The Composition of Sea Water and Its Concentrates

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ABSTRACT

The composition of the Caribbean sea water and concentrated brines resulting from the evaporation of water has been determined as a function of specific gravity. The sea water sample used is from the Morton Salt Company operation at Inagua, Bahamas. From this data, the following conclusions or calculations were made.

1. The composition of the Caribbean sample is exactly the same as sea water from the open oceans, although it is slightly more concentrated.

2. The specific gravity at the $CaSO_4 \cdot 2H_2O$ *and NaCl points is 1.0897 and 1.2185 respectively when the specific gravity is temperature corrected to 22.2/15.6.*

3. 96.47% of the original weight of water in this slightly concentrated sea water is evaporated when the density reaches 1.2500 while 76.60% of the NaCl is precipitated.

4. When salt-point brine is placed in a crystallizing pond and water evaporated between the densities of 1.2185 and 1.2500, the salt will theoretically contain 0.60% $CaSo_4$.

5. 1,000 liters of this sea water is reduced to 112.5 liters of salt-point brine at a specific gravity of 1.2185. On further evaporation to bitterns (1.2500) the volume is reduced to 39.2 liters.

6. All of these data are reported at a specific gravity of 22.2/15.6 whereas field data are reported or corrected to 15.6/15.6. We recommend correcting all specific gravities to 22.2/15.6

INTRODUCTION

Solar evaporation is the oldest known method of producing salt from sea water. It has been going on for centuries, long before plant or animal life appeared on earth. According to many authors, evaporation of water from lakes, oceans and other bodies of water is responsible for our naturally occurring salt deposits.

It was not until 1849 that theoretical aspects of salt deposition from sea water were studied. At that time Usiglio (Usiglio, 1849, p. 92) studied the deposition of salts from sea water during the evaporation process. Although it was an excellent piece of research, there is some question regarding the temperature at which the specific gravities were measured. Since then more studies have been made, but all lack detail and depth. The data points are spaced so far apart that it is difficult to interpolate with any precision. It is therefore the purpose of this study to determine the precise composition of sea water, at close density intervals, during the evaporation process. With this data it is possible to determine accurately the following:

1. The precise composition of sea water concentrates as a function of density.
2. The density and composition of the brine at the point where $CaSO_4 \cdot 2H_2O$ starts to crystallize.
3. The density and composition of the brine at the point where NaCl starts to crystallize.
4. The quantity of $CaSO_4 \cdot 2H_2O$ crystallizing with NaCl.
5. The volume of concentrated sea water remaining at any density level starting with a known volume of sea water.

EXPERIMENTAL

Sea water, from the Caribbean (received October, 1968), was evaporated in 9.5 liter polyethylene containers. (The reason for using polyethylene containers is that salt will not creep up the sides as it does with glass containers.) Non-equilibrium conditions existed during the evaporation as day and night temperatures varied about 10°C. After evaporating to the desired densities, the slurry was vigorously stirred for about 2 hours and a 50 ml. sample of slurry was removed. The slurry was bottled and placed in a constant temperature (22.2°C) room for about 2 weeks. Several times a day during every working day, the bottles were hand shaken to equilibrate the slurries. At the end of 2 weeks, the slurries were filtered to remove the solids and the specific gravity and density was then measured at 22.2°C. The specific gravity was measured with a Fisher Scientific Company precision hydrometer (15.6/15.6) graduated to 0.0005 units and read to the nearest 0.0005 units. The density was also measured at 22.2°C with a pycnometer and the specific gravity at 22.2/15.6 was calculated. In the discussion that follows density and specific gravity will be used interchangeably, but will be understood to always mean specific gravity at 22.2/15.6 unless clearly stated otherwise.

