

MINERALOGY AND MINERAL SUCCESSIONS

CRYSTALLIZATIONS OF THE WASTE RESIDUAL

BRINES

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Abstract

The waste residual leftover brine after extraction of anhydrous sodium sulphate and sodium chloride, at EMISAL industrial site was stored in storage ponds. In this article, the mineral composition and its petrography of the minerals successions crystallization during evaporation at different intervals of temperatures were investigated to judge its economic viability. The mineralogical investigation has been carried out using XRD, SEM, EDX and polarizing microscopy techniques and proved its economic potential as to produce many economic salts e.g. hexahydrate, epsomite, bischofite, carnallite, sylvite, sanderite and halite.

1.Introduction and location:

The preliminary studies of salt extraction from Lake Quaroun by the British White Young Engineering (WY, 1976), followed later on by the study of the American DSS Engineers INC Coopers and Lybrand CRS. (1979) proves the feasibility to extract 320 000 tons/year of salt from the lake (100 000 tons/year sodium sulphate, 200 000 ton/year sodium chloride and 20 000 tons/year magnesium salts). The recent studies approved the extraction of 320 000 tons/year: 100 000 tons/year anhydrous sodium sulphate, 200 000 tons/ year edible and industrial sodium chloride and 27 000 tons/year Epsom salt.

To materialize these studies and implement a salt extraction project, an area of 5 km² was cut from natural bay at the southern coast of the lake, west of Shakshuk village. Part of this area is located between latitudes of about 29° 26.5' and 29° 27' N and longitudes of about 30° 40.5' and 30° 41' E (Fig.1A). The

area is hot and dry, rainfalls are rare, the annual rain fall has been recorded as 10 mm, but this value may change from one year to another (Samy, 2000). The prevailing winds are relatively constant from N-NW and may be changed to NE and ranges from 2.74 to 5.16 m/sec (Al Kordy, 2003). The mean annual values of evaporation for 1982 to 1992 are 6.9 mm/m²/day (updating WYP, 1992), the hydraulic and water management research institute (HIR and WRI) had detected that the average values of the evaporation rate by 1947 mm/year (5.33 mm/ day), (HIR and WRI, 2004). Applying evaporation coefficient of Lake Quaroun, the rate of evaporation ranges between 1.07-8.8 mm/day (4.795 mm/day on average), (Abd Ellah, 1999 and 2003). The mean average temperature during 2006 was 23.8°C and the mean average relative humidity was 57.5% (these data are from EMISAL records).

Part of this area was divided into four successive solar evaporation ponds to prepare the suitable brine for anhydrous sodium

sulfate extraction in the first step, the mother liquor outlet from the first step was divided into: 30% to storage ponds and was left till almost sodium chloride precipitated at about Sp. Gr. 1.285 gm/cm³ and the other 70% was prepared to feed hydrous magnesium sulfate plant at about Sp. Gr. 1.263 gm/cm³.

The lake water total dissolved solid (TDS), which is approximately 35 g/l was concentrated in these ponds to about 350 g/l by solar energy. The percentage of salts concentrated in the fourth pond is as follows: Sodium sulphate constitutes 12% of the total dissolved solids (TDS), sodium chloride constitutes 68% of the TDS; magnesium salts constitutes 16% of the TDS and other salts such as potassium, boron and bromine constitutes 4 % of the TDS.

The brine of the fourth pond is pumped to the sodium sulphate plant, where it is cooled down to 1°C in two stages. At this temperature sodium sulphate decahydrate (Na₂SO₄.10H₂O) crystallizes out. It is then separated from the mother liquor solution by centrifuging process. The remaining other salts in brine are pumped into storage ponds to result into the raw of sodium chloride by solar energy. The raw salt of sodium chloride was harvested and accumulated to feed the sodium chloride plant for purification, drying and packing. The leftover bittern (residual) is mainly magnesium salts with potassium, boron and bromine. The annual accumulated residual bittern is about 120000 m³. These residual bittern should be pumped at specific density of about 1.285 gm/cm³ into another storage pond formulating a raw material for magnesium salts production. The production of magnesium salt as bischofite (MgCl₂.6H₂O), boron as borax and bromine salts. The estimated production of bischofite is about 27.000 tons, 5000 tons of sylvite, 1300 ton of bromine salts and about 2000 tons of borax or boric acid, besides 480 tons annually from the mother liquor of sodium sulphate plant.

