SHORTER CONTRIBUTIONS TO GENERAL GEOLOGY, 1916.

EVAPORATION OF BRINE FROM SEARLES LAKE, CALIFORNIA.

By W. B. Hicks.

INTRODUCTION.

The bed of crystalline salts known as Searles Lake,[1] in southeastern California, contains the most valuable potash-bearing brine known in the United States. This salt body has an exposed surface area estimated at 11 or 12 square miles and an average depth of about 70 feet. For the most part it is firm and compact enough to support a wagon and team, even during unusually wet seasons, when it is sometimes flooded with a thin sheet of water that dissolves the surface salts to a slight extent. The deposit contains in the interstices between the salt crystals a saturated brine the volume of which is estimated to be more than 25 per cent of that of the entire saline mass.[2]

The brine contained in this so-called lake carries about 2.1 per cent of potassium, or the equivalent of about 4 per cent of potassium chloride. It is composed chiefly of the chlorides, sulphates, carbonates, and borates of sodium and potassium. It is essentially different from the brines used in the manufacture of potash in Germany, and on that account a different process is required for the extraction of the potassium from it. Economical methods for extracting the commercial salts, including potash, from this brine are now eagerly sought, but none yet tried have been proved commercially successful. Fractional evaporation and crystallization form an essential part of the methods which appear to give the most promise, and detailed knowledge of the effect of evaporation on these brines is therefore of special interest. It is difficult to predict from theoretical considerations what will be the effect of evaporation on the various constituents of so complicated a system as that represented by the brine of Searles Lake. All the necessary data for an adequate discussion of the subject have not been worked out, and direct experimental data on the evaporation of brines of similar composition are meager.

In a recent Survey report by the writer[3] some results have been presented which were intended to throw further light on conditions governing the deposition of salts from solution and thus to aid in solving the problem of extracting potash from American natural brines. Solutions prepared in the laboratory were employed in the experiments. Simple salt mixtures were used at first, and by gradually including other salts more complex brines were obtained and subjected to evaporation, although none were strictly comparable with those found in nature. It was not possible to do more than a small part of the experimental work contemplated at the time, and the results were presented as a first chapter in the study of the general subject of potash brines. Some of the data obtained are significant and suggest the importance of a more thorough investigation of the subject.

As a continuation of the experiments just mentioned, the natural brine from Searles Lake, Cal., has been subjected to fractional evaporation and crystallization, and the effect determined by analyzing the crystals that separated from the solution. The results are presented in the present paper as a second contribution in the study of potash brines. It is hoped that they may be of value in developing an economical process for the extraction of the commercial salts from American brines and also in studying those general geologic problems with which the deposition of salts from solution is connected.

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[1] For a detailed description of this so-called lake, see Gale, H. S., Salines in the Owens, Searles, and Panamint basins, southeastern California: U. S. Geol. Survey Bull. 580, pp. 265–317, 1914 (Bull. 580–L).

[2] Gale, H. S., op. cit., p. 274.

[3] Hicks, W. B., Evaporation of potash brines: U. S. Geol. Survey Prof. Paper 95, pp. 64–72, 1915 (Prof. Paper 95–E).

Because of the acute condition in the potash situation and the eagerness with which economical methods for the extraction of potash from brines are sought, it seems desirable to give to the public as rapidly as possible all information bearing on the subject. This has led to the publication of this paper at the present time, although only a small part of the experimental work planned has been done. The results here set forth may be supplemented later.

THE BRINE.

Six samples of brine from Searles Lake were collected May 14, 1912, by R. B. Dole, and were preserved in sealed glass bottles. Each sample represented about equal quantities of brine from several wells as indicated below:

Samples of brine from Searles Lake, Cal.