The analyses were all carried out by standard analytical methods; chloride by the Volhard method, sulfates gravimetrically as barium sulfate, magnesium by EDTA at pH 10.0 and calcium by a modified EDTA method at pH 13.0 (modified because magnesium hydroxide co-precipitates calcium at the high magnesium to calcium ratios and only ½ or less of the calcium is then found). Sodium and potassium were not analyzed because the analytical precision and accuracy for these ions is not as good as for the four ions analyzed. However, the potassium concentration was calculated up to the salt point by multiplying the chloride concentration by the ratio of potassium to chloride as reported for sea water. Above the salt point the potassium to magnesium ratio was used. Bromine was similarily claculated while sodium was calculated by difference. Water was also calculated by difference by subtracting the total salts from the brine weight. In addition to analyzing sea water and its concentrates, a sample of sea water was analyzed after diluting with an equal volume of water. The reason for this is that this sea water is slightly more concentrated than sea water. This provided data to interpolate back to normal sea water and also to more dilute brine solutions.

DISCUSSION OF RESULTS

Original data

Table I shows the original analytical data. The specific gravity measured with the precision hydrometers agrees very well with the specific gravities measured with a pycnometer. Although pycnometers are very precise, the hydrometers are equally precise and we conclude that very accurate measurements can be taken with these hydrometers. As can be seen, the specific gravities are reported at 22.2/15.6. The reasons for this are several:

1. The densities were measured at 22.2°C both with pycnometers and hydrometers. To correct this reading to 15.6/15.6 we would have to know the temperature-density relationship. Since we did not know this relationship accurately we chose not to make the temperature correction to 15.6/15.6.

TABLE I

Analytical results for the Ionic composition of Caribbean Sea water during the evaporation process (laboratory evaporation of Caribbean Sea water)

Specific Gravity		g Ions/1000 g Brine in Solution at 22.2°C			
Hydrometer (22.2/15.6)	Pycnometer (22.2/15.6)	Ca	Mg	SO_4	Cl
1.0135	1.0130	0.228	0.683	1.456	10.33
1.0265	1.0272	0.442	1.409	2.876	20.89
1.0385	1.0383	0.628	1.916	4.035	28.82
1.0515	1.0516	0.806	2.546	5.392	38.34
1.0650	1.0651	1.005	3.164	6.712	47.76
1.0755	1.0757	1.170	3.687	7.805	55.55
1.0945	1.0952	1.306	4.599	9.438	69.23
1.1130	1.1123	1.134	5.456	10.29	82.21
1.1430	1.1430	0.870	6.941	11.76	104.4
1.1665	1.1669	0.683	8.072	12.87	121.5
1.1865	1.1867	0.542	8.947	13.73	134.8
1.2080	1.2076	0.408	9.936	14.79	148.9
1.2190	1.2194	0.330	11.02	16.11	155.9
1.2220	1.2217	0.312	12.48	18.05	155.2
1.2370	1.2367	0.212	21.68	30.68	152.3
1.2465	1.2462	0.160	27.05	37.89	151.1

2. A smaller error is incurred in solar operations if brine densities are corrected to 22.2/15.6 rather than 15.6 because most brine temperatures are closer to 22.2 than to 15.6°C. For this reason it is recommended that all brine densities in solar operations be corrected to 22.2/15.6.

The data in Table I are grouped in 3 sets of numbers. The first set of six numbers represents the ionic concentrations between the density of diluted sea water and the density where calcium sulfate begins to precipitate. The next six numbers represent ionic concentrations between the density where calcium sulfate starts to precipitate and the density where salt begins to crystallize. The next four numbers are between the salt point and the bitterns point which is arbitrarily picked.

Composition of brine versus density at close density intervals

Each set of data points from Table 1 was fitted to a second degree polynomial of the type: $Y = a + bX + cX^2$

where X = concentration of ion
Y = specific gravity
a,b,c = coefficients relating to the slope, intercept and curvature

Once the constants are known they are used in the equation to calculate the ionic composition as a function of brine density for any desired density. This data is presented in Table II. The data also includes ionic compositions 3 to 4 times more dilute than sea water because some operations use a very dilute sea water as feed.