2. TECHNIQUES AND METHDOLOGY:

The analytical methods are described as follows:

CO₃²⁻ : acid- base titration

K⁺, B²⁻ : atomic absorption (Model GPC 932)

Na⁺ : equivalent minus according to ion balance

Mg²⁺: titration complex metrically with Ca²⁺ by using Eriochrom black T

Ca²⁺: titration complex metrically by using murexide.

SO₄²⁻ : by barium sulfate precipitation (Dunk et. al., 1969).

Cl⁻ : titration with silver nitrate using potassium chromate as indicator.

XRD, SEM, EDX and Transmitted light microscope were used.

3. Experimental methods:

Five liters of the studied leftover brine were directly and indirectly evaporated in a glass vessel, through evaporation experiments [The directly evaporated means that the process of evaporation is simulation as to sun ray using the infrared lamp, 250v at fixed distance from the brine surface. Indirect evaporation means that evaporation exists through closed glass vessel put in a thermal coil with a thermometer to measure the temperature of the brines (boiling method)] (Fig.1B).

The end point of saturation for every effect of the evaporation system was defined by controlling the evaporation process through the experiments on different temperatures to ensure no-double salt crystallization through the whole evaporation stages. The end point at each temperature was defined by watching the mounted thermometer at which the bittern sample was taken by pipette and chemical analysis (completely) at once (recorded temperature), "effect evaporation system" means the changes (existed solid phases) in the evaporated bitterns during evaporation process. The gained solid phases constituting the precipitated salt at each temperature were separated by filtration. The samples of liquid phases at each intervals of temperature were chemically analyzed, (Tables 1and 2). Chemical analyses, X-ray diffraction (XRD), energy dispersive x-ray diffraction (EDX) and scanning electron microscope (SEM) were applied to characterize the solid phases. Minerals were identified by means of X-ray diffraction, energy dispersive, X-ray diffraction (XRD), scanning electron microscope (SEM, EDX) and transmitted light microscope. The XRD data were correlated with results obtained from the thin section studies and the results of the scanning electron microscope and EDX.

3.1. Fractional Crystallization Method:

Continuously evaporated by boiling experiment method was adopted. This method differs from the above methods where at each step of evaporation, The precipitated salts have been totally removed from solution by filtration. The current method was started with a newer 3 liters of the studied leftover brine sample. This method was carried out following the same steps as adopted in equilibrium evaporation method, where at every stage of evaporation, liquid sample was taken to measure its density and ionic conductance as well as to determine its ionic composition by chemical analysis, but the salt phases, were totally removed from the brine solution to be tested by XRD and SEM.

3.2. Equilibrium evaporation method

This method involves the evaporation of brine without harvesting of the precipitated salts except for those taken for testing (XRD and SEM) to determine their mineralogical composition and morphological features, respectively. The method was carried out as follows:

- 1- 3 liters of the brine sample was put in a glass pan. The glass pan was placed in a thermostatic water bath adjusted at required temperature for the studied bittern sample.
- 2- The operative conditions in the laboratory were as close as possible to those existing at the site of study.
- 3- Let the bittern to start the evaporation process.

After a time that allows appropriate changes in the bittern density, the remaining volume of brine solution, densities were measured. At the same time, brine sample was taken for chemical analysis to determine its ionic composition, and simultaneously a minute sample of the separated solid phases salt in the saturated liquid was slightly filtered and stocked in small plastic bags for protection from the atmospheric humidity, and then this solid phase sample was taken for examination by XRD and SEM techniques.

- 4- Restarting of evaporation process with repetition of the previous steps until the evaporation of solution is stopped.

4. Results and Discussions

4.1. Mineral composition of solid phases:

A brief assessment of the mineral composition distribution in the solid phase at

50 °C and specific gravity 1.290 gm/cm³ by evaporation is indicated at the X-ray diffraction patterns for the detected minerals as follows: halite, hexahydrite and sanderite (MgSO₄·2H₂O). Halite, hexahydrite and sanderite were detected through X-ray diffraction technique and under the polarizing microscope.

Tabular shaped and cubic halite crystals, in addition to some halite (of sand-sized crystals) with fine grained were described, (Photos. 1A and B). Sanderites of sand-sized crystals possessing twinkling and interference color intermixed with the tabular halite crystals were also observed. This might be related to change in crystal morphology of hexahydrite becoming euhedral, while most of them are of pseudo-hexagonal habit. The observations of hexahydrite crystals and obviously at the edges are seen as pseudo-hexagonal crystals. This indicates that the precession of applied separation of the solid phase(s) is high and accurate, hence hexahydrite crystals separates from solution after halite crystallization (Fig. 1D). SEM and EDX detected the hexahydrite and sanderite crystals, while the microscopic investigation revealed the presence of traces of epsomite (Photos. 2A and B).

