

Determination of Brine Evaporation Rates in Solar Ponds as a Function of Magnesium Chloride Concentration

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ABSTRACT

A parameter fundamental in the understanding of solar pond systems is the brine evaporation rate during the concentration process.

It is known that the evaporation rate diminishes as salinity in the brine increases, due to the influence of the dissolved solids on the water vapor pressure. The decline of water vapor pressure as aqueous solutions become more concentrated results in a lower quantity of energy leaving the solution as latent heat of vaporization, due to the lesser activity of mass transference in the interphase. The incident energy is transformed into latent heat, so that as salinity increases, a lower evaporation rate takes place.

Many empirical and theoretical correlations have been developed between the rate of evaporation and the main affecting parameters—wind, air and brine temperatures, and air relative humidity. It has been found that the brine evaporation rate diminishes as density increases, the latter being normally associated with increasing quantities of dissolved salts.

A fairly simple system to determine the evaporation rate in small metallic pans for alkali and alkaline earth brines of different compositions and densities is proposed and does not attempt to extrapolate these results to industrial solar ponds, a subject to be discussed in another paper.

INTRODUCTION

The paper attempts to predict the behaviour of brine evaporation rates through successive mathematical and empirical approximations as a function of dissolved solids, in particular magnesium chloride. It is only an approximation because the activity of water is affected by the different dissolved ions and not the salts.

DEVELOPMENT OF SOLAR EVAPORATION THEORY

Initial studies in this field stated that the rate of evaporation could be expressed by the Dalton equation:

$$E = k(P_w - P_a) \quad (1)$$

where

k = mass transfer coefficient, a function of horizontal wind speed, from water to air

P_w = vapor pressure of the water surface

P_a = partial pressure of water vapor in the air.

Ferguson stated the following (1952):

$$E = (2h/L) \cdot \{f' \cdot [(Q/h + 2P_a + \theta_a)] - P_a\} \quad (2)$$

where

Q = net gain of radiant energy

h = heat transfer coefficient

f' = a function of the vapor pressure vs. temperature curve for water

θ_a = air temperature ($^{\circ}\text{C}$)

L = latent heat of vaporization of water.

Also, we have

$$h = 0.48 + .083V$$

where

V = wind speed (ft/s).

A simplified version of the last equation (2), can be stated as

$$E = 2h/L \cdot (P_w - P_a). \quad (3)$$

As it can be observed, the estimation of evaporation rate as a function of meteorological parameters is a long and tedious task that requires a comprehensive and expensive data gathering process.

EVAPORATION RATE AS A FUNCTION OF CONCENTRATION

When evaporation rate measurements are taken on a set of brines at different concentration in small metallic pans of equal size and shape, concentration is the only variable.

Thus, we have the following:

$$E_o = 2h/L(P_{wo} - P_a) \quad (4)$$

where

E_o = evaporation rate of pure water

P_{wo} = vapor pressure of the water surface.

The evaporation of a brine can be expressed as

$$E = 2h/L(P_w - P_a) \quad (5)$$

Dividing (5) by (4), we have

$$E/E_o = (P_w - P_a)/(P_{wo} - P_a) = m \cdot (P_w - P_a) \quad (6)$$

It is known that vapor pressure P_w is a function of salinity. It can be observed in tables showing the relationship between the vapor pressure of aqueous solutions and the concentrations of various salts that for alkali and alkaline earth salt solutions an approximate linear relation takes place between the decrease of vapor pressure of the brine and concentration, at levels under 4 moles of salt per liter of solution.

That is to say, we have roughly the following linear relationship:

$$P_w = \beta_0 + \beta_1 \cdot CX \quad (7)$$

where

β_0 and β_1 = constants and

CX = concentration of a dissolved salt.

Studies by Lee (1927), Rohwer (1933), Adams (1934) and Young (1947), have presented papers indicating that the rate of evaporation of sodium chloride solutions decreases by 1% for each 1% salinity increase. These results are compatible with Equation (7).

Bonython and Myers (1958) in their paper *The Theory of Recovering Salt From Sea Water by Solar Evaporation*, have expressed the rate of evaporation as a function of a coefficient called "salinity" (wt. % of Mg divided by the volume of the brine).

The rate of evaporation would follow a linear relationship with "salinity" for sodium chloride saturated brines, which before further evaporation have the composition of seawater (Figure 1). During the concentration of nonsaturated brines, the relationship between relative evaporation rates and salinity is practically linear as well (Figure 2).