The intersection of two polynomials determines where a new phase is appearing and the concentration and density of the ions was calculated for these points (Where $CaSO_4 \cdot 2H_2O$ and NaCl start to crystallize). This data is presented at the bottom of Table II. The density of sea water from the open oceans was calculated by "plugging" the ionic composition of published sea water data into the second degree polynomial and solving for the density. Then the density and composition of open sea water was calculated, using our analytical data. There is excellent

TABLE II

Grams of Ions per 1000 grams of brine as a function of brine density (22.2/15.6) g/1000 g of brine at 22.2°C

Sp. Gr.	°Be	Ca	SO_4	Mg	Cl	K	Na	Br	Total Salts	H_2O
1.0050	0.72	0.099	0.627	0.302	4.52	0.091	2.50	0.016	8.16	991.84
1.0100	1.44	0.179	1.140	0.548	8.20	0.164	4.53	0.028	14.79	985.21
1.0150	2.14	0.257	1.652	0.793	11.88	0.238	6.57	0.041	21.43	978.57
1.0200	2.84	0.335	2.163	1.037	15.51	0.311	8.58	0.053	27.99	972.01
1,0300	4.22	0.489	3.183	1.520	22.81	0.457	12.63	0.078	41.17	958.83
1.0400	5.58	0.641	4.199	2.000	30.04	0.601	16.64	0.103	54.22	945.78
1.0500	6.91	0.790	5.211	2.474	37.22	0.745	20.63	0.127	67.20	932.80
1.0600	8.21	0.937	6.220	2.944	44.35	0.888	24.61	0.152	80.10	919.90
1.0700	9.49	1.083	7.226	3.410	51.43	1.030	28.55	0.176	92.91	907.09
1.0800	10.74	1.226	8.229	3.872	58.47	1.171	32.48	0.200	105.65	894.35
1.0900	11.97	1.363	9.204	4.344	65.27	1.307	36.23	0.224	117.94	882.06
1.1000	13.18	1.256	9.686	4.844	72.91	1.460	40.51	0.250	130.92	869.08
1.1100	14.37	1.157	10.17	5.339	80.44	1.610	44.72	0.275	143.71	856.29
1.1200	15.54	1.063	10.64	5.828	87.85	1.759	48.85	0.301	156.29	843.71
1.1300	16.68	0.975	11.12	6.313	95.17	1.905	52.93	0.326	168.74	831.26
1.1400	17.81	0.892	11.59	6.793	102.4	2.050	56.95	0.351	181.03	818.97
1.1500	18.91	0.812	12.07	7.268	109.5	2.192	60.90	0.375	193.12	806.88
1.1600	20.00	0.735	12.54	7.739	116.5	2.332	64.78	0.399	205.03	794.97
1.1700	21.07	0.662	13.01	8.206	123.5	2.473	68.55	0.423	216.82	783.18
1.1800	22.12	0.591	13.48	8.668	130.4	2.611	72.50	0.447	228.70	771.30
1.1900	23.15	0.522	13.94	9.127	137.1	2.745	76.17	0.470	240.07	759.93
1.2000	24.17	0.456	14.41	9.581	143.8	2.879	80.06	0.492	251.68	748.32
1.2100	25.17	0.391	14.87	10.03	150.5	3.013	83.63	0.515	262.95	737.05
1.2200	26.15	0.325	16.33	11.40	155.9	3.405	84.97	0.583	272.71	727.29
1.2300	27.11	0.254	25.16	17.63	153.3	5.270	74.96	0.952	277.53	722.47
1.2400	28.06	0.194	33.17	25.53	151.9	7.029	65.83	1.20	282.85	717.15
1.2500	29.00	0.140	40.71	29.16	150.7	8.711	57.18	1.49	288.09	711.91
1.0247[1]	3.50	0.408	2.643	1.265	18.95	0.380	10.48	0.065	34.19	965.81
1.0273[2]	3.85	0.448	2.907	1.390	20.85	0.418	11.54	0.071	37.62	962.38
1.0897[3]	11.94	1.364	9.195	4.322	65.14	1.304	36.13	0.223	117.27	882.73
1.2185[4]	26.00	0.338	15.26	10.42	156.23	3.128	86.79	0.535	272.64	727.36
1.2450[5]	28.53	0.166	37.00	26.38	151.23	7.880	61.43	1.348	285.38	714.62

[1] Sea water from the open oceans.