The mineral composition distribution in the solid phase at 55 °C and specific gravity 1.293 gm/cm³ by evaporation is detected, where X-ray diffraction patterns for the detected minerals are as follows: halite, and bloedite [Na₂(MgSO₄)₂·4H₂O]. Halite and bloedite were detected through X-ray diffraction technique and under the polarizing microscope, while traces of sanderite and hexahydrite were detected under crossed-nicols. At this temperature, the tabular crystals become longer in shape and almost of hexagonal. So, some of these hexagonal crystals may be related to hexahydrite, Autenrieth and Braune, (1960) and Wali, (2000). SEM and EDX investigations revealed that the pseudo-bipyramidal crystals are of bloedite, (Photos. 2C and D). Accretions of halite cubic crystals, in addition to some halite of sand-sized crystals with pseudo-bipyramidal bloedite crystals were detected as seen in (Photo. 1C).

The mineral composition distribution in the solid phase at 65 °C and specific gravity 1.296 gm/cm³ by evaporation is also recorded. The X-ray diffraction patterns for the detected minerals indicate the following: halite and kieserite with traces of sanderite and

hexahydrate. Agglutinations of kieserite crystals were detected under crossed-nicols. Kieserite crystals were revealed with sanderite in (Photos. 1E and F). SEM and EDX technique confirms the presence of Kieserite crystals (Photos. 3A and B). The mineral composition revealed in the solid phase at 70°C and specific gravity 1.298 gm/cm³ by evaporation is given, (Fig. 2A). The X-ray diffraction patterns for the detected minerals which are as follows: halite and carnallite with traces of kieserite, gypsum and anhydrite. Carnallite was differentiated by its bipyramidal prismatic shape as tiny crystals from halite, kieserite, gypsum and anhydrite under the microscope, (Photos. 4A and B). The crystallization phase of carnallite was also detected. The phase of carnallite with polyhalite was revealed in (Photos. 4C), seen as single pseudo-hexagonal crystals of carnallite under crossed-nicols, (Photos. 4A and B). SEM and EDX detected the carnallite crystals, (Photos. 4C).

The mineral(s) of the solid phase at 75°C and specific gravity 1.315 gm/cm³ reveal the presence of carnallite; halite and polyhalite were confirmed through the X-ray diffraction patterns for the detected minerals which are as follows: halite and carnallite with traces of polyhalite, (Fig. 2B). The size of carnallite crystals vary from large-size crystals to fine ones (100µm to 200µm) intercalated with halite of sand-sized crystals, (Photos. 4, A and B). The beginning of the main crystallization phase of carnallite is shown in Photos. 4A. Eugster et. al. (1980) and McCaffery, (1987), explained that the presence of polyhalite with solid phase of carnallite is due to the back reaction of early gypsum with the brine to form polyhalite. SEM and EDX detected and confirmed the carnallite crystals with polyhalite, (Photos. 3, C and E). The mineral assemblages identified by XRD and EDX at physiochemical parameters (Temp., Sp. Gr. And pH), (Table 1).

Table 1: show the mineral assemblages identified by XRD and EDX at physiochemical parameters (Temp., Sp. Gr. and pH)

Temperature (°C)	Mineral assemblages	(Sp.Gr.)	pH (10% soul.)
50	Hex, Ep, San, H	1.290	8.8
55	Blo, Hex, San, H	1.293	8.78
65	Kis, San, Hex, Blo, H	1.296	8.76
70	Car, Kis, H	1.298	8.75
75	Car, Pol, H	1.315	8.72
85	Bis, Car, H	1.331	8.7
100	Bis, H	1.370	8.6
110	Tach, Bis	1.370-drynes	

The mineral(s) of the solid phase at 85°C and specific gravity 1.331gm/cm³ reveal the presence of carnallite, halite and bischofite which were confirmed by X-ray diffraction patterns for the detected minerals: carnallite with bischofite and halite. The detection of carnallite with traces of bischofite might be the result of either non-accurate separation of the phase rule or the result of humidity effect during analyzes and/or preparation of thin-section. The microscopic investigations indicate the presence of carnallite as

bipyramidal crystals intermixed with halite cubic crystals with high interference color under crossed-nicols. The bischofite is seen as fine prismatic crystals, (Photo 4D). The main phase of crystallization of carnallite was detected under polarizing microscope according to the variation in the crystals size, (Photo 4C). The X-Ray diffraction patterns revealed that the solid phase of bischofite crystallization is present. Also, SEM and EDX confirmed the presence of bischofite crystals. The beginning of crystallization

