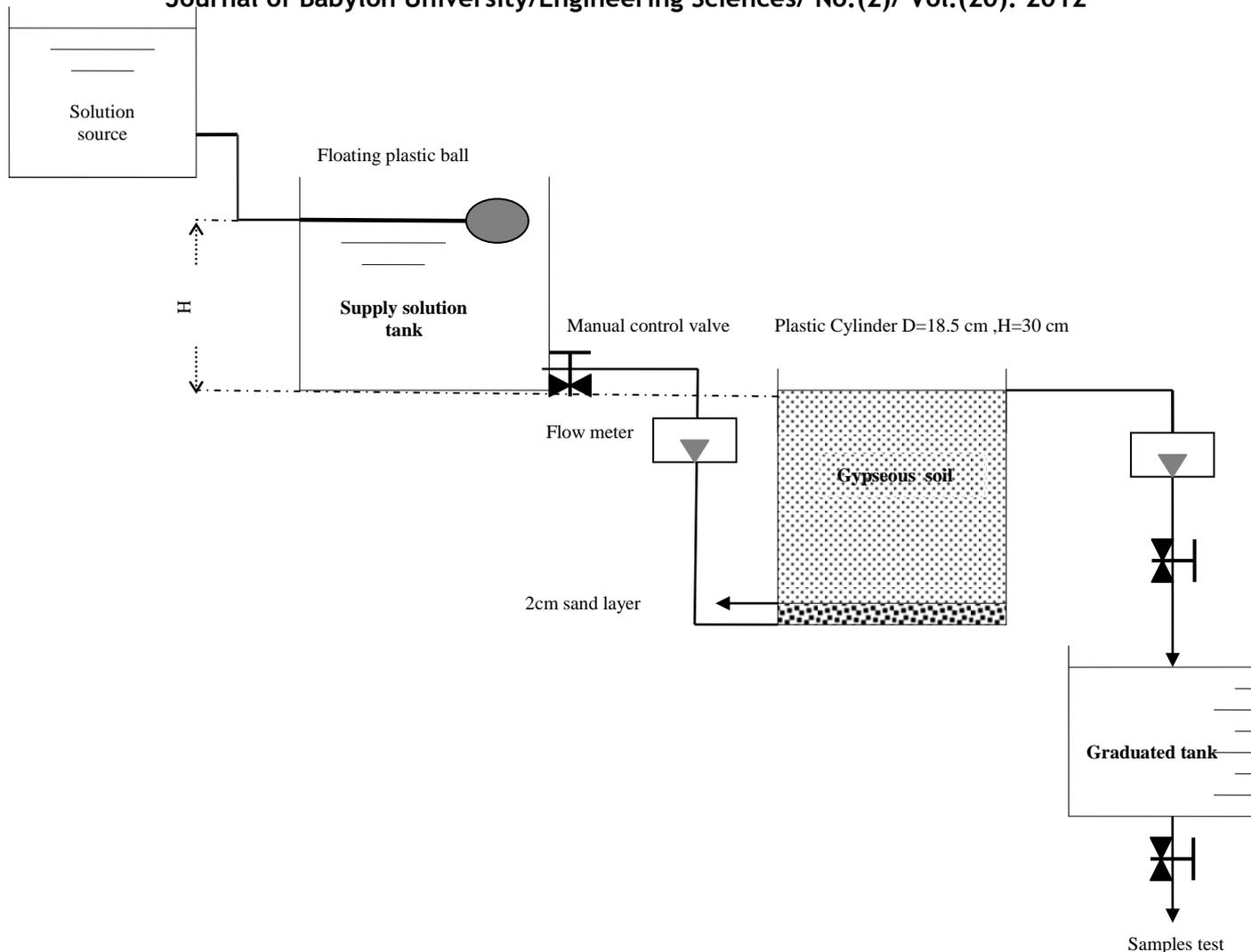


Fig. (3) Model assembly

6. Result and discussions:

During leaching process under hydraulic gradient, the rate flow of the used solution would migrate the fine particles of weakly bonds after gypsum dissolving and leaching from soil matrix.