[2] Caribbean Sea water.

[3] Density where $CaSO_4$ starts to precipitate assuming little or no carbonates.

[4] Density where NaCl starts to precipitate.

[5] Density where bitterns is discarded.

agreement between our analytical data and published data for sea water from the open oceans, indicating that the analysis was very good and that this Caribbean sea water has the same composition as sea water from the open oceans, although it is slightly more concentrated.

The data between sea water and the calcium sulfate point is a straight line function of specific gravity. However, if the data is extrapolated to zero concentration of the ions as we did, then the line is slightly curved. Between the calcium sulfate point and the salt point, the plot of ionic composition versus specific gravity is also slightly curved as is the plot above the salt point.

Tables III, IV and V were calculated from Table II and present the composition in grams per liter and grams per

TABLE III

Grams of Salts per 1000 grams of brine as a function of brine density (22.2/15.6) g/1000 g. of brine at 22.2°C

Sp. Gr.	°Be	$CaSO_4$	$MgSO_4$	$MgCl_2$	NaCl	KCl	NaBr	Total Salts	H_2O
1.0050	0.72	0.337	0.491	0.795	6.35	0.172	0.012	8.16	991.84
1.0100	1.44	0.608	0.891	1.443	11.50	0.312	0.036	14.79	985.21
1.0150	2.14	0.871	1.300	2.076	16.67	0.453	0.052	21.43	978.57
1.0200	2.84	1.137	1.704	2.714	21.76	0.593	0.068	27.99	972.01
1.0300	4.22	1.661	2.522	3.957	32.05	0.871	0.101	41.17	958.83
1.0400	5.58	2.178	3.335	5.195	42.22	1.146	0.133	54.22	945.78
1.0500	6.91	2.682	4.159	6.399	52.36	1.420	0.164	67.20	932.80
1.0600	8.21	3.186	4.978	7.590	62.44	1.693	0.196	80.10	919.90
1.0700	9.49	3.676	5.803	8.761	72.46	1.964	0.226	92.91	907.09
1.0800	10.74	4.166	6.627	9.918	82.43	2.233	0.257	105.65	894.35
1.0900	11.97	4.629	7.440	11.12	91.95	2.493	0.288	117.94	882.06
1.1000	13.18	4.268	8.361	12.36	102.80	2.784	0.322	130.92	869.08
1.1100	14.37	3.928	9.270	13.58	113.48	3.070	0.354	143.71	856.29
1.1200	15.54	3.608	10.14	14.80	123.97	3.354	0.388	156.29	843.71
1.1300	16.68	3.315	11.00	15.97	134.32	3.633	0.419	168.74	831.26
1.1400	17.81	3.029	11.85	17.23	144.53	3.909	0.452	181.03	818.97
1.1500	18.91	2.757	12.68	18.43	155.73	4.180	0.483	193.12	806.88
1.1600	20.00	2.498	13.53	19.60	164.41	4.447	0.514	205.03	794.97
1.1700	21.07	2.246	14.31	20.81	173.96	4.716	0.544	216.82	783.18
1.1800	22.12	2.008	15.11	21.98	183.99	4.979	0.575	228.70	771.30
1.1900	23.15	1.872	15.81	23.23	193.30	5.234	0.605	240.07	759.93
1.2000	24.17	1.552	16.69	24.32	203.18	5.490	0.633	251.68	748.32
1.2100	25.17	1.327	17.46	25.46	212.24	5.746	0.663	262.95	737.05
1.2200	26.15	1.103	19.49	29.23	215.60	6.493	0.750	272.71	727.29
1.2300	27.11	0.865	30.76	44.70	189.87	10.05	1.22	277.53	722.47
1.2400	28.06	0.659	40.98	59.72	166.49	13.41	1.54	282.85	717.15
1.2500	29.00	0.476	50.59	74.17	144.27	16.61	1.91	288.09	711.91
1.0247[1]	3.50	1.385	2.086	3.302	26.61	0.723	0.0833	34.19	965.81
1.0273[2]	3.85	1.520	2.297	3.624	29.29	0.796	0.0922	37.62	962.38
1.0897[3]	11.94	4.632	7.430	11.05	91.69	2.486	0.287	117.27	882.73
1.2185[4]	26.00	1.149	18.10	26.49	220.25	5.963	0.689	272.64	727.36
1.2450[5]	2~~3~~8.53	0.565	45.87	67.00	155.18	15.03	1.73	295.38	714.62