Garrett (1966) provides information on tests run in New Zealand and Pakistan on the evaporation rates of sea brines

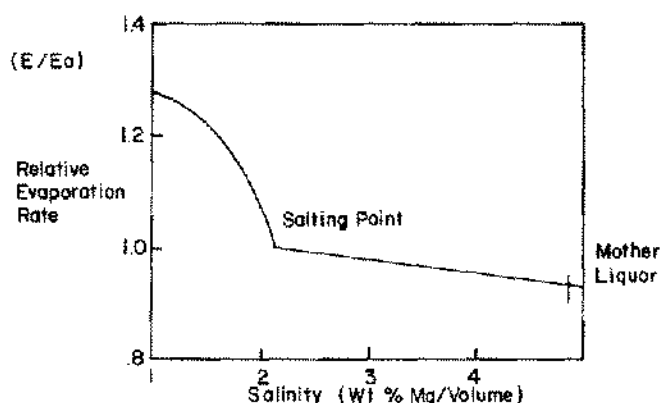


Figure 1. The rate of evaporation for sodium chloride saturated brines.

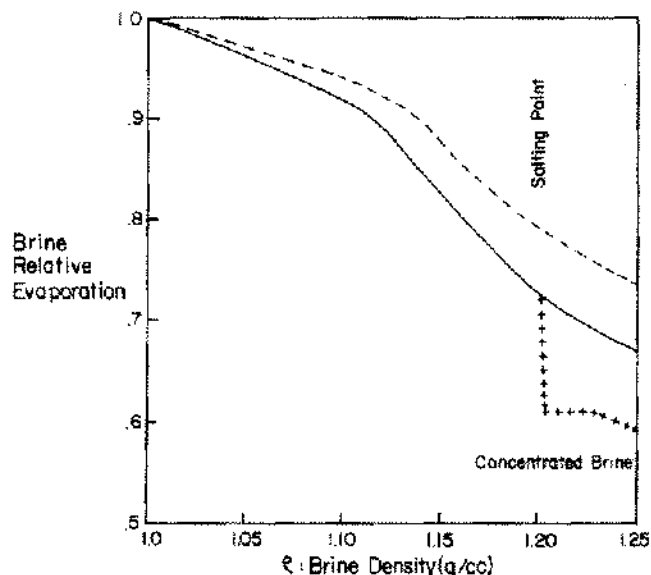


Figure 2. The relative rate of evaporation versus density.

within a density range between 0° and 35° Be. The results of these tests, expressed as the relative evaporation rate (brine evaporation rate divided by pure water evaporation rate), versus $MgCl_2$ concentration, show the co-existence of two lines of different slopes, the change in slope occurring at the saturation point of sodium chloride (Figure 3). These tests, run with a multicomponent brine system, indicate that a linear relationship exists between the brine relative rate of evaporation and some distinct parameter.

Through a successive set of approximations, it will be shown that $MgCl_2$ concentration is the parameter which exhibits a linear relationship with the relative rate of evaporation for sodium chloride saturated brines.

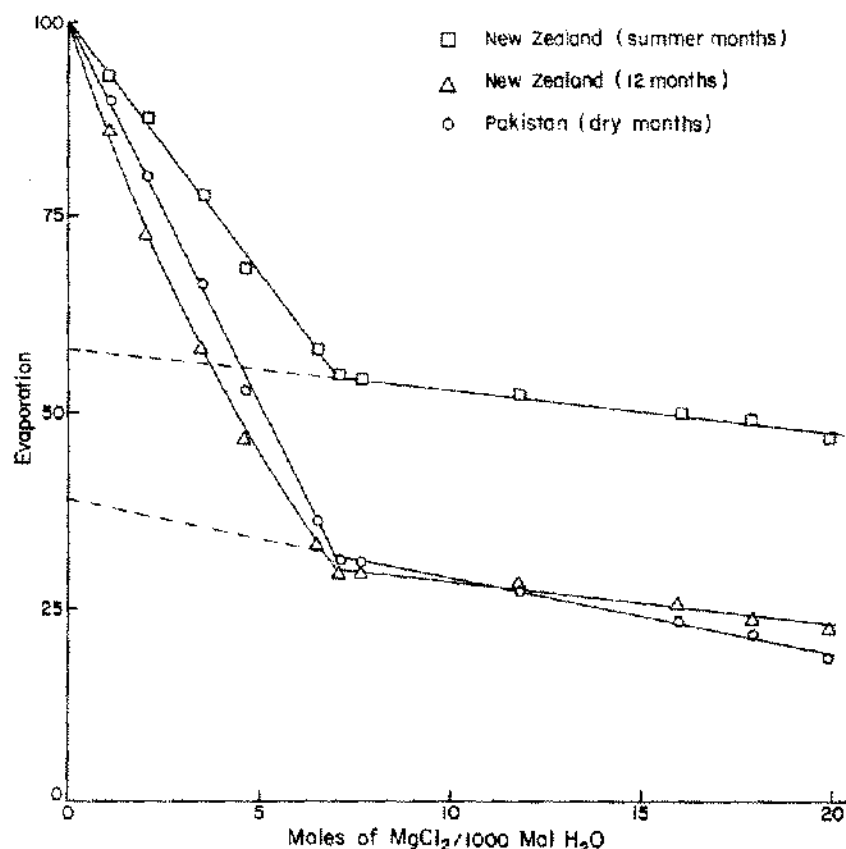


Figure 3. Effect on MgCl_2 concentration on evaporation rate.