It was found that the dissolution rate (K) by using equation -1 increasing with increasing flow rate velocity and sodium chloride presence in the dissolving water, i.e., the dissolution rate is controlled by the flow velocity of water associated with a unit area of the soil and the salinity of the water [Peter,2008; Bell,et.al.,1986], this result is in close agree with that reported by [Cooper and Calow,1998] "large concentration of gypsum in the flowing water can slow the dissolution rate, however, the presence of dissolved sodium chloride (salt) or magnesium carbonate (from dolomite) can considerably increase the dissolution rate".

This behavior can be contributed to the phenomenon of "common ions", that means the solubility increases in the presence of other salts without a common ion, but decreases in the presence of small to moderate amounts of other salts with a common ion [Netterberg,1970],[Characteristics of gypsiferous soils,2009] and according to (Le-Chatelier law), "increasing substance concentration in one side of reaction leads to move the equilibrium to other reaction side to reduce its concentration" [Al Hassawi,et.al.,1998].



The results of all tested samples were presented in figures from (4) to(20).Table (3) and figure (20) explained the (K) values which were obtained from figures (5,6,7,9,10,11,13,14,15,17,18,19) that explained the change of accumulative mass of dissolved gypsum with time (dm/dt) until 160 minutes. It should be noticed that value of (C) in all model test must be taken equal to zero in case of sodium chloride solution and distilled water, and all model tests temperature were ranging from (43-45) °C during July and August months, thus the solubility of gypsum (C_s) must be 3 g /l after Subhi, 1978.

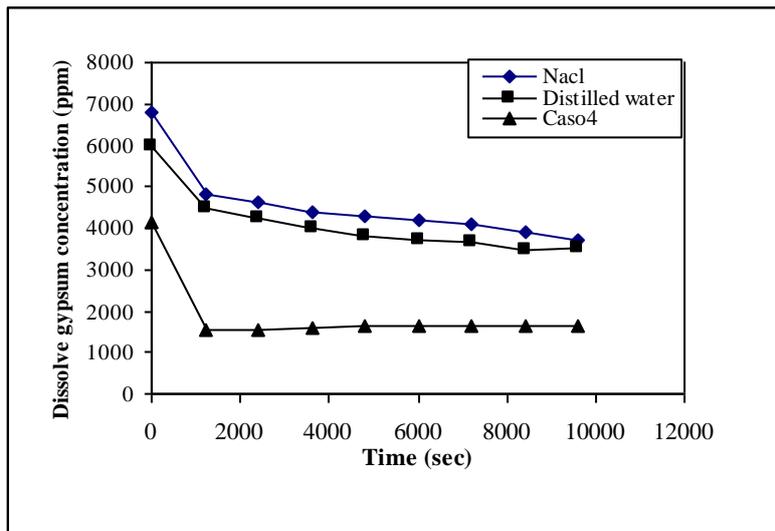


Fig.(4) Dissolved gypsum concentration - time relation for $v=0.0093\text{m/sec}$

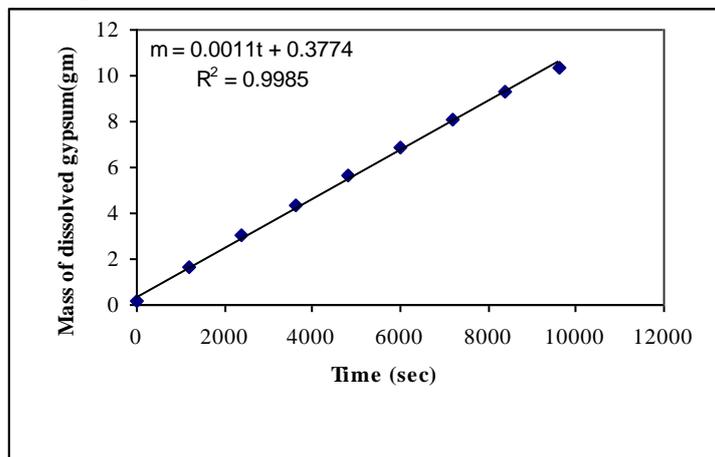


Fig.(5)Mass of dissolved gypsum - time relation for sodium chloride solution for $v=0.0093\text{m/sec}$