[1] Sea water from the open oceans.

[2] Caribbean Sea water.

[3] Density where $CaSO_4 \cdot 2H_2O$ starts to precipitate assuming little or no carbonates.

[4] Density where NaCl starts to precipitate.

[5] Density where bitterns is discarded.

1000 grams for both the ionic composition and for the ational analysis. In calculating the rational analysis it was assumed that little or no carbonates were present even though the data shows that there is a trace of $CaCO_3$ precipitating. $CaCO_3$ was not included in the rational analysis because in the actual solar operations the $CaCO_3$ crystallizing depends on the CO_2 content and pH of the brine which depends on plant and animal life present in the brine. In actual solar operations the density where $CaSO_4 \cdot 2H_2O$ starts to crystallize may be higher than our data shows. This may be due to supersaturation of $CaSO_4 \cdot 2H_2O$. It will also depend on how much calcium has crystallized as $CaCO_3$ and this then will influence the quantity of sulfates present at the bitterns point.

TABLE IV

Grams of Ions per liter of brine as a function of brine density (22.2/15.6) g/liter of brine at 22.2°C

Sp. Gr.	°Be	Ca	SO_4	Mg	Cl	K	Na	Br	Total Salts	H_2O
1.0050	0.72	0.100	0.630	0.304	4.55	0.091	2.51	0.016	8.20	996.80
1.0100	1.44	0.181	1.151	0.553	8.29	0.166	4.58	0.028	14.94	995.06
1.0150	2.14	0.257	1.677	0.805	12.06	0.242	6.67	0.041	21.75	993.25
1.0200	2.84	0.342	2.206	1.056	15.82	0.317	8.75	0.054	28.55	991.45
1.0300	4.22	0.504	3.278	1.566	23.49	0.471	13.01	0.080	42.41	987.59
1.0400	5.58	0.667	4.367	2.080	31.24	0.625	17.31	0.107	56.39	983.61
1.0500	6.91	0.830	5.472	2.598	39.08	0.782	21.66	0.133	70.56	979.44
1.0600	8.21	0.993	6.593	3.120	47.01	0.941	26.09	0.161	84.91	975.09
1.0700	9.49	1.159	7.732	3.649	55.03	1.102	30.55	0.188	99.41	970.59
1.0800	10.74	1.324	8.887	4.182	63.15	1.265	35.08	0.216	114.10	965.90
1.0900	11.97	1.486	10.032	4.735	71.14	1.424	39.50	0.244	128.56	961.44
1.1000	13.18	1.382	10.65	5.328	80.20	1.606	44.56	0.275	144.00	956.00
1.1100	14.37	1.284	11.29	5.926	89.29	1.787	49.64	0.305	159.52	950.48
1.1200	15.54	1.191	11.92	6.527	98.39	1.970	54.71	0.337	175.05	944.95
