Ministry of Energy

Geological Institute

Testing the feasibility of dissolving and removing the salt from the salt harvest

of Pool 5 to the Dead Sea through the dissolution in seawater

And concentrated water from desalination - kinetics of halite dissolution

Itay Gabrieli and Itay Reznik

Summary

The salt harvesting project promoted by the Dead Sea Enterprises by virtue of a government decision from 2012 includes transporting the salt harvested in pool 5 to the northern basin of the Dead Sea and burying it in the Dead Sea. The volume of salt that will be transported is approximately 16 million cubic meters per year (16 mm/h) with a weight estimated by the factories to be approximately 20 million tons. Transporting such large volumes of salt through the Linz Straits, and burying them in the deep sea raises serious concerns regarding visibility and footprint The expected petition for the project on the Linz straits and the southern Dead Sea. The Dead Sea factories are aware of these concerns and are open to alternative proposals to their original proposal to transport the salt to the northern basin by means of a conveyor belt that would cross the Linz straits and bury the salt in the southern sea while plugging Tzalim Bay and later by transporting the salt in barges or as a suspension further north and sinking it in the middle of the sea.

The current work examines an alternative proposal for salt disposal that combines the salt harvesting project and the Red Sea - Dead Sea pipeline project, if and when it is established. The proposal examines the possibility that the harvested salt will be dissolved by sea water and/or concentrated and tributary water to the north in a dissolved state without the need to establish a conveyor belt and heavy infrastructure in the northern basin of the Dead Sea. Calculations and thermodynamic experiments of the dissolution of salt collected from the salt harvesting batteries indicate the high dissolution potential of the two solutions in question (sea water and concentrated water). In addition, kinetic experiments show that under conditions of constant mixing, the solutions reach saturation and the full exhaustion of their dissolution potential in only two and a half minutes.

The implementation of the proposal in question is conditional on the establishment of a Red Sea - Dead Sea pipeline project in a format similar to that proposed in the feasibility study of the World Bank in 2012 and which was approved in principle by the governments of Israel and Jordan. The calculations show that given the volume of harvest and the limitations of discharge into the Dead Sea that were proposed as part of the feasibility study for the project (up to 400 mm/h per year), then it will be possible to melt all the annual salt harvested by the Dead Sea factories and the Jordanian factories (which are estimated together at about 35 mm/h) And still not exhausting the full dissolution potential of the solutions. Realizing the full dissolution potential will allow the diversion or flow of only about 110 ml" of sea water or about 125 ml" of concentrated water for the purpose of dissolving the full volume of the annual harvest of the two factories. At the end of the mixing process and the melting, the salt-rich solutions will flow into the Dead Sea. The mixing of these solutions in the Dead Sea is expected to lead to the deposition of salt in a mechanism similar to the one that accompanies the deposition of salt when mixing the final salinities in the Dead Sea water and to the development of the salt delta at the outlet of Nahal Arba.

The work does not deal with the techno-engineering and economic aspects of the implementation of the proposal.

introduction

Government Decision No. 4060 dated 1-1-2012 states that the level of pool 5 of the Dead Sea factories must be preserved at a height of up to 15.1+ in the Dead Sea factories network by harvesting the salt at its bottom. Pool 5 is the first pool in the evaporation ponds of the factories and it sinks the "tefal" The main ingredient of the industry, cooking salt (halite - NaCl), at a rate estimated by the factories to be about 20 cm per year. Along the western shores of the pool, the major tourist complexes of the Dead Sea - Hami Zohar and Ein Bokek - were established. The central factor in this regard was a decision on the government The salt harvest was the rise of the water level in the pool following the deposition of the salt. This level rise was accompanied by a rise in the ground water level which led to flooding and undermining of the foundations and structures closest to the pool and required water pumping in order to lower the levels. It was expected that the continued rise in the pool level would also lead to direct flooding of the hotels, And it will require the construction of protective embankments which will harm the visibility and attractiveness of the place (some of which have already been erected). Additional considerations for promoting the salt harvesting project was the fear of the continued elevation of the embankments and their breach following a seismic event. To this were also added environmental considerations concerning the continuous mining of wadi material required for the elevation of the embankments.

Given that the area of the pool is about 80 square kilometers and based on the factory's assessment of an accumulation rate of about 20 cm per year, then the annual volume of salt that must be harvested and removed from the pool in order to maintain its level is about 16 million cubic meters. The Dead Sea factories estimate the weight of salt to be reduced by about 20 million tons per year. Initiating, planning, promoting and carrying out the salt harvest was assigned to the Dead Sea factories under the supervision of the state's planning committees, headed by the National Infrastructures Committee (HOT). Lensky et al., 2010. Since the Dead Sea brine is saturated with halite, then the rye salt is expected to sink to the bottom without affecting the composition of the sea. A landfill of 16 million cubic meters is relatively negligible in terms of the volume of the Dead Sea and is equivalent to a level rise of less than 3 cm. And this against the background of an average annual drop of 1.15 meters in the last decade.

As of the time of writing this report, the salt harvest has already begun using a dedicated harvester and it is stacked inside Pool 5 as batteries with a general east-west direction, the cumulative length of the two batteries is about three kilometers, 140 meters wide and 15 meters high and they touch the eastern battery of Pool 5. Lifting the batteries in the pool area 5 harms the production of the factories as it somewhat reduces the evaporation area of the raw solution.

The Dead Sea factories have not yet proposed a long-term solution for the method of transporting and burying the salt from the salt harvest in the Dead Sea. However, the factories are examining and promoting, among other things, the construction of a conveyor belt to transport the salt which will cross the Linz Straits and end in the southern Dead Sea/Tzalim Bay. Hence, there are several alternatives for burying the salt, among them filling and plugging the Gulf of Tzalim, which is expected to dry up anyway due to the drop in the level. In addition, the factories are currently promoting their plan for the "Green Sodom" In the Linz Straits, a plan that includes, among other things, the stacking of salt from the salt harvest as a base for placing solar panels.