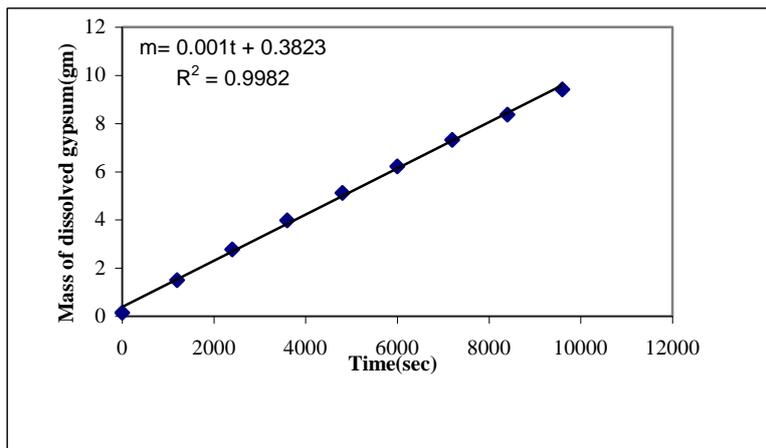


Fig.(6) Mass of dissolved gypsum- time relation for distilled water for $v=0.0093\text{m/sec}$

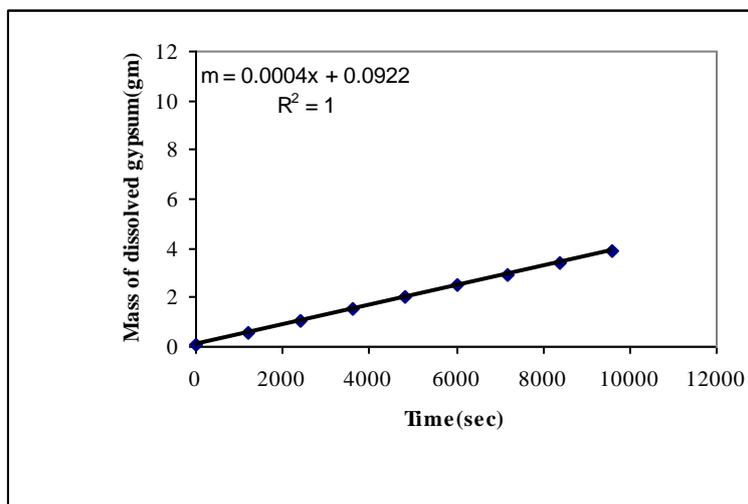


Fig.(7) Mass of dissolved gypsum - time relation for calcium sulphate solution for $v=0.0093\text{m/sec}$

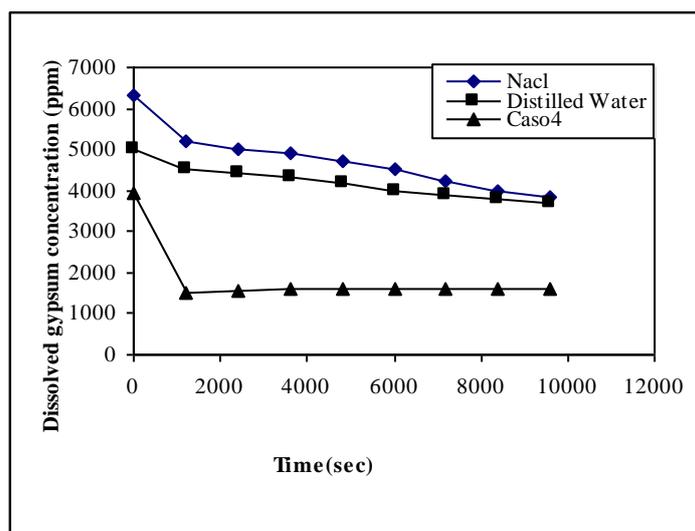


Fig.(8) Dissolved gypsum concentration - time relation for $v=0.01328\text{m/sec}$

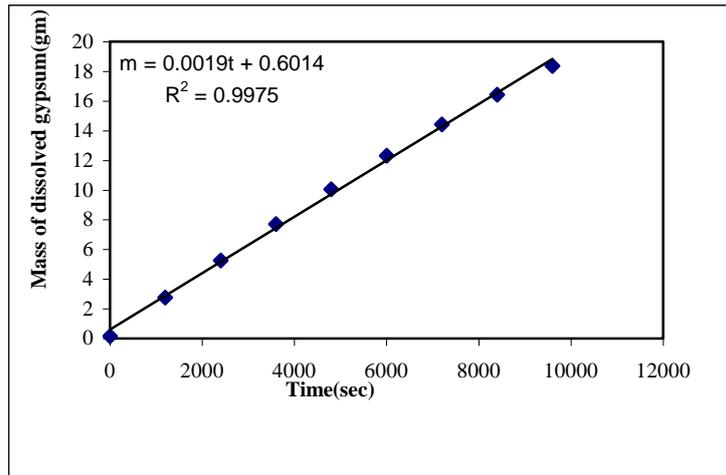


Fig.(9) Mass of dissolved gypsum - time relation for sodium chloride solution for $v=0.01328\text{m/sec}$