No.	Source.	Location.[a]	Depth.
			Feet.
1	Brine at surface....	SW. ¼ sec. 15...	2
	Well S. E. V.......	......do.........	20
	Well S. E. IV......	NE. ¼ sec. 23...	20
2	Well B...........	SE. ¼ sec. 15...	30
	Well A...........	NE. ¼ sec. 22...	25
	Well S. E. VI......	Center sec. 22..	30
3	Well E. 6.........	SW. ¼ sec. 22...	(?)
	Well S. E. 6.......	Center sec. 23..	(?)
	Well 8...........	SW. ¼ sec. 23...	Deep.
	Well F...........	NE. ¼ sec. 26...	Shallow.
4	Well S. E. 3.......	NW. ¼ sec. 25...	Deep.
	Well S. E. 4.......	NE. ¼ sec. 25 ..	Very deep.
	Well S. E. 8.......	SE. ¼ sec. 25...	Very deep.
	Well E. 9.........	NW. ¼ sec. 30[b].	Deep.
5	Well E. 10.........	NE. ¼ sec. 31[b].	10
	Well E. 11.........	SE. ¼ sec. 36...	Very deep.
	Well E. 13.........	SW. ¼ sec. 36...	Deepest.
	Well S. E. 2.......	SE. ¼ sec. 26...	Deep.
	Well S. E. I.......	SW. ¼ sec. 27...	Very deep.
	Well N...........	NW. ¼ sec. 31[b].	6
	Well T...........	SW. ¼ sec. 28...	Deep.
	Well U...........	NW. ¼ sec. 28...	Very deep.
6	Well S. E. I.......	SW. ¼ sec. 27 ..	Deep.

[a] All in T. 25 S., R. 43 E., except as otherwise indicated.
[b] In T. 25 S., R. 44 E.

In October, 1914, the writer prepared a composite sample of brine consisting of 1 liter from each of the six bottles described above. The brine was filtered from the suspended matter, thoroughly mixed, and preserved in a large bottle closed with a rubber stopper. When this solution was allowed to stand crystals were slowly deposited from it. These crystals would not redissolve readily on warming and shaking. In April, 1915, the brine was filtered at 22.5° C., and both the crystals and the solution were analyzed. The crystals, collected on a Monroe crucible and dried by suction, weighed 18 grams. Microscopic ex-

amination by W. T. Schaller showed that the crystals were composed largely of a mixture of sodium chloride and borax. This was confirmed by analysis, which gave the following results:

Analysis of crystals deposited by composite sample of brine from Searles Lake, Cal.

Na...	21.26
K..	.29
Cl...	22.25
SO₄...	.49
B₄O₇.......................................	22.51
CO₃...	.40
H₂O (by difference).......................	32.80
	100.00

Accordingly the 18 grams of crystals deposited from 6 liters (7.763 grams) of brine contained only 4 grams of borate and like quantities of both sodium and chlorine. Therefore the quantity of each of these three constituents deposited represents only 0.05 per cent of the original solution, which is probably about the limit of error in the analysis and does not appreciably affect the accuracy of the analysis of the original brine.

The filtered brine which was used in the present investigation had a straw-yellow color and a cloudy appearance. The composition is given below along with that of other brines from Searles Lake for comparison.

Composition of brines from Searles Lake, Cal.

	A	B	C
K............................	6.17	6.34	6.07
Na...........................	33.66	33.80	33.61
Cl...........................	36.36	37.04	37.10
SO₄.........................	12.86	13.00	12.99
CO₃ [a]....................	7.72	7.24	6.71
B₄O₇.......................	3.23	2.50	3.01
Other constituents (Li, Mg, Al₂O₃, Fe₂O₃, SiO₂, Br, I, PO₄, As₂O₃, etc.)...........	(?)	.08	.51
	100.00	100.00	100.00
Total salts by summation.....	34.04	33.91	[b] 32.90
Specific gravity.............	{1.2938 at 23°C	1.2974 at (?)	....

[a] This represents the combined carbonates and bicarbonates. The amount of HCO₃ in the original brine found by Ross was 0.55 per cent.
[b] Approximate. The specific gravity of this sample was not reported, and the original analysis was stated in grams per liter.