Even if the above-mentioned plans are implemented, they only provide an answer to the salt harvest for a period of a decade or two, but they do not provide a long-term solution for the expected industrial activity in the coming decades. Such a solution, which was proposed in the past by the Dead Sea Enterprises, may include the establishment of a port in the south of the sea and the launching of ships/barges that will load the salt that will arrive with the conveyor belt, go out into the sea and there they will release their cargo. Such a move will turn the southern Dead Sea into an industrial area and change its appearance from end to end. The fear of the environmental impact and the huge footprint expected for the salt harvesting project on the southern Dead Sea, brings various parties to propose other creative solutions for transporting the salt to the Dead Sea, apart from the conveyor belt and the port at its end.

The Jordanian potash plants - Arab Potash Co. -APC, harvesting the salt in their evaporation ponds and piling them there for many years. Although APC is not subject to restrictive environmental guidelines such as those that exist in Israel, it can be assumed that any solution for the removal of salt to the northern basin that is found to be applicable in Israel will also be adopted by the Jordanians, especially if the solution is based on resources shared by Israel and Jordan.

The current document examines the potential of dissolving the salt from the salt harvest by sea water and/or concentrated water from desalination and transporting it in a dissolved state to the Dead Sea, without the need to build heavy infrastructure on the coast of the sea. This solution will only be applicable if the governments of Israel and Jordan reach an agreement on the construction of a pipeline from the Red Sea to the Dead Sea, in a similar outline to that proposed in the feasibility study of the World Bank which ended in 2012. The results of the feasibility study at the time supported a combination of pumping seawater from the depths of the Eilat Bay, the sea in pipes on the Jordanian side of the Arabah towards the Dead Sea, the construction of several hydroelectric stations along the route, the construction of a desalination plant that will supply desalinated water mainly to Jordan and the flow of concentrated water from the desalination to the south of Lisan Bay in the Jordanian Dead Sea in order to slow down the rate of the level drop. The feasibility study also included examining the consequences of mixing seawater with saltwater, and as a result it was determined that the discharge of up to 400 million cubic meters per year into the Dead Sea is not expected to significantly change its properties (Gavrieli et al., 2011).

A combination of the Red Sea - Dead Sea pipeline project with a solution for the salt of the salt harvest by melting it and transporting it to the Dead Sea without building heavy infrastructure to the coast may be a spurring factor for promoting the pipeline project and even possibly a source of its partial financing, subject to a techno-economic analysis of the proposal being considered in The current h.

Materials

Salt from the salt harvest was sampled from dikes in Pool 5 where it was piled up. The batteries sampled are 154-4 and 154-2 where the first is a battery that was harvested six months to a year before sampling while the second is a fresh battery that contained salt that was harvested during the month before sampling. Accordingly, the first battery was covered with a thin layer of dust that was removed before sampling.

For the purpose of defining the boundary conditions of the experiments, the solid halite and the end solutions were characterized:

The level of cleanliness of the salt was determined by completely dissolving it and testing the ions dissolved in the water. This test showed that the harvested salt is halite with a very high level of cleanliness (>99.5% NaCl). The grain size distribution of the harvested salt was determined by filtering through sieves representative samples from each pile. The results indicate relatively homogeneous grinding for a grain size between 0.354-4 mm (Figure 1).

Seawater was collected from the beach of Palmahim. Concentrated desalination water (hereafter concentrated water) was received courtesy of Mekorot's desalination facility in Ashdod.

The chemical analyzes of the experimental solutions were carried out in the laboratories of the Geological Institute.
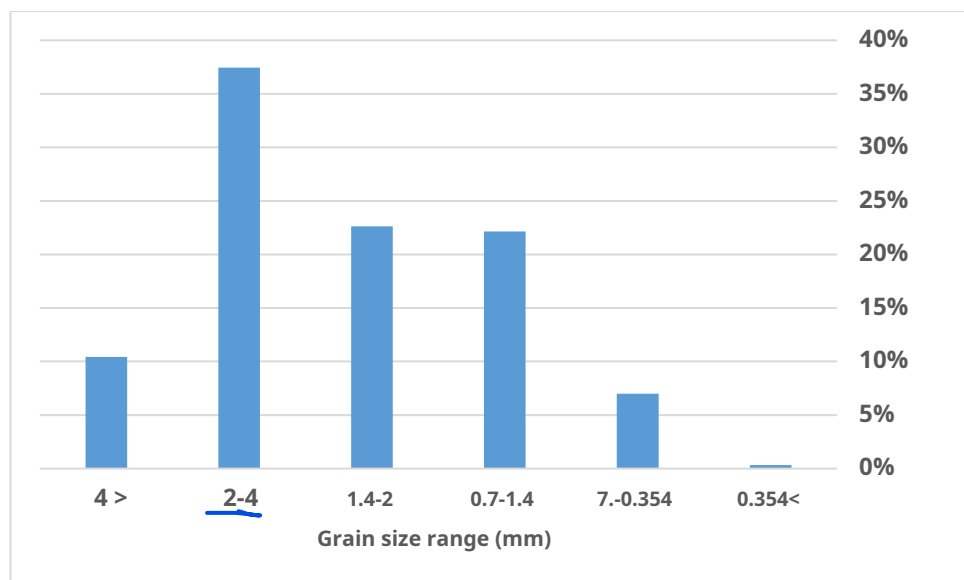
Figure 1 Grain size distribution of the salt from the pool salt harvest5 (average of three siftings from two different salt piles)

The course of the experiments and results

In order to chemically and quantitatively describe the dissolution reaction of the salt from the salt harvest (hereafter halite) in seawater and concentrated water, thermodynamic and kinetic experiments were performed while comparing the results of dissolution experiments in distilled water. The dissolution experiments were conducted in a controlled manner and at different ratios of solid (halite) to solution (table) 1) After the complete dissolution of the halite, the density and electrical conductivity of the solution were measured. The mass experiments were also conducted during which the electrical conductivity was measured continuously for the purpose of analyzing the dissolution rates. These experiments were conducted while intensively mixing the salt grains and the solution using a magnetic stirrer.