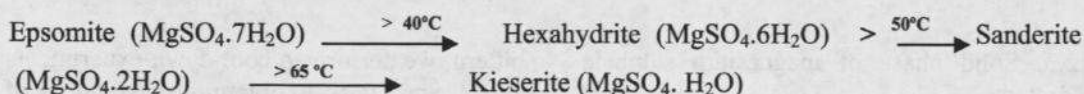
phase of bischofite was detected by SEM investigations, (Photo. 4D). The main phase of crystallization of bischofite was detected at 100 °C, (and specific gravity 1.370 gm/cm³, X-ray diffraction patterns confirmed this solid phase of crystallization of bischofite, (Fig.2C). SEM confirmed more the stages, where the detected elaboration of gases and formed vugs during crystallization and growth of bischofite is seen following from in to out manner. The phases of bischofite crystallization were detected as in two stages before the main crystals growth as seen in) representing meta-stable crystalline stages of bischofite. The final stage of evaporation from specific gravity 1.370 gm/cm³ till dryness at 110 °C indicate that the detected solid phases are bischofite and tachyhydrite. The X-ray diffraction patterns detected the tachyhydrite crystals, (Fig.2D).

The main phase of hydrated magnesium sulphate detected during evaporation at Sp. Gr. 1.270 gm/cm³ under crossed nicols. Prismatic and needle shaped crystals of hydrated magnesium sulphate were detected under crossed-nicols, (Photo. 4E), method of vug filling during the growing of crystals of hydrated magnesium sulphate were also detected as outer to inner manner under crossed nicols, (Photo. 4F).

The main crystallization phase of hydrated magnesium sulphate detected under crossed-nicols, (Photo. 4G), during the growing of crystals of hydrated magnesium sulphate and penetration was detected as bending for crystals, (Photo. 4H). Slightly bending crystals were detected also, (Photo. 4H) and the center of nucleation was detected. SEM and EDX of solid phase of hydrated magnesium sulphate crystals, (Photo. 3B) confirm the reached observation.

5.2.Path of Lake Quaroun bittern:

The path of Lake Quaroun brine at Sp. Gr. 1.290 gm/cm³ after extracting the anhydrous sodium sulphate plotted on Jänecke projection of the system Na⁺, Mg²⁺, Cl⁻, K⁺, SO₄²⁻ and H₂O at temperature 50 °C - 110 °C, (Fig. 3A). Plotting of Na - Mg // Cl - SO₄ - H₂O bittern of Lake Quaroun on Jänecke projection of the reciprocal system MgCl₂ - MgSO₄ - Na₂SO₄ - Na₂Cl₂ at 50 °C and 55 °C to show the range of compositions and their mineral precipitates. The path of the solid phase at 50 °C is shown in the (Fig. 3B) as hexahydrite and halite with traces of sanderite and epsom. The path of the solid phase at 55 °C as bloedite and halite with traces of sanderite, this indicated the hexahydrite is stable above 50 °C. The thermal effect on the epsomite show as:-



The epsomite is stable at the Na⁺/Mg²⁺ ratio < 2 Usdowski and Dietzel, (1998).

The path of the solid phase at 65 °C, 70 °C and 75 °C is shown as mainly kieserite and halite, with traces of sanderite and hexahydrite. The path of the solid phase at 75 °C is as carnallite and halite with traces of sanderite and kieserite. The initial kieserite will dissolve because it is unstable below 67.5 °C. This is in agreement with Usdowski and Dietzel (1998) observations.

Carnallite precipitates at the corner of MgCl₂ and is stable at the Mg²⁺/K²⁺ ratio > 2. In the studied bittern, carnallite is begins to precipitate at Sp. Gr. 1.315 gm/cm³ and temperature of 75 °C, the Mg²⁺/K²⁺ ratio is about 36.8. The solid phase at 75 °C, carnallite precipitates at the corners of MgCl₂ with traces of polyhalite. Polyhalite may be formed by back reaction of early formed gypsum with brines to make polyhalite.