A. Composite sample of brine prepared by the writer as described above and used in the present investigation. W. B. Hicks, analyst.
B. Average of six analyses of brines from wells in Searles Lake. Walton Van Winkle, analyst. Gale, H. S., op. cit., p. 277.
C. Analysis of brine from Searles Lake. W. H. Ross, analyst. Gale, H. S., op. cit., p. 277.
NOTE. B and C have been recalculated to 100 per cent.

METHODS.

METHOD OF EXPERIMENTATION.

In conducting the experiments 1,000 grams of brine continuously stirred in a beaker was evaporated on the steam bath at about 78° C. to approximately two-thirds of its original volume, and the hot solution was then separated from the deposited crystals by filtration through a paper filter supported by a platinum cone and contained in a funnel surrounded by a steam coil of brass to maintain the temperature of the steam bath during filtration. As much as possible of the adhering mother liquor was removed by strong suction, and the main bulk of the crystals were transferred to a small tared flask and weighed. The remainder of the crystals, which adhered to the beaker, filter paper, etc., were washed into a tared platinum dish, evaporated to dryness, and weighed. The combined weights so obtained represent the amount of salts deposited during the first stage of the evaporation. The two portions of the crystals were then combined and thoroughly mixed. The sample so prepared was designated 1 A and was preserved in a paraffin-sealed flask for analysis.

The filtrate, well covered to prevent evaporation, was placed in a bath having a constant temperature of 30° C. (±0.05°) and was stirred vigorously until the temperature of the solution adjusted itself to that of the thermostat and for an hour or so thereafter. The deposited crystals were allowed to settle and were then separated from the solution by filtration through paper at room temperature (approximately 30° C.) and dried as much as possible by strong suction. The main bulk of the crystals were then transferred to a small tared flask and weighed. Those adhering to the beaker, filter paper, etc., were washed into a weighed platinum dish, evaporated to dryness, and weighed. The combined weights so obtained represent the amount of salts deposited during cooling from 78° C. to 30° C. in the first stage of the evaporation. The two portions of the crystals were then combined and thoroughly mixed. The sample so prepared was designated 1 B and was preserved in a paraffin-sealed flask for analysis.

The filtrate obtained in the last operation from sample 1 B was weighed, and its specific gravity was determined by means of the Westphal balance. The solution adhering to the funnel, specific-gravity cylinder, etc., was washed into a platinum dish, evaporated to dryness, and weighed. This weight multiplied by 3 and added to that of the main portion of the solution gave the corrected weight of the filtrate. The residue was dissolved in as little water as possible and added to the main portion of the solution. The combined solution was returned to the steam bath for further concentration.

The process just described—fractional evaporation with consequent removal of the crystals deposited during evaporation and also those separated during cooling—was repeated at intervals until only a small portion of the solution remained. This produced fourteen fractions of crystals, representing seven stages in the evaporation. Each fraction was analyzed, as was also the final mother liquor, according to the methods described below.

METHODS OF ANALYSIS.

Weighed samples of the crystals were dissolved in water and diluted to definite volume (weighed samples of the brines were simply diluted to definite volume), and aliquots each containing roughly 0.5 gram of solids were taken for analysis. The determinations were made in duplicate, and practically all the figures given in the tables (pp. 6–7) are averages of two closely agreeing results. Common methods of analysis were usually employed, but short cuts were taken wherever possible, and a brief description of the procedure therefore seems advisable. The sulphate radicle was precipitated and weighed as barium sulphate, and potassium was estimated by the modified chlorplatinate method.[1] After the sample had been acidified with hydrochloric acid and the borates removed by repeated evaporation with methyl alcohol and hydrochloric acid, sodium was determined by weighing the combined bases as sulphates (after igniting to constant weight with ammonium carbonate) and subtracting the potassium sulphate. Chlorine was determined by titration with N/10 silver nitrate after neutralizing the solution with nitric acid, and the borate radicle was estimated by titration with N/10 sodium hydroxide in the presence of mannite and

[1] Hicks, W. B., A rapid modified chlorplatinate method for the estimation of potassium: Jour. Ind. Eng. Chem., vol. 5, pp. 650–653, 1913.

phenolphthalein. The carbonate radicle was determined by titrating with N/10 hydrochloric acid in the presence of methyl orange and subtracting the borate equivalent, and therefore the results include both carbonates and bicarbonates. The latter were not evaluated. Other constituents that have been reported in traces or in very small amount in the brine were disregarded.