The chemical compositions of the solutions at the end of the dissolution reactions (Table 2) were modeled in the PhreeqC software (Appelo, 2013 Parkhurst and) for the purpose of calculating the degree of saturation of the solution.

T (°C)	Density (kg/L)	Leftover crystals?	pH	T (°C)	EC (mS/cm)	Salt [C] (g/Kg initial solution)	Grain size (mm)	Water type	Exp. #
23.9	0.9973	no	7.45	23	0.0106	0	DW	Unsorted	TD-1
23.9	1.0307	no	8.668	22.6	72.9	50	DW	Unsorted	TD-2
23.9	1.0617	no	7.02	22.4	128.3	100	DW	Unsorted	TD-3
24	1.0914	no	6.388	22.7	171.6	150	DW	Unsorted	TD-4
24	1.1185	no	6.04	22.6	203	200	DW	Unsorted	TD-5
24.1	1.1448	no	5.511	22.8	226	250	DW	Unsorted	TD-6
24.1	1.1689	no	5.5	22.9	241	300	DW	Unsorted	TD-7
24.5	1.1923	no	7.02	24.1	249	350	DW	Unsorted	TD-8
24.3	1.1939	Yes	7.16	24.1	250	400	DW	Unsorted	TD-9
23.8	1.0270	no	8.439	23	58.5	0	SW	Unsorted	TD-10
23.8	1.0593	no	8.416	23	117.9	50	SW	Unsorted	TD-11
23.8	1.0903	no	8.318	22.9	163.8	100	SW	Unsorted	TD-12
23.8	1.1191	no	8.288	23.1	197.9	150	SW	Unsorted	TD-13
23.9	1.1453	no	8.158	23	221	200	SW	Unsorted	TD-14
24	1.1713	no	8.038	23.3	237	250	SW	Unsorted	TD-15
24.2	1.1968	no	7.953	23.4	246	300	SW	Unsorted	TD-16
24.4	1.1969	Yes	7.88	24.1	24 7	350	SW	Unsorted	TD-17
23.8	1.0479	no	8.653	23.3	93	0	RB	Unsorted	TD-18
23.8	1.0804	no	8.539	22.8	145.2	50	RB	Unsorted	TD-19
23.8	1.1106	no	8.417	22.8	184.3	100	RB	Unsorted	TD-20
23.9	1.1387	no	8.32	22.8	212	150	RB	Unsorted	TD-21
24	1.1659	no	8.329	23.3	231	200	RB	Unsorted	TD-22
24.1	1.1911	no	8.146	23.4	241	250	RB	Unsorted	TD-23
24.2	1.1980	Yes	8.137	23.7	244	300	RB	Unsorted	TD-24
24.4	1.1983	Yes	7.11	23.6	250	400	DW	1.4-2	K-1
24.4	1.2018	Yes	7.69	23.7	24 7	400	SW	1.4-2	K-2
24.7	1.2034	Yes	8.127	23.8	244	400	RB	1.4-2	K-3
24.5	1.1987	Yes	7.255	23.7	250	400	DW	2-4	K-4
24.9	1.2011	Yes	7.944	24.1	24 7	400	SW	2-4	K-5
25	1.2031	Yes	8.11	24.1	244	400	RB	2-4	K-6

Table 1 Details of the set of thermodynamic and kinetic melting experiments. The table lists the experiment number, whether the salt stacks The salt is sifted and if so, to what range of grain size, the type of solution (DW - distilled water); SW - sea water; RB - concentrated water from desalination), the amount of salt added to the solution (in units of grams of salt per kilogram of solution before dissolution), the electrical conductivity and the temperature measured at the end of the experiment after dissolution, the value of the rise, whether there were any crystals left at the end of the experiment, and the density and temperature of the liquid at the end of the experiment. Must be taken into account that since the salt dissolving reaction is endothermic there is a temperature amplitude of 1.5 degrees between the temperature measured using the electrical conductivity sensor in real time and the temperature of the density meter measured about an hour after the end of the reaction.