APPLICATION OF THE FERGUSON EQUATION TO PREDICT EVAPORATION RATES OF BRINES

In industrial operations the sodium chloride saturation point in solar ponds does not represent the final stage. On the contrary, it marks the beginning of a series of solar ponds and industrial processes. Where NaCl is the main salt to be recovered from a brine, it corresponds to crystallization and harvesting ponds. In other cases, where other more valuable products are the main recovery goal, such as potassium, iodine, bromine, magnesium, sulfate, it is an intermediate stage.

Beyond its saturation point sodium chloride concentration declines as evaporation continues, with the concentration of other components in the brine increasing until they reach saturation.

Within concentration ranges under 4 gram moles per liter, the effect of alkali and alkaline earth salts (chlorides, sulfates, nitrates) in the decrease of the partial vapor pressure of water follows a roughly linear relation with concentration. This same relationship holds for most of the salts that are harvested from solar ponds. (See Table 1).

There are two clear exceptions: MgSO_4 and MgCl_2 . The effect of the first salt in the decrease of vapor pressure of

TABLE 1

Lowering of Partial Water Vapor Pressure at 100°C Due to the Concentration of Different Salts

	Gram Moles						
	0.5	1.0	2.0	3.0	4.0	5.0	6.0
H_3BO_3	6.0	12.3	25.1	38.0	51.0		
KCl	12.2	24.4	48.8	74.1	100.9	128.5	152.2
LiCl	12.1	25.5	57.1	95.0	132.5	175.5	219.5
Li_2SO_4	13.3	28.1	56.8	89.0			
MgSO_4	6.5	12.0	24.5	47.5			
MgCl_2	16.8	39.0	100.5	183.3	277.0	377.0	
NaCl	12.3	25.2	52.1	80.0	111.0	143.0	176.5
NaNO_3	10.6	22.5	46.2	68.1	90.3	111.5	131.7
KNO_3	10.3	21.1	40.1	57.6	74.5	88.2	102.1

Source: Smithsonian Tables.

water is approximately half of the majority of the alkali and alkaline earth salts; and the latter shows an influence that is higher than the average by 80% to 100%.

Two alternatives are possible when a brine during its concentration process has achieved the sodium chloride saturation stage, and further evaporation proceeds, when there is no magnesium in the brine. They are as follows:

1. If upon further evaporation, the concentration of the dissolved solids in the brine increases, the relative rate of evaporation will continue to decline, but the decline will show a slower rate after the sodium chloride saturation point.
2. If the concentration of the dissolved solids remains roughly constant, the evaporation rate beyond the sodium chloride concentration will be fairly stable.

When magnesium is present in a brine this ion concentrates during the evaporation process and its concentration turns out to be the main parameter affecting evaporation. As indicated, the influence of MgCl_2 in the decrease of the vapor pressure of water is much higher than the remainder of the alkali and alkaline earth salts, and this influence is very clear when magnesium concentration is over 10g/l (0.5 gram mol/l). Equation (6) was expressed as

$$E/E_o = (P_w - P_a) \cdot m \quad (6).$$

Let $P_w = f(C \text{ MgCl}_2, C \text{ other salts})$.

As a first approximation, all the alkali and alkaline earth salts except MgCl_2 will be considered to exert the same influence on vapor pressure. Accepting the latter statement, we have

$$P_w = \sum_{i=1}^n F(CX_i)$$

where CX_i = concentration of salt (grams/l). It has been stated that the following applies:

$$P_{wi} = (\beta_0)_i - (\beta_1)_i \cdot CX_i \quad (7)$$

Then for a multicomponent system

$$P_w = \sum_{i=1}^n \{(\beta_0)_i - (\beta_1)_i \cdot (CX_i)\} \quad (8)$$

Replacing (8) in (6) the following is obtained:

$$E/E_o = m \cdot [\sum_{i=1}^n ((\beta_0)_i - (\beta_1)_i \cdot (CX_i)) - P_a] \quad (9)$$

$$E/E_o = m \cdot [\gamma_0 - \sum_{i=1}^n (\beta_1)_i \cdot (CX_i)] \quad (10)$$

$$\text{Where } \gamma_0 = \sum_{i=1}^n (\beta_0)_i - P_a, \text{ and} \quad (11)$$

$$\begin{aligned} \sum_{i=1}^n (\beta_1)_i \cdot (CX_i) &= (\beta_1)_1 \cdot CKCL + (\beta_1)_2 \cdot CNaCl \\ &+ (\beta_1)_3 \cdot CMgCl_2 \\ &+ \dots + (\beta_1)_n \cdot CX_n \end{aligned} \quad (12).$$