1.1300	16.68	1.102	12.57	7.134	107.5	2.153	59.81	0.368	190.64	939.36
1.1400	17.81	1.017	13.21	7.744	116.7	2.337	64.92	0.400	206.33	933.67
1.1500	18.91	0.934	13.88	8.358	125.9	2.521	70.04	0.431	222.06	927.94
1.1600	20.00	0.853	14.55	8.977	135.1	2.705	75.14	0.463	237.79	922.21
1.1700	21.07	0.775	15.22	9.601	144.5	2.893	80.20	0.495	253.68	916.32
1.1800	22.12	0.697	15.91	10.23	153.9	3.081	85.55	0.527	269.90	910.10
1.1900	23.15	0.621	16.59	10.86	163.1	3.267	90.64	0.559	285.64	904.36
1.2000	24.17	0.547	17.29	11.50	172.6	3.455	96.07	0.590	302.05	897.95
1.2100	25.17	0.473	17.99	12,14	182.1	3.646	101.2	0.623	318.17	891.83
1.2200	26.15	0.397	19.92	13.91	190.2	4.154	103.7	0.711	332.99	887.01
1.2300	27.11	0.312	30.95	21.68	188.6	6.482	92.20	1.171	341.40	888.60
1.2400	28.06	0.241	41.13	29.18	188.4	8.716	81.63	1.488	350.79	889.21
1.2500	29.00	0.175	50.89	36.45	188.4	10.89	71.48	1.863	360.15	889.85
1.0247[1]	3.50	0.418	2.708	1.296	19.42	0.389	10.74	0.0665	35.04	989.66
1.0273[2]	3.85	0.460	2.986	1.428	21.42	0.429	11.86	0.0734	38.66	988.64
1.0897[3]	11.94	1.486	10.02	4.710	70.98	1.421	29.27	0.243	128.23	961.47
1.2185[4]	26.00	0.412	18.59	12.70	190.37	3.811	105.75	0.652	332.29	886.21
1.2450[5]	28.53	0.207	46.07	32.84	188.29	9.811	76.48	1.678	355.38	889.62

[1] Sea water from the open oceans.

[2] Caribbean Sea water.

[3] Density where $CaSO_4 \cdot 2H_2O$ starts to precipitate assuming little or no carbonates.

[4] Density where salt starts to precipitate.

[5] Density where bitterns is discarded.

Weights of salts remaining during the evaporation of sea water

Table VI presents the weight of constituents remaining in solution and the volume of solution (as a function of density) starting with 1000 liters of Caribbean sea water or 1103 liters of open ocean water. The calculations were made using chloride ratios* (from Tables II to V) for all densities below 1.2185. Above 1.2185, magnesium ratios were used. The reason for using both chloride and magnesium ratios to make the calculations is that the chloride analysis is the most accurate of the two analyses. However

TABLE V

Grams of Salts per liter of brine as a function of brine density (22.2/15.6) g/ liter of brine at 22.2°C