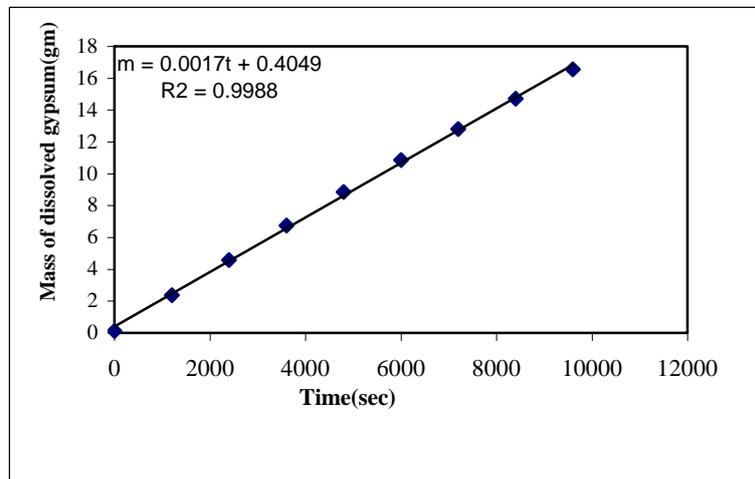


Fig.(10) Mass of dissolved gypsum-time relation for distilled water for $v=0.01328\text{m/sec}$

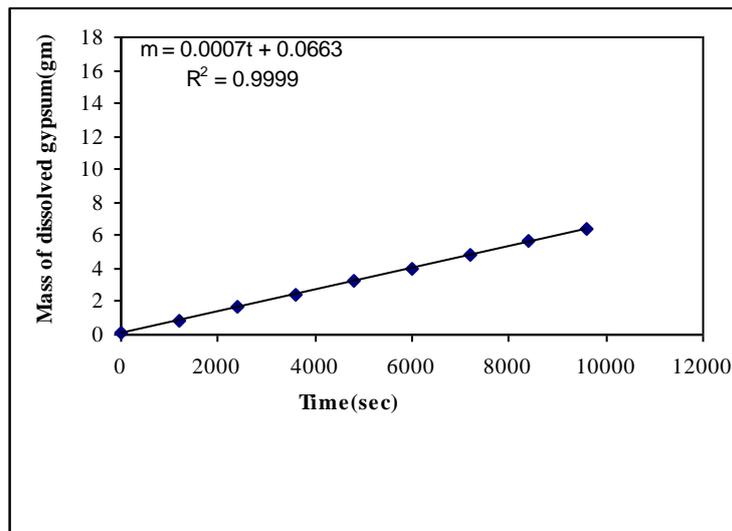


Fig.(11) Mass of dissolved gypsum - time relation for calcium sulphate solution for $v=0.01328\text{m/se}$

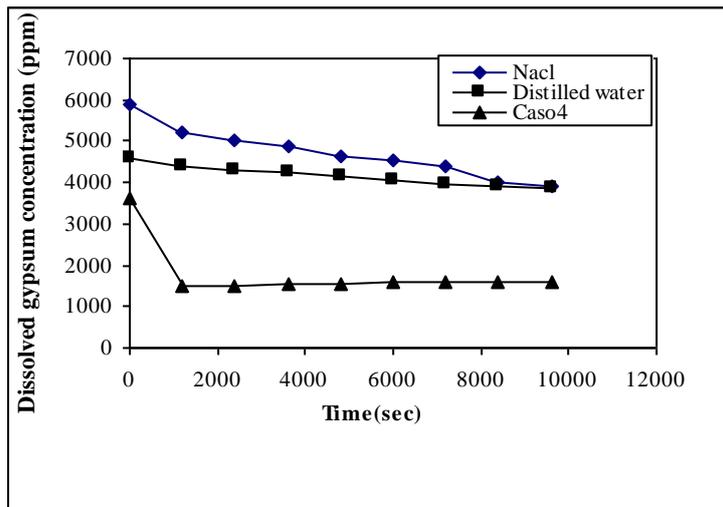


Fig.(12) Dissolved gypsum concentration - time relation for $v=0.0186\text{m/sec}$