As indicated

$$\begin{aligned} \beta_3 &= \beta_{MgCl_2} \approx 2 \cdot \beta_{KCl} \approx 2 \cdot \beta_{NaCl} \approx 2 \cdot \beta_{K_2SO_4} \\ &\approx \text{etc.} \approx 2 \cdot \beta_2 \dots \approx 4 \cdot \beta_{MgSO_4} \end{aligned} \quad (13).$$

Then

$$\sum_{i=1}^n (\beta_1)_i \cdot CX_i = \beta_3 \cdot \{CMgCl_2 + 1/2 \cdot \sum_{i=1}^n (CX_i^*)\} \quad (14)$$

where CX_i = total dissolved solids minus MgCl_2 . Then

$$\begin{aligned} \sum_{i=1}^n (\beta_1)_i \cdot CX_i &= (\beta_3) \cdot CMgCl_2 + 1/2 \cdot (\beta_3) \cdot (\sum_{i=1}^n (CX_i^*)) \\ &= 1/2 \cdot (\beta_3) \{2CMgCl_2 + \sum_{i=1}^n (CX_i^*)\} \\ &= 1/2 \cdot (\beta_3) \{CMgCl_2 + CMgCl_2 \\ &\quad + \sum_{i=1}^n (CX_i^*)\} \\ &= 1/2 \cdot (\beta_3) \{CMgCl_2 + \sum_{i=1}^n (CX_i)\} \end{aligned} \quad (15).$$

If $\sum_{i=1}^n (CX_i) \approx \text{constant}$, then

$$\sum_{i=1}^n (\beta_1)_i \cdot (CX_i) \approx 1/2 \cdot (\beta_3) \cdot \{CMgCl_2 + \sum_{i=1}^n (CX_i)\} \quad (16).$$

Replacing (16) into (10), it can be derived

$$E/E_o = m \cdot \{\gamma_0 - 1/2 \cdot (\beta_3) \cdot [CMgCl_2 + \sum_{i=1}^n (CX_i)]\} \quad (17).$$

Then if $\sum_{i=1}^n (CX_i)$ is approximately constant, equation (17) becomes

$$E/E_o = m \cdot \{\alpha_0 - \alpha_1 \cdot C \text{ MgCl}_2\} \quad (18)$$

where

$$\begin{aligned} \alpha_0 &= (\gamma_0) - 1/2 \cdot (\beta_3) \cdot \{\sum_{i=1}^n (CX_i)\} \\ \alpha_1 &= 1/2 \cdot (\beta_3). \end{aligned}$$

If $\sum_{i=1}^n (CX_i)$ is not constant, equation (17) becomes

$$E/E_o = m \cdot [\alpha_0 - \alpha_1 \cdot C \text{ MgCl}_2 - \alpha_2 \cdot \sum_{i=1}^n (CX_i)] \quad (19)$$

where

$$\begin{aligned} \alpha_0 &= \gamma_0 \\ \alpha_1 &= 1/2 \cdot \beta_3 \approx \alpha_2. \end{aligned}$$

FIELD AND EMPIRICAL TESTS

In an effort to evaluate the proposed approximation, data from various independent tests run in Australia (Bonython 1966), the United States (Kayser Aluminium and Chemical Corp.) and Chile (CORFO, Salar de Atacama) were examined.

Bonython experimented with seawater within a density range of 1.03 to 1.24 g/cc. The composition and densities of the brines utilized in the test at Bonneville (Kayser, U.S.A.) and at the Salar de Atacama (CORFO, Chile) are shown in Tables 2 and 3.

In these tests, the evaporation rates of water and brines at different compositions were measured for a certain period of time. Kayser's test lasted three months. The experiment at the Salar de Atacama was run for 3.5 years (in this paper only the first two years have been included) and Bonython's test lasted a year.

Metallic pans were used in each of the three trials. They were placed side by side and had uniform size and physical characteristics (shape, color, location, size, etc.) In the Salar de Atacama the following precautions were taken:

1. Keep the brines colored.
2. Keep the metallic pan walls with a salt crust, in order to diminish energy losses and to have a white inside colored wall.