kgw/kgs	TDS	SO_4^{-2}	Bro^-	Cl^-	Sr^{+2}	Mg^{+2}	Ca^{+2}	K^+	No^+	mg/L
1.00	0	0	0	0	0.0	0	0	0	0	TD-1
0.95	50840	119	30	30321	0.4	38	50	31	20235	TD-2
0.90	96884	159	44	59071	0.7	74	89	91	37339	TD-3
0.85	146378	191	54	88395	1.2	116	134	53	57176	TD-4
0.81	190799	315	67	114636	1.5	136	182	49	75157	TD-5
0.77	232868	331	80	140712	1.7	187	220	57	91027	TD-6
0.73	271021	403	94	163286	2.0	249	249	39	106450	TD-7
0.68	315136	450	76	193452	2.4	240	286	97	120281	TD-8
0.68	318268	479	101	194748	2.2	274	286	22	122126	TD-9
0.96	42868	2865	88	24346	8.2	1562	496	447	12805	TD-10
0.91	93657	2953	99	55133	8.4	1574	534	491	32621	TD-11
0.86	139653	3329	118	82256	9.1	1585	562	473	51067	TD-12
0.81	190337	3381	129	112003	9.2	1592	609	468	71888	TD-13
0.77	230896	3287	143	136703	9.4	1633	655	467	87744	TD-14
0.73	268317	3250	150	162289	9.4	1547	680	478	99660	TD-15
0.69	312601	3348	162	188507	9.8	1642	705	508	117461	TD-16
0.68	321274	3517	175	194318	10.2	1694	752	455	120094	TD-17
0.93	72464	5615	137	40102	15.0	2800	864	857	21828	TD-18
0.88	124702	5743	153	71603	15.2	2733	910	767	42527	TD-19
0.83	169309	5620	165	98876	14.9	2682	914	706	60080	TD-20
0.78	221380	5772	181	128906	15.5	2760	969	784	81738	TD-21
0.73	265697	5635	190	154954	15.3	2665	980	767	100232	TD-22
0.70	302270	5598	198	179824	15.8	2724	1027	802	111822	TD-23
0.68	324248	5654	211	194005	15.6	2714	1043	783	119563	TD-24
0.68	319656	501	103	196047	2.3	284	296	19	122150	K-1
0.68	322134	3570	166	194659	9.9	1669	743	438	120619	K-2
0.66	335072	6130	224	198280	16.9	2951	1134	838	125237	K-3
0.68	316880	457	99	193448	2.1	265	276	26	122103	K-4
0.67	329062	3387	159	194666	9.8	1613	722	424	127826	K-5
0.68	321754	5552	202	192625	15.3	2618	1001	813	118665	K-6

Table 2 The composition of the main ions of the solutions from the thermodynamic and kinetic experiments (in units of milligrams per liter) in the final The halite melt. In order to switch to weight units, the water concentration in the brines at the end of each experiment is also indicated (in units of kilograms of water per kilogram of solution - kgw/kgs). The deviation in the charge balance (RE - reaction error) in all solutions does not exceed ±2%.

(a) Thermodynamic experiments (TD):

The purpose of the thermodynamic experiments is to calibrate the relationship between the amount of dissolved salt and the electrical conductivity, density and degrees of saturation in each of the three solutions tested (distilled water, sea water and concentrated water).

The dissolution experiments were conducted in series of 7 containers for each solution. Each series included an increasing amount of halite in increments of 50 grams of salt per kilogram of solution. Upon reaching complete dissolution, the electrical conductivity and density of the solution were measured (Figures 2 and 3, respectively). These parameters were also measured for the experimental solutions themselves, without the addition of halite. The maximum amount of salt dissolved in each series of experiments (the dissolution potential of each solution) was calculated by extrapolation of polynomial regressions adjusted between the electrical conductivity and the amount of dissolved salt and between the density and the amount of dissolved salt up to the maximum values measured in experiments in which an excess amount of salt was introduced which did not dissolve even after several hours (see horizontal lines representing the equilibrium values and regression lines based on the results of the experiments). According to these calculations, the maximum amounts of halite dissolved in distilled water, seawater, and concentrated water are 356, 302, and 266 grams per kilogram of original solution (before dissolution), respectively. These values translate to a mass potential of 355, 310, and 279 grams of halite per liter of solution Original (before melting) for distilled water, sea water and concentrated water, respectively.

These differences illustrate the difference in the melting potential between the solutions, and as expected indicate a decrease in the melting potential with the increase in salinity.
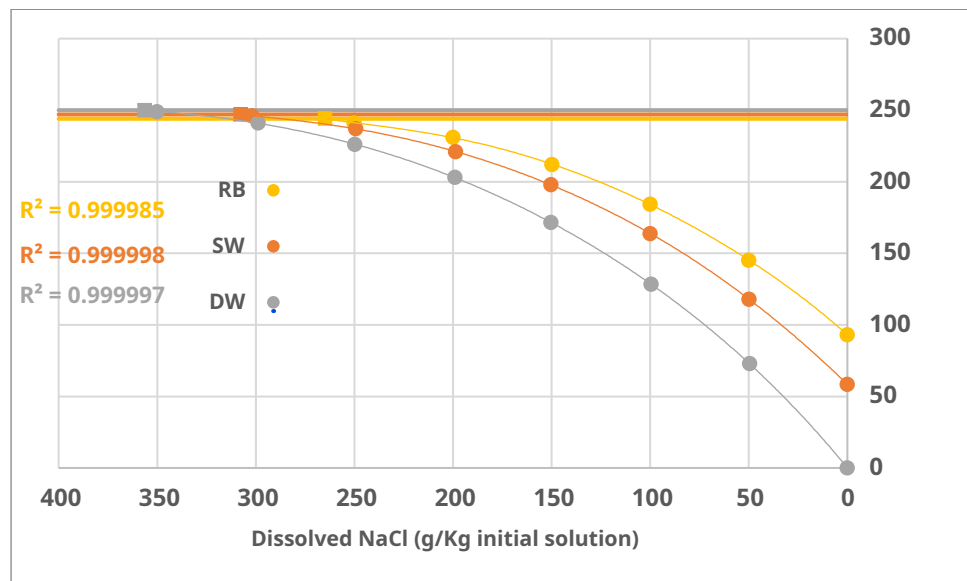