The solid phase at 85 °C represented on the diagram is mainly carnallite with kieserite, halite and gypsum. The gypsum in this zone may be secondary gypsum. At 100 °C, the solid phase is mainly carnallite and bischofite with halite and with presence of traces of kieserite. Finally the solid phase at 110 °C to dryness is mainly bischofite, carnallite with traces of tachydrate.

5.2.1. Path of carnallite - bischofite precipitation

Carnallite precipitated in zones from 70 °C - 100 °C in Lake Quaroun bittern at specific gravities from 1.290 gm/cm³ -1.370 gm/cm³ and bischofite precipitated with carnallite at >70 °C - 110 °C. The brine from sea water is slightly under saturated in carnallite; KCl will precipitate until the carnallite reaches saturation [(Lowenstein and Spencer, 1990) and (Fokker et. al, 2000)]. In the studied bittern, presence of bischofite with carnallite

prevents direct sylvite precipitation. In the residual bittern of Lake Quaroun, sylvite is not precipitate only, but it will precipitate as carnallite at 70 °C followed by bischofite. This is due to the presence of bischofite with carnallite in the bittern at Sp. Gr. ranging from 1.298 gm/cm³ to 1.370 gm/cm³. So we can not detect the sylvite in the solid samples by using the available techniques, (Fig.4A).

5.2.2. Solid phase of bloedite mineral

The bloedite begins to precipitate at concentration of Mg²⁺=20 g/l with chloride

fraction = 0.5, the zone of bloedite extends to {Mg²⁺} = 58g/l with chloride fraction =0.76. In the studied bittern, bloedite begin to precipitate at {Mg²⁺} = 85 g/l with chloride fraction = 0.65, with increasing {Mg²⁺} and chloride fraction by evaporation, the epsom precipitates and followed by hexahydrate at {Mg²⁺} at about 80 g/l with chloride fraction about 0.85 and finally kieserite precipitates at {Mg²⁺} > 80 g/l with chloride fraction = ≈ 0.9, (Fig.4B) .

$$\text{Where } \{Mg^{2+}\} = \{MgCl_2\} + \{MgSO_4\}$$

$$fCl_2 = \{Cl_2^{2-}\} / CT$$

$$CT = \{Na_2^{2+}\} + \{K_2^{2+}\} + \{Mg^{2+}\} = \{Cl_2^{2-}\} + \{SO_4^{2-}\}.$$

$$fCl_2 = \{Cl_2^{2-}\} / \{Cl_2^{2-}\} + \{SO_4^{2-}\}. = 239.3/296.6 = 0.61.$$

The bloedite solid phase extends from 45 °C to up to 55 °C with {Mg²⁺} about >85 g/l. Where {Mg²⁺} = {MgCl₂} + {MgSO₄}.

The water content in the solid phase of bloedite is 357.2 moles

$$\text{Where: } \{Mg^{2+}\} = \{MgCl_2\} + \{MgSO_4\}$$

$$Wt = 10^5 / CT$$

$$CT = \{Na_2^{2+}\} + \{K_2^{2+}\} + \{Mg^{2+}\} = \{Cl_2^{2-}\} + \{SO_4^{2-}\}.$$

$$Wt = 10^5 / \{Cl_2^{2-}\} + \{SO_4^{2-}\}. = 10^5 / 296.6 = 357.2 \text{ moles.}$$

5.2.3. Solid phase of magnesium sulphate hydrated

The imitation of solar evaporation experiments were done by one liter of bittern at Sp. Gr. = 1.270 gm/cm³ by evaporation the volume decreases to reach 0.4 liter, where its Specific Gravity became 1.285 gm/cm³, and ratio of Na⁺ / Mg²⁺ ranges between 1.7 - 2.0. Through the experiments, we defined the end point of concentration by every effect of the system through controlling the evaporation experiments on different temperatures to ensure no double salt crystallized in whole evaporation stage in end of evaporation stage, Sp. Gr. = 1.285 gm/cm³ and bittern volume becomes about 0.4 liter and the ratio of Na⁺ / Mg²⁺ reaches about 0.4. (Fig.4C) show the plotted experiment evaporation data on the Quaternary phase diagram of Na⁺, Mg²⁺ // SO₄²⁻, H₂O. The studied experiment data located in the zone of hydrated magnesium sulphate with halite, the XRD and EDX revealed the solid phase crystals of epsomite, hexahydrate, kieserite and halite. When ratio of Na⁺/Mg²⁺ reaches about 0.4 in the studied

bittern, we performed cool down experiments at 0 °C and 10 °C, to obtain the high purity of epsomite, with care to test different cooling and washing conditions. This means that we can get high quality epsomite by dissolving and cooling recrystallization procedures.