Sp. Gr.	°Be	$CaSO_4$	$MgSO_4$	$MgCl_2$	NaCl	KCl	NaBr	Total Salts	H_2O
1.0050	0.72	0.340	0.493	0.799	6.38	0.173	0.012	8.20	996.80
1.0100	1.44	0.614	0.900	1.457	11.62	0.315	0.037	14.94	995.06
1.0150	2.14	0.884	1.320	2.107	16.92	0.460	0.053	21.75	993.25
1.0200	2.84	1.160	1.738	2.768	22.20	0.605	0.070	28.55	991.45
1.0300	4.22	1.711	2.598	4.076	33.01	0.897	0.104	42.41	987.59
1.0400	5.58	2.265	3.468	5.403	43.91	1.192	0.138	56.39	983.61
1.0500	6.91	2.816	4.367	6.719	54.98	1.491	0.172	70.56	979.44
1.0600	8.21	3.377	5.277	8.045	66.19	1.795	0.208	84.91	975.09
1.0700	9.49	3.933	6.209	9.374	77.53	2.101	0.242	99.41	970.59
1.0800	10.74	4.499	7.157	10.71	89.02	2.412	0.278	114.10	965.90
1.0900	11.97	5.046	8.110	12.12	100.23	2.717	0.314	128.56	961.44
1.1000	13.18	4.695	9.197	13.60	113.08	3.062	0.354	144.00	956.00
1.1100	14.37	4.360	10.29	15.07	125.96	3.408	0.393	159.52	950.48
1.1200	15.54	4.041	11.36	16.58	138.85	3.765	0.435	175.05	944.95
1.1300	16.68	3.746	12.43	18.05	151.78	4.105	0.473	190.64	939.36
1.1400	17.81	3.543	13.51	19.64	164.76	4.456	0.515	206.33	933.67
1.1500	18.91	3.171	14.58	21.19	179.09	4.807	0.555	222.06	927.94
1.1600	20.00	2.898	15.69	22.74	190.72	5.159	0.596	237.79	922.21
1.1700	21.07	2.628	16.74	24.35	203.53	5.518	0.636	253.68	916.32
1.1800	22.12	2.369	17.83	25.94	217.11	5.875	0.679	269.90	910.10
1.1900	23.15	2.228	18.81	27.64	230.02	6.228	0.720	285.64	904.36
1.2000	24.17	1.862	20.03	29.18	243.81	6.588	0.760	302.05	897.95
1.2100	25.17	1.606	21.13	30.81	256.81	6.953	0.802	318.17	891.83
1.2200	26.15	1.346	23.78	35.66	263.03	7.921	0.915	332.99	887.01
1.2300	27.11	1.064	27.83	54.98	233.54	12.36	1.50	341.40	888.60
1.2400	28.06	0.817	50.82	74.05	206.45	16.63	1.91	350.79	889.21
1.2500	29.00	0.595	63.24	92.71	180.34	20.76	2.39	360.15	889.85
1.0247[1]	3.50	1.419	2.138	3.384	27.27	0.741	0.085	35.04	989.66
1.0273[2]	3.85	1.562	2.360	3.723	30.09	0.818	0.095	38.66	988.64
1.0897[3]	11.94	5.048	8.096	12.04	99.92	2.709	0.313	128.33	961.47
1.2185[4]	26.00	1.400	22.06	32.28	268.38	7.266	0.840	332.29	886.21
1.2450[5]	28.53	0.703	57.11	83.42	193.20	18.71	2.16	355.38	889.62

[1] Sea water from the open oceans.

[2] Caribbean Sea water.

[3] Density where $CaSO_4 \cdot 2H_2O$ starts to precipitate assuming little or no carbonates.

[4] Density where NaCl starts to precipitate.

[5] Density where bitterns is discarded.

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*It is necessary to have a reference point when calculating the weight of water evaporating or some other component crystallizing. In this case, the reference point picked was Cl. The ratio Cl (initial)/Cl (final) multiplied by the water (final) should give the final weight of water in the solution. This is the ratio discussed above.

above 1.2185 the chloride crystallizes out and therefore magnesium data has to be used. Nevertheless there is excellent agreement between the calculations irregardless of whether the calculations are made with the use of chloride ion or magnesium data.

It is seen that 1000 liters of Caribbean sea water contains 30.09 kilograms of NaCl which starts to crystallize at 1.2185. However only a part of this is removed during crystallization in a solar pond. Most of the $CaSO_4{\cdot}2H_2O$ and water are removed during solar operations.

The calculations were made to show that KCl and NaBr do not crystallize out with salt when in fact they do. However the amount in solid solution with NaCl is small and depends on such factors as rate of salt crystallization, temperature, brine movement and other factors. This data can only be obtained from salt samples in the field and cannot be predicted.