Figure 2 Electrical conductivity against the amount of salt dissolved in each experiment. The horizontal lines represent the electrical conductivity values The maximum in each series of experiments to which the polynomial regressions adjusted to the experimental results were extrapolated. DW - distilled water. SW - sea water. RB - concentrated water from desalination.
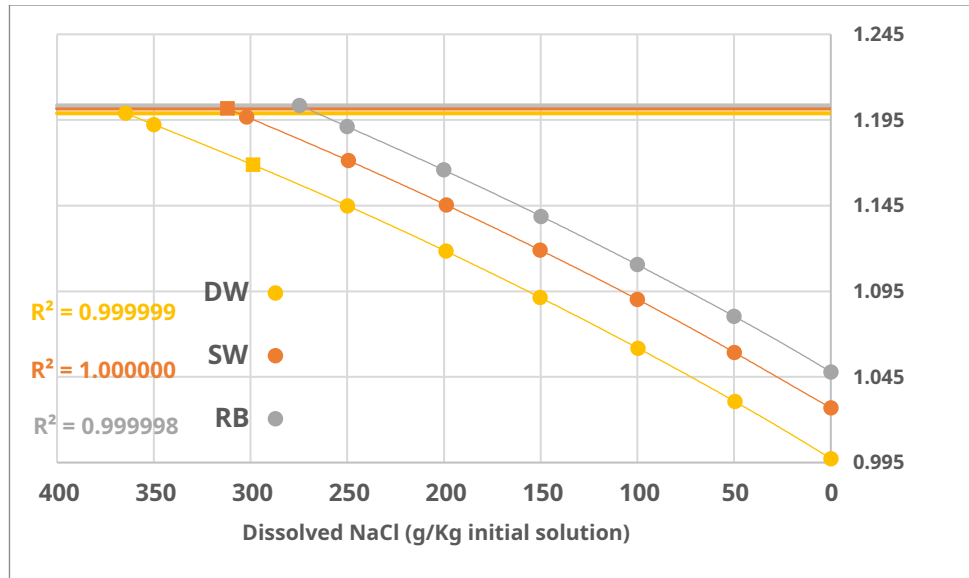
Figure 3 Density against the amount of salt dissolved in each experiment. The horizontal lines represent the maximum density measured in each A series of experiments to which the polynomial regressions adjusted to the results of the experiments were extrapolated. DW - distilled water, SW - sea water, and RB - concentrated water from desalination.

(b) Kinetic experiments (K):

Kinetic experiments were performed on a fixed and excess amount of salt (400 grams of salt per kilogram of solution) that were added at once to the different solutions (distilled water, sea water, and concentrated water) while they were mixed and stirred using a magnet and a magnetic stirrer located at the bottom. Two series of experiments were performed, one on salt with a grain size of 1.4-2 mm, and the second on salt with a grain size of 2-4 mm. The monitoring of the dissolution kinetics was carried out through continuous measurement of the electrical conductivity of the solution in time, with a resolution of one second, using a WTW type sensor (Multi 3630) The electrical conductivities measured during the experiments were converted to the amount of salt dissolved at any given moment by using the empirical relationships established in the thermodynamic experiments (Part A).
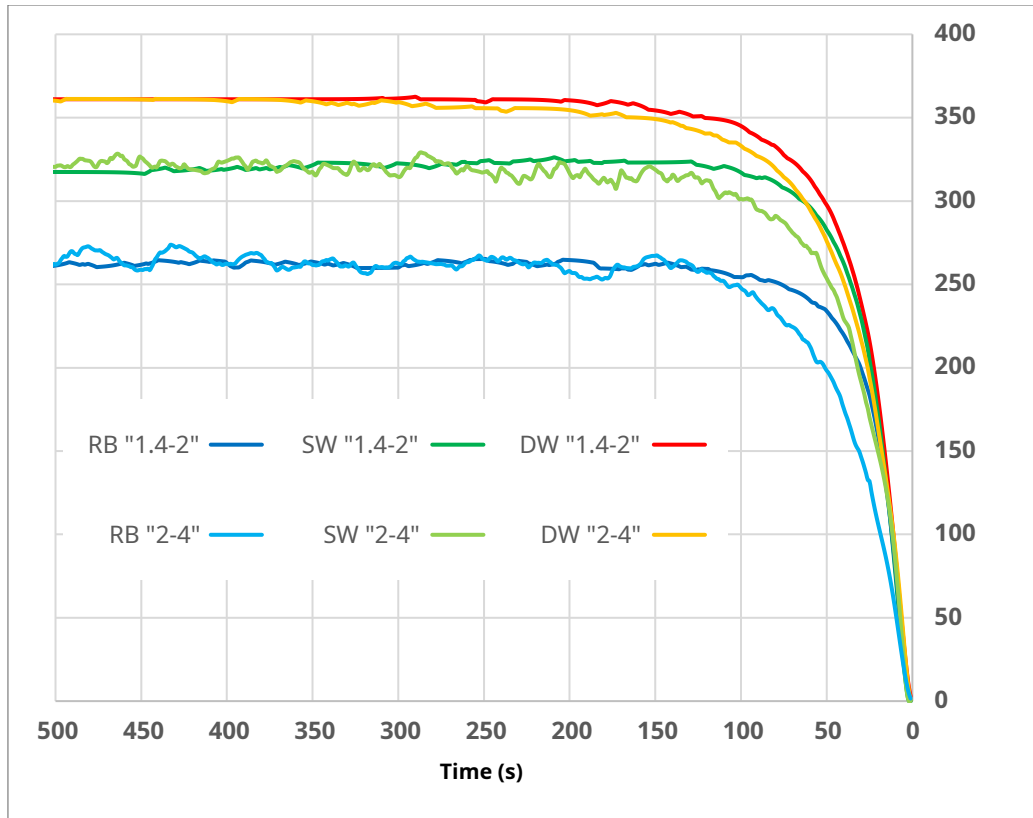
8

Figure 4 The amount of salt dissolved as a function of time in each experiment. The experiments indicate that equilibrium is reached within two and a half hours

subtlety. It can be clearly recognized that for each solution, the salt dissolution rate is faster when the grain size is smaller.

discussion

Figure 4 indicates two familiar points from the theory of mass kinetics but important to note:

1. The dissolution rate is smaller the closer the solution is to equilibrium.
2. The smaller the grain size (that is, the larger available surface area) the faster the melting rate.