TABLE 2
Initial Compositions for Brines Used in the Bonneville
Evaporation Experiment (Utah, U.S.A.)

(In Wt.%)					Relative Evaporation
Density	KCl	MgCl ₂	NaCl	SO ₄	
1.20	4.20	5.13	15.65	0.94	69
1.24	5.48	15.75	5.86	1.80	57
1.26	5.83	17.17	6.16	1.89	47
1.28	3.63	22.88	2.85	2.37	39
1.30	2.80	25.82	1.83	2.51	27.5
1.32	0.28	30.78	0.67	2.17	15
1.34	0.22	32.20	0.60	2.25	10
1.00					100

TABLE 3
Average Compositions for Brines Used in the Salar de Atacama
Evaporation Experiment*

gr/liter					Relative Evaporation
Density	KCl	MgCl ₂	NaCl	MgSO ₄	
1.234	63	40	197	26	70
1.267	80	86	114	56	59
1.300	50	160	48	35	43
1.312	13	289	14	—	37
1.330	5	356	3	—	28
1.350	—	415	1	—	15
1.000	—	—	—	—	100

*Also in solution is Li₂SO₄ (and H₃BO₃).

Results from other experiments were available but not used due to the lack of knowledge of the systems employed and the accuracy of the data provided. In his report Bonython (1966) explains the different major sources of error in the determination of evaporation rates, specifically if the tests are not run accurately.

The results of the three cited experiments expressing the rate of evaporation versus density are shown in Figure 4. From that figure the influence of MgSO₄ can be noticed: for any given density, the evaporation rate is higher for the brines that started with the higher MgSO₄ concentration in the feed brine.

The relative rate of evaporation of different sodium chloride saturated brines versus MgCl₂ concentration is seen in Figure 5. This was done to verify whether the approximations derived previously in this paper could be utilized as a useful tool for the prediction of the evaporation rates of brines during their evaporation process. A value equal to 100 was given to the rate of evaporation of pure water and 73 for a sodium chloride saturated brine.

According to previous studies, the relative rate of evaporation for a NaCl saturated brine should be close to 73.5%. At the Salar de Atacama the same value was arrived at, and in Australia the value obtained was 72.5% (Rowher, 1933; Lee, 1927; Adams, 1934).

REGRESSIONS

A regression correlating relative rates of evaporation with concentration of MgCl₂ (in moles/mole of water) was performed.

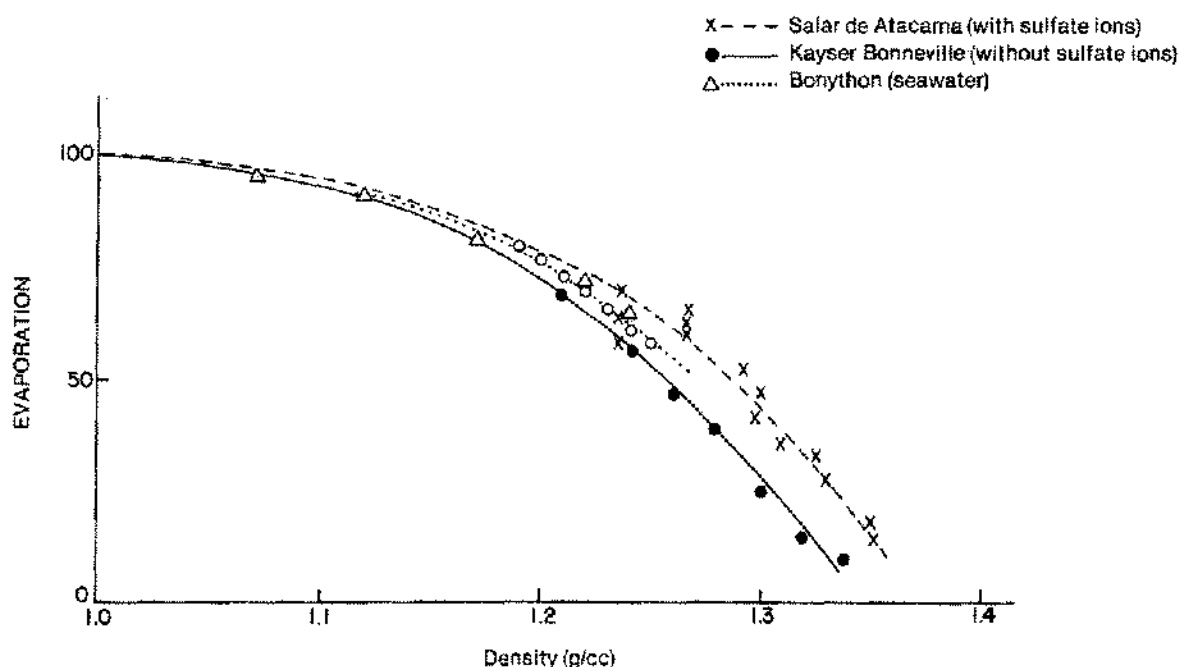


Figure 4. Results of Salar de Atacama, Kayser Bonneville and Bonython experiments expressing the rate of evaporation versus density.