Between a density of 1.2185 and 1.25 there are 30.09–7.04=23.05 kilograms of NaCl crystallized and 0.162–0.024=0.138 kilograms of $CaSO_4$ crystallized. If all the

TABLE VI

Weight of constituents remaining in solution at 22.2°C as a function of density (22.2/15.6) starting with one cubic meter of Caribbean Sea water.

Sp. Gr.	°Be	Volume of Brine Remaining (liters)	$CaSO_4$	Kilograms of Salts or Water Remaining in Solution					
				$MgSO_4$	$MgCl_2$	NaCl	KCl	NaBr	H_2O
1.0247[1]	3.50	1103.0	1.562	2.360	3.723	30.09	0.818	0.095	1091.52
1.0273[2]	3.85	1000.0	1.562	2.360	3.723	30.09	0.818	0.095	988.64
1.0300	4.22	911.9	1.562	2.360	3.723	30.09	0.818	0.095	900.58
1.0400	5.58	685.7	1.562	2.360	3.723	30.09	0.818	0.095	674.46
1.0500	6.91	548.1	1.562	2.360	3.723	30.09	0.818	0.095	536.84
1.0600	8.21	455.6	1.562	2.360	3.723	30.09	0.818	0.095	444.25
1.0700	9.49	389.2	1.562	2.360	3.723	30.09	0.818	0.095	377.75
1.0800	10.74	339.2	1.562	2.360	3.723	30.09	0.818	0.095	327.64
1.0897[2,3]	11.94	301.8	1.562	2.360	3.723	30.09	0.818	0.095	290.18
1.0900	11.97	301.1	1.557	2.360	3.723	30.09	0.818	0.095	289.49
1.1000	13.18	267.1	1.286	2.360	3.723	30.09	0.818	0.095	255.33
1.1100	14.37	239.9	1.073	2.360	3.723	30.09	0.818	0.095	228.02
1.1200	15.54	217.7	0.902	2.360	3.723	30.09	0.818	0.095	205.72
1.1300	16.68	199.3	0.765	2.360	3.723	30.09	0.818	0.095	187.21
1.1400	17.81	183.5	0.650	2.360	3.723	30.09	0.818	0.095	171.33
1.1500	18.91	170.1	0.553	2.360	3.723	30.09	0.818	0.095	157.84
1.1600	20.00	158.5	0.471	2.360	3.723	30.09	0.818	0.095	146.17
1.1700	21.07	148.2	0.399	2.360	3.723	30.09	0.818	0.095	135.80
1.1800	22.12	139.2	0.338	2.360	3.723	30.09	0.818	0.095	126.69
1.1900	23.15	131.3	0.300	2.360	3.723	30.09	0.818	0.095	118.77
1.2000	24.17	124.1	0.236	2.360	3.723	30.09	0.818	0.095	111.43
1.2100	25.17	117.6	0.193	2.360	3.723	30.09	0.818	0.095	104.88
1.2185[4]	26.00	112.5	0.162	2.360	3.723	30.09	0.818	0.095	99.70
1.2200	26.15	102.7	0.143	2.360	3.723	26.92	0.818	0.095	91.10
1.2300	27.11	65.90	0.071	2.360	3.723	15.34	0.818	0.095	58.56
1.2400	28.06	48.96	0.041	2.360	3.723	10.07	0.818	0.095	43.54
1.2450[5]	28.53	43.51	0.031	2.360	3.723	8.37	0.818	0.095	38.71
1.2500[5]	29.00	39.20	0.024	2.360	3.723	7.04	0.818	0.095	34.88

[1] Sea water from open oceans.

[2] Caribbean feed brine.

[3] Density where $CaSO_4 \cdot 2H_2O$ starts to precipitate assuming little or no carbonates.

[4] Density where NaCl starts to precipitate.

[5] Alternate densities where bitterns are discarded.

$CaSO_4$ were contained in the NaCl, the NaCl would contain 0.60% $CaSO_4$.

REFERENCES

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