In addition, until about 80% of the dissolution potential of the salt in each solution is exhausted, the dissolution rate remains relatively linear and less dependent on the available surface area and proximity to equilibrium. Reaching equilibrium occurs within two and a half minutes in all experiments despite the different experimental conditions in terms of grain size and the different solutions.

The kinetic analysis of the experiments was based on the following equation (Brantley, 2008):

$$\text{Eq. (1): Log Rate (g halite kg solution-1 s-1) = log (k) + n log (1-}\Omega\text{)}$$

Where: n is the order of the reaction (average value of 2±10%), k is the kinetic constant (average value of 0.95±10%) and Ω is the degree of saturation calculated by the PhreeqC.

Figure 5 describes the results of the experiments based on equation 1. The low dispersion obtained from the rate law between experiments shows that there is no distinct chemical mechanism difference (same rate law per unit mass) between the different solutions and the different grain sizes

tested in ... a smaller regger,
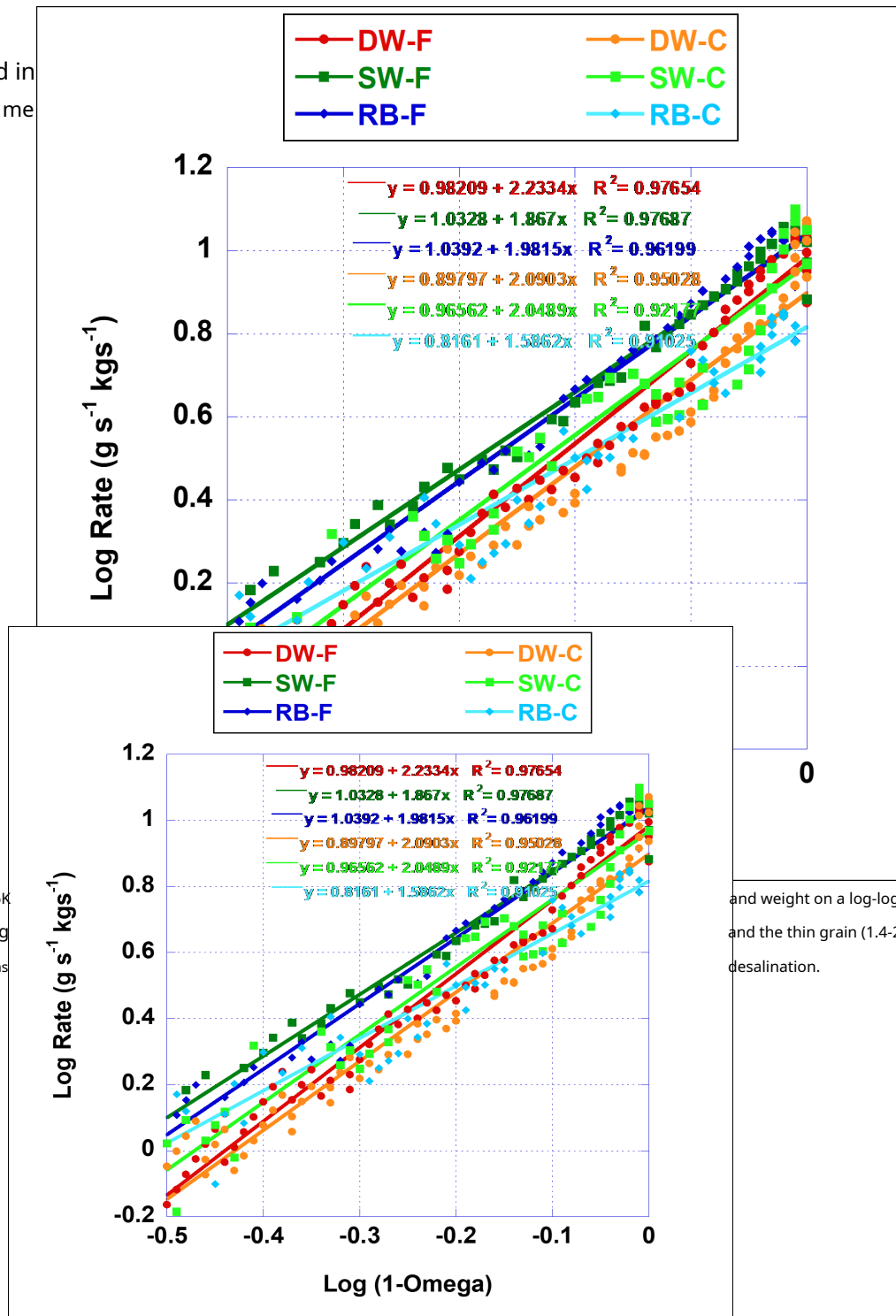cause me

Figure 5 ... and weight on a log-log scale. This scale

allowing ... and the thin grain (1.4-2 mm), (C) 27 from

- Fractions ... desalination.

Implications for the salt harvest project

A kinetic/thermodynamic analysis based on the results of the described experiments makes it possible to determine the melting potential of the salt from the salt harvest in seawater or concentrated water from desalination if and when these reach the southern Dead Sea as part of the Dead Sea Transport Project: it should be emphasized that the analysis here does not take into account the technical challenges- engineering-economic in implementing this method of removing the salt from the southern basin to the northern basin.

According to the Dead Sea Enterprises, the salt harvesting project is expected to harvest about 20 million tons of salt per year. Assuming that the factories in Jordan (APC) harvest about 15 million tons per year (estimation based on the ratio of the evaporation areas), the general amount of salt to be disposed of is about 35 million tons per year.