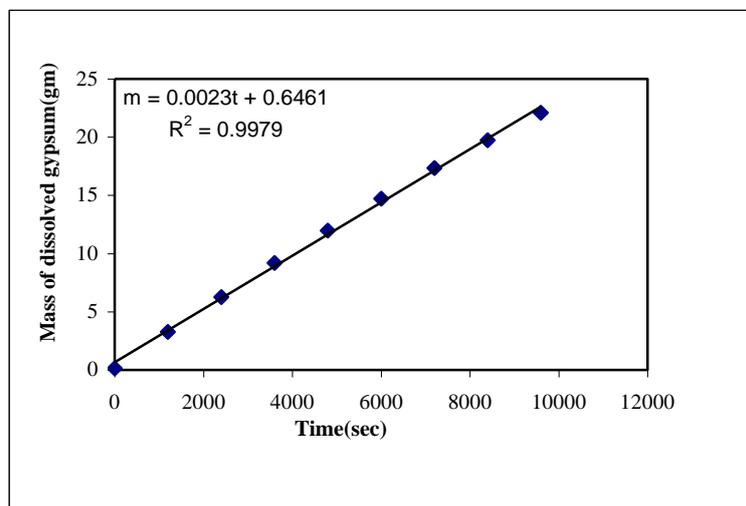


Fig.(13) Mass of dissolved gypsum - time relation for sodium chloride solution for $v=0.0186\text{m/sec}$

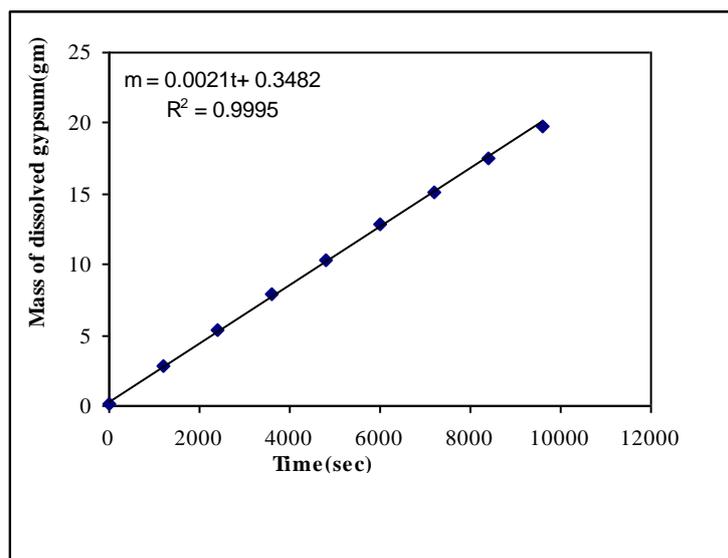


Fig.(14) Mass of dissolved gypsum - time relation for distilled water for $v=0.0186\text{m/sec}$

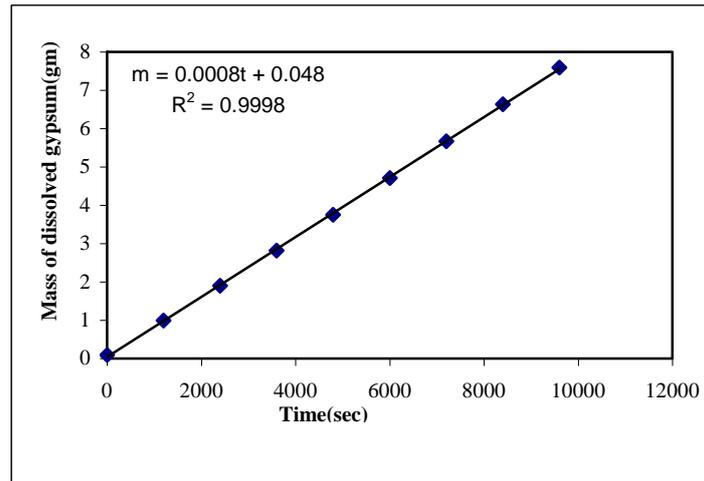


Fig.(15) Mass of dissolved gypsum - time relation for calcium sulphate solution for $v=0.0186\text{m/sec}$