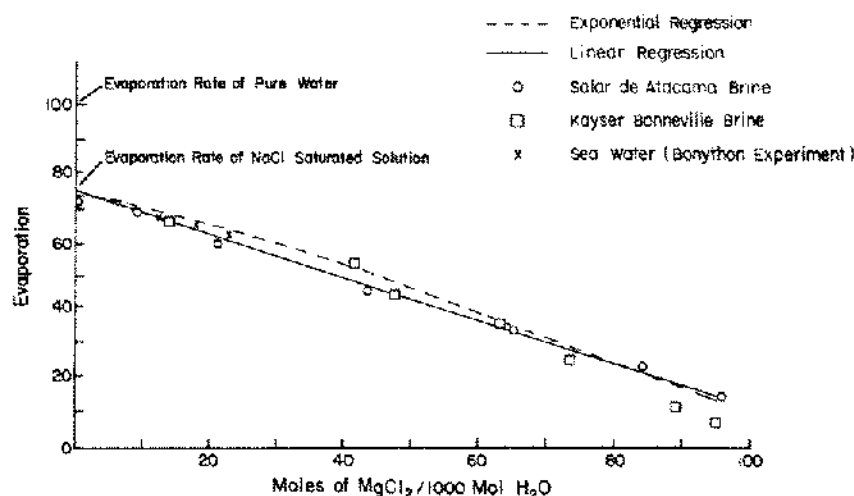


Figure 5. The relative rate of evaporation of different sodium chloride saturated brines versus MgCl_2 concentration.

In Appendices 1 through 3, the compositions of the brines used in the experiments performed in the United States, Australia and Chile are given. In Appendix 4, Table 1, the results of the three experiments are shown in terms of relative evaporation rates vs. MgCl_2 concentration. Regression results are given in Tables 2 and 3 of Appendix 4.

The confidence tests performed (Student t and Fischer-Snedecor) show that there exists a highly linear relationship between the relative rate of evaporation and the concentration of MgCl_2 up to four moles per liter. The probability of error, if the linear relationship hypothesis is accepted, is less than .1%.

A second regression was performed, assuming that the effect of MgCl_2 in the relative rate of evaporation did not follow a linear relation but a geometric one ($y = a \cdot x^b$),

$$D - ev_r = ev_r^* = A \cdot C^B$$

where

ev_r = relative evaporation

C = MgCl_2 concentration

$D = 74$ (Rohwer's value for relative evaporation rate for a solution saturated in NaCl).

As in the previous case, confidence test analysis shows a high correlation between the relative evaporation rate and MgCl_2 concentration for the model developed. The probability of error, if the geometrical relationship hypothesis is accepted, is less than .1%.

It can be deduced from the previous calculations, which are validated by experiments performed in Chile, Australia and the United States, that a good correlation exists between relative evaporation rates and the concentration of MgCl_2 in solutions saturated in Na_2Cl_2 which also contain other alkali and alkaline earth salts.

FINAL COMMENTS

The relative evaporation rates for solutions saturated in NaCl, which are concentrated in solar ponds, possess a high correlation with MgCl_2 concentration, which can be expressed in linear or geometrical forms.

An approximation for the rapid determination of relative evaporation rates for NaCl saturated solutions that are concentrated in solar ponds and contain high levels of magnesium ion is presented. Given only the evaporation rate of pure water and of sodium chloride saturated solutions as a check, the form of this curve can be estimated to be

$$ev^* = \alpha_0 + \alpha_1 \cdot C \text{ MgCl}_2$$

where $C \text{ MgCl}_2$ is in moles of $\text{MgCl}_2/1000$ moles of water, where

$$\alpha_0 = 76.7 \text{ (relative evaporation rate of a solution saturated only in NaCl)}$$

$$\alpha_1 = .5906.$$

This equation, as has been shown, can be used as a first approximation to determine relative evaporation rates for concentrations of magnesium less than 4.0–5.0 gram moles/liter of water (90–110 grams of Mg /liter of solution).