In the feasibility study for the Red Sea - Dead Sea project conducted for the World Bank by the Geological Institute and Theal (Gavrieli et al., 2011), it was determined that the discharge of up to 400 mm/h of seawater/concentration water is not expected to substantially change the nature of the sea

According to these numbers, if the pipeline project is realized and includes in the first stage a discharge of the upper limit of 400 mm/s, then the melting of approximately 0.088 tons of halite per cubic meter (m"c) of solution (88 g) will be sufficient. per liter of solution (to remove the full weight of the salt harvest of the two plants.

In practice, the melting potential of seawater and concentrate water from desalination are significantly higher than 0.088 tons of halite per cubic meter of solution and stand at 0.310 and 0.279 tons of halite per cubic meter, respectively. That is, the mass of 0.088 tons of halite per cubic meter of solution exhausts only 28% and 32% of the melting potential of sea water and concentrated water, respectively. Therefore, if the engineering solution is found to maintain a constant ratio of mixing salt and solution in suitable mixing/spinning facilities, and an amount of sea water and/or concentrated water in a volume of 400 ml/h is poured in, the great melting potential will not be exhausted and the melting rate is expected to be very fast (less than 20 seconds). Accordingly, the required residence time of the solution-salt mixture in the mixing facility is expected to be extremely short.

Alternatively, since the potential amount of salt that can be removed by melting according to the above calculations significantly exceeds the annual amount of salt harvested by the two factories, it will be possible to melt all the salt harvested from the two factories even in volumes smaller than 400 ml/h. Assuming that you will find a way to bring the solutions to saturation at the rate observed in the laboratory (about two and a half minutes), then the annual volume of seawater required to remove all the salt is:

$$ _3\,_610 \cdot 110 \sim\ =\ \frac{0.31}{3}\ \div _610 \cdot 35 $$

And who is the coordinator:

$$ _3\,_610 \cdot 125 \sim\ =\ \frac{0.28}{3}\ \div _610 \cdot 35 $$

It can be assumed that even after it is agreed upon between the parties, it will take a long time until the implementation of the Red Sea and Dead Sea project. On the other hand, the adoption of the solution of dissolving the harvest salt using sea water allows temporary storage of the salt in the ponds knowing that with the establishment of the project it will be possible within a few years to melt and remove the entire volume of salt that had accumulated until then. The annual amount of salt that can be removed while bringing the seawater to saturation with a discharge of 400 mm/h is:

$$ _610 \cdot 125 \sim = \frac{0.31}{3} \cdot _3 \; _610 \cdot 400 $$

And who is the coordinator:

$$ _610 \cdot 110 \sim = \frac{0.28}{3} \cdot _3 \; _610 \cdot 400 $$

These amounts are 3-3.5 times higher than the amount of salt that sinks annually in the Israeli and Jordanian factories combined.

As mentioned, the residence time required according to the laboratory experiments to reach the exhaustion of the melting potential and reach equilibrium is about two and a half minutes. If necessary, it will be possible to reduce the above residence time by grinding the salt grains to a finer grain size than is currently done by the barges in order to speed up the melting rate.

Another point that must be taken into account is that it is likely that if a fine grain of salt that has not fully dissolved remains, it will be able to be removed in suspension as it melts, towards the northern basin, thereby even increasing the potential amount of salt that can be transported to the northern basin.

As described in the introduction, the World Bank's recommendation, which was adopted at the time by all parties involved, was to establish the entire Red Sea-Dead Sea pipeline in Jordan and to release the sea water and/or the concentrate water in the Gulf of Lisan in the southeast of the Dead Sea, also within the territory of the Kingdom of Jordan. Hence, in order to realize the idea presented here, it will be necessary to transport the salt from the salt harvest of the Dead Sea factories to the territory of Jordan and from there mix it with the transported water, or alternatively, pull part of the volume of the transported water towards the factories and perform the melting there. However, it must be carefully considered whether it would be correct to release these solutions, after the melting, in a free flow through Nahal Arba, between the batteries of the Dead Sea and APC plants, since these solutions will still have the potential to dissolve and therefore they may melt parts of the batteries built from litium. In addition, there is a fear of increased silting in Nahal Arava, which could endanger the ponds as well. Because of this, even if the melting of the salt from the salt harvest of the Dead Sea factories takes place on the territory of the Israeli factories, it will still be necessary to flow the solutions back to the Kingdom of Jordan for their release in the Lysan Gulf, in accordance with the World Bank's proposal.

Apart from the techno-economic question, the consequences of mixing the sea water and the concentrated water, which dissolved large amounts of salt, with the Dead Sea must also be examined. Preliminary thermodynamic calculations indicate that such mixing will be accompanied by outsalting of salt, similar to what happens in the Salt Delta (1997 Beyth, M., 1998, Gavrieli et al., 1989, Gavrieli). This is in addition to the expected deposition of gypsum when mixing water Sea and concentrated water in the Dead Sea, 2009, Reznik et al., 2010, Reznik et al., 2012, Reiss et al., 2021 (Reznik et al.). These topics will be examined in separate works.

thanks

bibliography

Beyth, M., Katz, O., Gavrieli, I., 1998. Propagation and retrogradation of the Salt Delta in the Southern Dead Sea: 1985 – 1992. Isr. J. Earth Sci. 46, 95 – 106.

Brantley, S.L., 2008. Kinetics of mineral dissolution. In Kinetics of water-rock interaction (pp. 151 - 210). Springer, New York, NY.