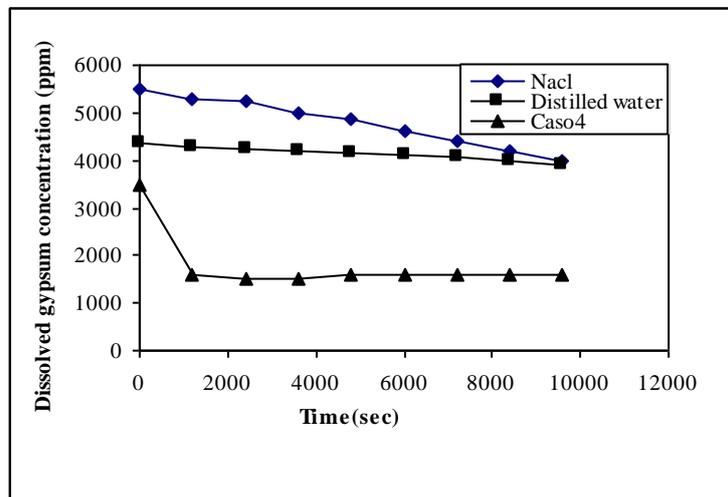


Fig.(16) Dissolved gypsum concentration - time relation for $v=0.02656\text{m/sec}$

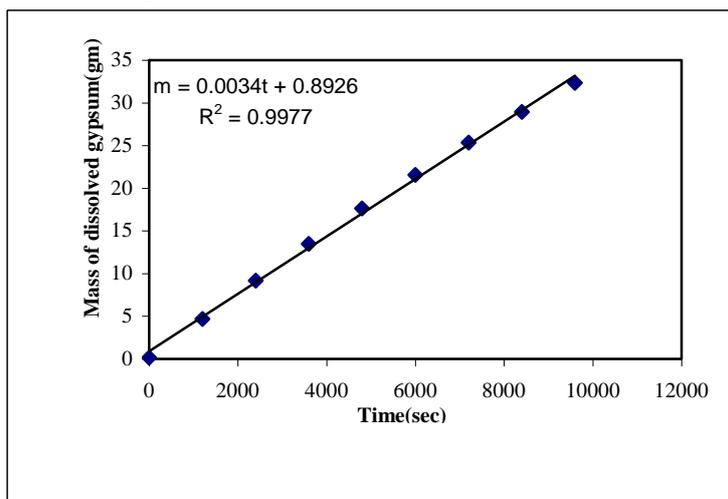


Fig.(17) Mass of dissolved gypsum - time relation for sodium chloride solution for $v=0.02656\text{m/sec}$

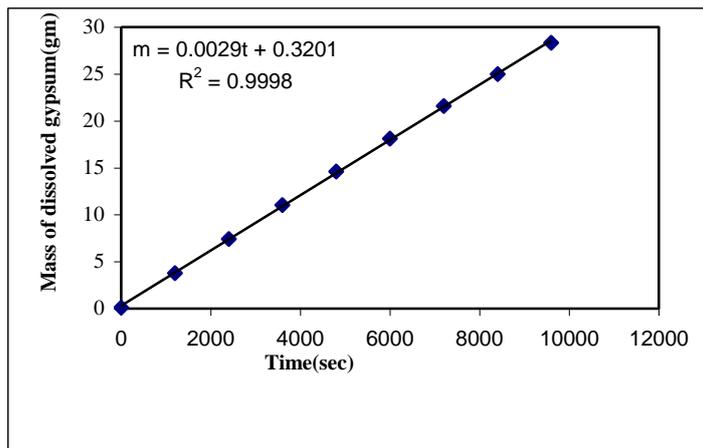


Fig.(18) Mass of dissolved gypsum - time relation for distilled water for $v=0.02656\text{m/sec}$