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Appendix 1

TABLE 1

Composition of Bonneville Experimental Brines

(In Wt. %)						
Density	MgCl ₂	KCl	NaCl	MgSO ₄ *	Total Solids	Water
1.20	5.13	4.2	15.65	1.12	26.1	73.9
1.24	15.65	5.48	5.86	2.16	29.15	70.85
1.26	17.19	5.83	6.16	2.27	31.45	68.55
1.28	22.88	3.63	2.85	2.84	32.2	67.8
1.30	25.82	2.80	1.83	3.01	33.46	66.54
1.32	30.78	0.28	0.67	2.60	34.33	65.67
1.34	32.20	0.22	0.60	2.70	35.72	64.28

*The original work gave concentrations in terms of sulfate; here it is assumed that the sulfate is in the form MgSO₄.

TABLE 2

Relative Evaporation Rates as a Function of MgCl₂ Concentration*

Density	Moles MgCl ₂ per 1000 moles H ₂ O	Relative Evaporation
1.2	13.15	69
1.24	41.85	57
1.26	47.51	47
1.28	63.94	39
1.30	73.52	27.5
1.32	88.81	15
1.34	94.91	10
1.00	—	100

*The evaporation data was taken from the curve of evaporation rate as a function of density.

Appendix 2

TABLE 1

Composition of Salar de Atacama Experimental Brines

(In Wt. %)							
Density	MgCl ₂	KCl	NaCl	MgSO ₄	Other	Total Solids	Water
1.000	—	—	—	—	—	—	—
1.200	—	—	26.00	—	—	26.00	74.00
1.238	3.32	4.90	17.64	2.59	1.67	30.13	69.87
1.268	7.34	6.35	9.03	5.13	4.42	32.26	67.74
1.299	14.72	3.82	4.31	3.16	8.63	34.64	65.36
1.310	22.95	2.19	2.14	—	8.51	35.80	64.20
1.314	27.11	1.16	1.16	—	7.33	36.76	63.24
1.340	31.02	0.57	0.57	—	6.65	38.81	61.19

TABLE 2

Relative Evaporation Rates as a Function of MgCl₂ Concentration

Density	Moles MgCl ₂ per 1000 Moles H ₂ O	Relative Evaporation
1.238	9.0	70.5
1.268	20.5	69.0
1.299	43.0	50.0
1.310	66.0	39.2
1.314	84.4	30.0
1.340	96.0	15.0

Appendix 3

TABLE 1
Composition of Australian Experimental Brines*

(In Wt. %)							
Density	MgCl ₂	KCl	NaCl	MgSO ₄	MgBr ₂	Total Solids	Water
1.208	2.2	0.6	21.9	2.8	0.06	27.40	72.56
1.234	4.6	1.2	18.8	4.3	0.10	28.88	71.12
1.247	6.5	1.5	16.7	5.0	0.15	29.87	70.13
1.260	8.7	1.9	12.5	6.1	0.18	29.38	70.62
1.318	21.5	0.5	4.1	4.9	0.50	31.39	68.61

*It was not possible to obtain brine compositions for Bonython's experiments. These figures were estimated from curves given by Don Garrett in the Second Salt Symposium (Vol. 2, page 179).

TABLE 2
Relative Evaporation Rates as a Function of MgCl₂ concentration

Density	Moles MgCl ₂ per 1000 Moles H ₂ O	Relative Evaporation*
1.208	5.73	72.5
1.234	12.73	68.0
1.247	17.86	67.0
1.260	23.24	64.0
1.000	—	100

*Source: Bonython: Factor Determining the Rate of Evaporation in the Production of Salt. Second Salt Symposium (page 761).

TABLE 3
Approximate Seawater Composition Concentrated to a Density
of up to 1.208

Product	Wt. %	g/l	Molecular Wt	Moles	Moles/1000 Moles H ₂ O
Na ₂ Cl ₂	21.87	264.2	117	2.2581	46.37
MgCl ₂	2.18	26.3	95	0.2768	5.68
MgSO ₄	2.75	33.2	120	0.2767	5.68
K ₂ Cl ₂	0.58	7.0	149	0.0470	0.97
MgBr ₂	0.061	0.74	184	0.0040	0.08
Subtotal	27.44	—	—	—	—
Water	72.56	876.5	18	48.694	1.000
Total	100.0	1208.0	—	—	—

TABLE 4
Approximate Seawater Composition Concentrated to a Density of up to 1.234

Product	Wt. %	g/l	Molecular Wt	Moles	Moles/1000 Moles H ₂ O
Na ₂ Cl ₂	18.82	232.2	117	1.9849	40.469
MgCl ₂	4.56	57.7	95	0.5928	12.084
MgSO ₄	4.25	52.5	120	0.4373	8.915
K ₂ Cl ₂	1.15	14.2	149	0.0952	1.942
MgBr ₂	0.06	1.31	184	0.0071	0.144
Subtotal	28.88	357.9	—	—	—
Water	71.12	876.1	18	48.67	1.000
Total	100.0	1234.0	—	—	—