Gavrieli, I., Starinsky, A., Bein, A., 1989. The solubility of halite as a function of temperature in the highly saline Dead Sea brine system. Limnol. Oceanogr. 34(7), 1224-1234.

its setting (eds. T. Niemi, Z. Ben-Avraham, J.R. Gat) chap. 14, p.161-170. Oxford University Press
Gavrieli, I., 1997. Halite deposition from the Dead Sea 1960-1993. In: The Dead Sea: the lake and

Sea Study. Final Report. Isr. Geol. Surv., Rep. GSI/10/2011 and TAHAL Rep. IL-201280-R11-218 Y., Dvorkin, Y., Gertman, I., Wells, S., Simon, E., Rosentraub, Z., Reznik, I., Elias, E., (2011). Dead Gavrieli, I., Lensky, N., Abelson, M., Ganor, J., Oren, A., Brenner, S., Lensky, I., Shalev, E., Yechieli, (Submitted to the World Bank)

Lensky, N., Gertman, I., Rosentraub, Z., Lensky, I., Gavrieli, I., Katz, O. (2010). Alternative dumping sites in the Dead Sea for harvested salt from pond 5. Rep. GSI/05/2010.

geochemical calculations. In: Modeling and Techniques. In: U.S. Geol. Surv. Tech. Methods, vol. a computer program for speciation, batch-reaction, one-dimensional transport, and inverse Parkhurst, D.L., Appelo, C.A.J., 2013. Description of input and examples for PHREEQC version 3 – 6. U.S. Geological Survey, Denver, Colorado.

Gypsum Precipitation under Saline Conditions: Thermodynamics, Kinetics, Morphology, and Size Reiss, A.G.; Gavrieli, I.; Rosenberg, Y. O.; Reznik, I. J.; Luttge, A.; Emmanuel, S.; Ganor, J. (2021). Distribution. Minerals, 11, 141.

Reznik, I. J., Gal, A., Ganor, J., and Gavrieli, I., (2009). Gypsum saturation degrees and precipitation potential from Dead Sea-Seawater mixtures. Environmental Chemistry, 6 (5), 416-423.

high ionic strength solutions; case study of Dead Sea-seawater mixtures. Geochimica et Reznik, I. J., Antler, G., Gavrieli, I., and Ganor, J., (2010). Kinetics of gypsum crystal growth from Cosmochimica Acta 75, 2187-2199.

Reznik, I. J., Gruber, C., Ganor, J., and Gavrieli, I. (2012). Towards the establishment of a general rate law for gypsum nucleation. Geochimica et Cosmochimica Acta, 85, 75-87.

and the salt is temporarily being accumulated on dams northwards across Lynch Strait to the southern shores of the Dead Sea and the disposal of the salt in the project. The said project includes harvesting of salt from the bottom of the Pond, its conveyance this trend and maintain a constant water level in Pond 5, ICL-DS is to plan and execute the Salt Harvesting in the water level of the Pond. However, in 2012 the Government of Israel decided that in order to stop meters (MCM) or about 20 million tons of salt. Until recently, this accumulation lead to a continuous rise (ICL-DS; formerly known as the Dead Sea Works -DSW) is estimated by the industry to be 16 million cubic The annual volume of salt (halite- NaCl) that accumulates in Pond 5 of the Israel Chemicals LTD, Dead Sea2020visual impact on the Lynch Strait and the Southern Dead Sea. ICL-DS is aware of these concerns and is sunk. Consequently, there is a growing concern that the project will have a significant environmental and be conveyed as slurry or by large vessels to the deeper parts of the lake, where it will be released and The salt that will be conveyed will first be used to fill the Ze'elim Bay and as space runs out, it will need to tentative plans include the construction and operation of a long conveyance belt across the Lynch Strait. within Pond 5. The details of the rest of the project are still undecided and under discussion whereas the Dead Sea. Dredging of the salt began in

willing to consider alternatives to their tentative plans.

for the construction of large infrastructures in the Lynch Strait and along the shores of the Southern Dead reject brine (RB) from desalination, that will be available through the RSDSP, thereby eliminating the need (in dissolved state) of the harvested salt from the industrial complex to the Dead Sea by seawater (SW) or if and when the latter will be constructed. We investigate the potential for the dissolution and transport salt, which integrates the Salt Harvesting project with the Red Sea – Dead Sea Conveyance Project (RSDSP), Here we present and examine an alternative suggestion for the transport and disposal of the harvested

Sea.

harvested salt show that under constant stirring and with enough available salt, dissolution to full potential by the two stock solutions (SW and RB), whereas kinetic experiments with samples of the Thermodynamic calculations and laboratory experiments confirm the high solubility values/dissolution

Saturation requires no more than 2.5 minutes.

is similar to the mechanism responsible for the precipitation of salt upon mixing of the Industries' end the solutions with the Dead Sea brine would lead to salt precipitation, under a chemical mechanism that salt (35 million tons) is much smaller: 110 MCM/yr of SW or 125 MCM/yr of RB. The mixing of either of solutions were to attain full saturation, the volumes required to dissolve the entire amount of harvested tons annually). Under these conditions, the SW/RB will still remain undersaturated. Furthermore, if the DSW and its Jordanian counterpart, the Arab Potash Company (APC) (estimated together as 35 million of the project (400 MCM/yr) it is possible to dissolve the entire volume of salt that is harvested by both Given the constraints on the volume of solution that may be discharged to the Dead Sea in the first phase construction of the RSDSP as outlined by the World Bank and approved in principle by Israel and Jordan. The realization of the described transport and disposal solution for the harvested salt depends on the

brines in the Southern Dead Sea and the development of the Salt Delta.

The work does not investigate the techno-industrial-economic aspects of the proposed solution for the

harvested salt.

Ministry of Energy
Geological Survey of Israel

the Dead Sea by seawater or reject brine from disposal of the harvested salt from Pond 5 to Feasibility study for the dissolution and desalination: Halite dissolution kinetics

Ittai Gavrieli and Itay Reznik