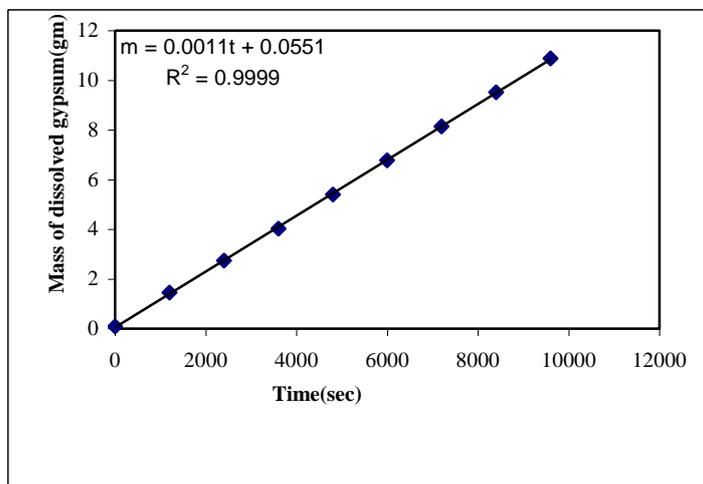


Fig.(19) Mass of dissolved gypsum - time relation for calcium sulphate solution for $v=0.02656\text{m/sec}$

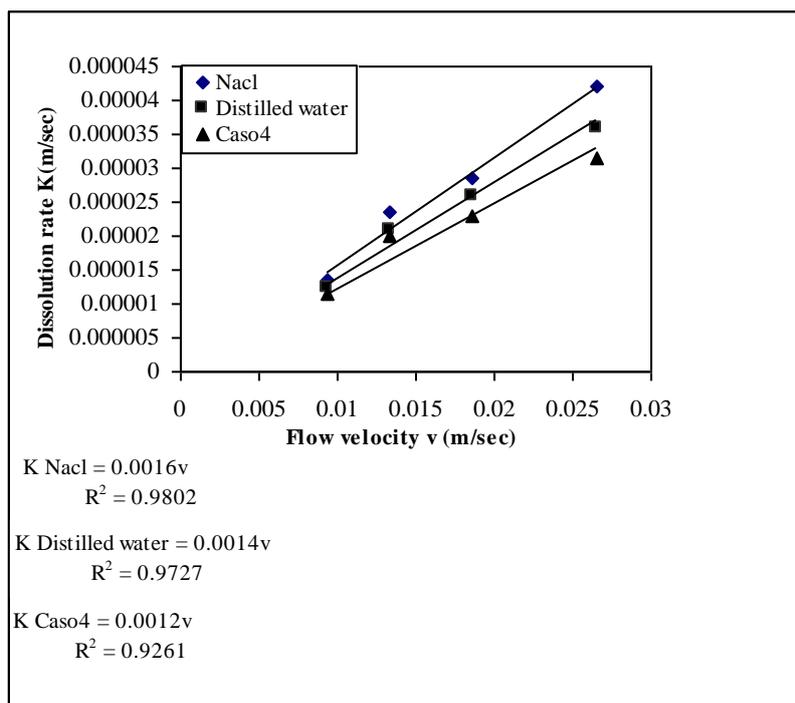


Fig.(20) Dissolution rate -flow velocity relation for solutions ,distilled water and (sodium chloride and calcium sulphate) salts with concentration of 1700ppm.

Table (3) dissolution rate (K) values

<i>Solution flow rate (m/sec)</i>	<i>Solution type</i>		
	<i>Sodium chloride 1700 ppm</i>	<i>Distilled water</i>	<i>Calcium sulphate 1700 ppm</i>
0.0093	$1.36 \cdot 10^{-5}$	$1.24 \cdot 10^{-5}$	$1.14 \cdot 10^{-5}$
0.01328	$2.35 \cdot 10^{-5}$	$2.1 \cdot 10^{-5}$	$2 \cdot 10^{-5}$
0.0186	$2.85 \cdot 10^{-5}$	$2.6 \cdot 10^{-5}$	$2.28 \cdot 10^{-5}$
0.0266	$4.2 \cdot 10^{-5}$	$3.59 \cdot 10^{-5}$	$3.14 \cdot 10^{-5}$

7. Conclusions

1. The "common ions" phenomenon has a more significant role on dissolution rate value, i.e., (K) value increasing and decreasing in case of sodium chloride and calcium sulphate presence in the dissolving water respectively.
2. The salinity and chemical composition of the ground water is of fundamental importance on gypsum dissolution process, thus it is important to use accurate methods for determining ground water chemical composition and salinity.
3. Dissolution rate value of gypsum may be a distinct hazard in cases of sodium chloride presence in ground water and increasing of flow rate velocity.

8. References

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