Summary and Conclusions

The mineral composition of the solid phase crystals at 50 °C and the specific gravity 1.290 gm/cm³ were identified by above mentioned techniques. The solid phase crystals are characterized by the presence of hexahydrate, epsomite, sanderite and halite. Microscopically, crystals were tabular, ideal cube halite crystals, in addition to some halite sand crystals. Sanderite sand crystals have twinkling and interference color intermixed with prismatic hexahydrate crystals obvious at the edges of prismatic hexahydrate crystals. This indicates the precession separating the solid phase because the hexahydrate separates from solution after halite crystals.

The mineral composition of the solid phase

crystals at 55 °C and the specific gravity 1.293 gm/cm³ were identified by mentioned techniques. The solid phase crystals are characterized by the presence of bloedite, hexahydrate, sanderite and halite. Microscopically, there were accretions of cube halite crystals, in addition to some halite sand crystals with prismatic bloedite crystals. The mineral composition of the solid phase crystals at 65 °C and specific gravity 1.296 gm/cm³ were identified by mentioned techniques. The solid phase crystals are characterized by the presence of halite, and kieserite, with traces sanderite and hexahydrate. Microscopically, kieserite is characterized by hexagonal crystals.

The solid phase crystals at 70 °C and specific gravity 1.2985 gm/cm³ are characterized by the presence of halite, and Carnallite with traces kieserite, gypsum and anhydrite. Carnallite revealed microscopically as bipyramidal prism with tiny crystals of halite, kieserite, gypsum and anhydrite.

The mineral composition of the solid phase at 75 °C and specific gravity 1.315 gm/cm³ reveal the presence of carnallite, halite and polyhalite, the size of carnallite crystals vary from large size crystals to fine crystals intercalated with halite sand grained crystals, the presence of polyhalite with solid phase of carnallite due to back reaction of early gypsum with the brine to make polyhalite.

The mineral of the solid phase at 85°C and specific gravity 1.331 gm/cm³ reveal the presence of carnallite, halite and bischofite.

The microscopic investigation revealed that presence of carnallite as bipyramidal crystals intermixed with halite cube crystals with high interference color under crossed nicols, the bischofite presence as fine prismatic crystals. The phase(s) of crystallization of carnallite were detected under polarizing microscope according to the varying in the crystals size (from 100µm to 200µm).

The main phase of crystallization of bischofite detected at 100 °C and specific gravity 1.370 gm/cm³, SEM revealed the stages of gases vuges (bio-capsules) during crystallization of bischofite crystals. The final stage of evaporation from specific gravity 1.370 gm/cm³ – dryness at 110°C, the solid phase detected bischofite and tachyhydrite, X-ray diffraction and EDX detected the tachyhydrite crystals.

The path of carnallite–bischofite precipitation was detected. The solid phase of hydrated magnesium sulphate was detected by

evaporation at Sp. Gr. 1.270 gm/cm³ to Sp. Gr. 1.285 gm/cm³. The ratio of Na⁺ / Mg²⁺ ranges between about 1.7 - 2.0 and at the end of the evaporation stage, Sp. Gr. = 1.285 gm/cm³, the ratio of Na⁺ / Mg²⁺ reaches about 0.4. The plotted experiment evaporation data on the Quaternary phase diagram of Na⁺, Mg²⁺ // SO₄²⁻, H₂O shows the studied experiment data located in zone of hydrated magnesium sulphate with halite.

When ratio of Na⁺ / Mg²⁺ reaches about 0.4 in studied bittern, we performed cooling experiments at 0 °C and 10 °C, to obtain the high purity of epsomite. We tested different cooling and washing conditions, this means we could get high quality epsomite by dissolving and cooling recrystallization. The plotted experiment cooling data on the Quaternary phase diagram of Na⁺, Mg²⁺ // SO₄²⁻, H₂O at 0 °C and 10 °C, shows the studied experiment data at 0 °C located mainly in the zone of epsomite with traces of halite. The crystallization salt sequences of the evaporation experiment of the studied bittern at Sp. Gr. from 1.270 gm/cm³ - 1.285 gm/cm³ and Temp. (60 °C - 75 °C) compared with sea water solar salt sequences.

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