TABLE 5
Approximate Seawater Composition Concentrated to a Density of up to 1.247

Product	Wt. %	g/l	Molecular Wt	Moles	Moles/1000 Moles H ₂ O
Na ₂ Cl ₂	16.66	207.8	117	1.7761	36.56
MgCl ₂	6.53	81.4	95	0.8568	17.64
MgSO ₄	5.00	62.4	120	0.5200	10.70
K ₂ Cl ₂	1.528	19.1	149	0.1282	2.64
MgBr ₂	0.153	1.90	184	0.0104	0.21
Subtotal	29.87	—	—	—	—
Water	70.13	874.5	18	48.58	1.000
Total	100.0	1247.0	—	—	—

TABLE 6
Approximate Seawater Composition Concentrated to a Density of up to 1.260

Product	Wt. %	g/l	Molecular Wt	Moles	Moles/1000 Moles H ₂ O
Na ₂ Cl ₂	12.5	157.5	117	1.3462	27.23
MgCl ₂	8.7	109.6	95	1.1539	23.34
MgSO ₄	6.1	76.9	120	0.6405	12.95
K ₂ Cl ₂	1.9	23.9	149	0.1607	3.25
MgBr ₂	0.18	2.27	184	0.0123	0.25
Subtotal	29.38	37.02	—	—	—
Water	70.62	889.8	18	49.433	1.000
Total	100	1260.0	—	—	—

TABLE 7
Approximate Seawater Composition Concentrated to a Density of up to 1.318

Product	Wt. %	g/l	Molecular Wt	Moles	Moles/1000 Moles H ₂ O
Na ₂ Cl ₂	4.07	53.6	117	0.4581	9.12
MgCl ₂	21.47	283.0	95	2.9786	59.29
MgSO ₄	4.88	64.3	120	0.5358	10.66
K ₂ Cl ₂	0.48	6.3	149	0.0424	0.84
MgBr ₂	0.49	6.5	184	0.0351	0.70
Subtotal	31.39	413.7	—	—	—
Water	68.61	904.3	18	50.24	1000
Total	100.0	1318.0	—	—	—

Appendix 4

TABLE 1
Relative Evaporation Data as a Function of MgCl_2
Concentration*

(In moles per 1000 moles of water)			
No.	Relative Evaporation Rate	MgCl_2 Concentration	74-Relative Evaporation Rate
1	72.5	5.7	1.5
2	70.5	9.0	3.5
3	69.0	13.2	5.0
4	68.0	12.1	6.0
5	69.0	20.5	5.0
6	67.0	17.9	7.0
7	64.0	21.2	10.0
8	57.0	41.9	17.0
9	50.0	43.0	24.0
10	47.0	47.5	27.0
11	39.0	63.9	35.0
12	39.0	66.0	35.0
13	30.0	84.4	44.0
14	27.5	73.5	46.5

*Summary of three experiments (U.S.A., Chile, Australia).

TABLE 2

Linear Regression of Relative Evaporation Rate as a
Function of MgCl_2

The following regression model was proposed:

$$ev_r = A + B \cdot C$$

where A and B are constants

C = MgCl_2 concentration (in moles MgCl_2 /1000 moles H_2O)

The following was obtained:

$$ev_r = 76.7 - .5906 \times C$$

$$r^2 = .9703$$

$$Sc = 26.5308 \text{ (Standard Deviation)}$$

$$Sev = 15.9777 \text{ (Standard Deviation)}$$

$$t_A = 57.03 \text{ (Student t)}$$

$$t_B = 19.80 \text{ (Student t)}$$

$$F = 392.37 \text{ (Fischer-Snedecor)}$$

TABLE 3

Exponential Regression (geometrical) of Relative Evaporation
Rate as a Function of MgCl_2

The following regression model was proposed:

$$74 - ev_r = A \cdot C^B = ev_r^*$$

$$\ln(ev_r)^* = \ln A + B \times \ln C$$

The following was obtained:

$$ev_r^* = 0.202308 \times C^{1.23537}$$

$$\ln ev_r^* = -1.597963 + 1.23537 \times \ln C$$

$$r^2 = .965882$$

$$S' \ln(C) = .86168$$

$$S \ln(ev_r)^* = 1.08313$$

$$t(\ln A) = 6.9768 \text{ (Student t)}$$

$$t(\ln B) = 18.4316 \text{ (Student t)}$$

$$F = 339.72 \text{ (Fisher-Snedecor)}$$