RESULTS.

SUMMARY OF STAGES IN THE EVAPORATION.

By conducting the experiments according to the methods above described, fourteen fractions

FIGURE 1.—Diagram showing the percentages of the various constituents deposited during evaporation of brine from Searles Lake, Cal.

of crystals, representing seven stages in the evaporation, were obtained. A summary of the procedure followed is given below, together with the quantity of salts making up the several fractions and the weight and specific gravity of the solution remaining after each stage in the evaporation.

First stage.—1,000 grams of brine from Searles Lake was evaporated on the steam bath at 78° C. to about two-thirds of the original volume, and during this process 75.00 grams of salts, which were designated 1 A, separated from the hot solution. On cooling from 78° to 30° C., 19.11

grams additional were deposited, which were marked 1 B. The filtrate that was separated from the crystals had a specific gravity of 1.278 at 30° C. and weighed 750 grams.

Second stage.—The 750 grams of solution remaining from the first operation was concentrated on the steam bath to about two-thirds of the original volume, and 28.93 grams of solids were deposited. The crystals so obtained were designated 2 A. When the filtrate was cooled from 78° to 30° C., 14.30 grams of solids, marked 2 B, were deposited. The filtrate remaining after the separation of the crystals had a specific gravity of 1.282 at 30° C. and weighed 617 grams.

Third stage.—The 617 grams of solution obtained in the second stage was concentrated on the steam bath at 78° C. to about 500 cubic centimeters. During this treatment 21.52 grams of salts, designated 3 A, separated from the hot solution. The solution was then cooled from 78° to 30° C., when an additional deposition of 13.56 grams occurred. This lot was designated 3 B. The filtrate that was separated from the crystals had a specific gravity of 1.295 at 30° C. and weighed 502 grams.

Fourth stage.—The filtrate from the third stage, amounting to 502 grams, was evaporated to about two-thirds its volume on the steam bath at 78° C., resulting in the separation from the hot solution of 41.01 grams of salt, designated 4 A. When the solution was cooled from 78° to 30° C., 8.88 grams of crystals separated. These were marked 4 B. The filtrate remaining had a specific gravity of 1.318 at 30° C. and weighed 351 grams.

Fifth stage.—The 351 grams of solution obtained as indicated above was evaporated to about 200 cubic centimeters on the steam bath at 78° C., and during this process 28.81 grams of crystals were deposited from the hot solution. These were designated 5 A. Cooling from 78° to 30° C. resulted in the deposition of 14.31 grams of crystals, designated 5 B. The solution that was separated from the crystals had a specific gravity of 1.351 and weighed 230 grams.

Sixth stage.—The filtrate remaining from the fifth operation, which amounted to 230 grams, was concentrated on the steam bath at 78° C. to about 100 cubic centimeters. The salts deposited during the evaporation from the hot solution weighed 24.68 grams and were designated 6 A. Those deposited during cooling from 78° to 30° C. weighed 29.37 grams and were designated 6 B. The filtrate had a specific gravity of 1.386 at 30° C. and weighed 114 grams.

Seventh stage.—The 114 grams of solution obtained as described above was evaporated on the steam bath at 78° C. to about 50 cubic centimeters, and the salts deposited during this operation from the hot solution weighed 19.22 grams and were designated 7 A. The crystals that separated on the cooling of the solution from 78° to 30° C. weighed 10.41 grams and were marked 7 B.
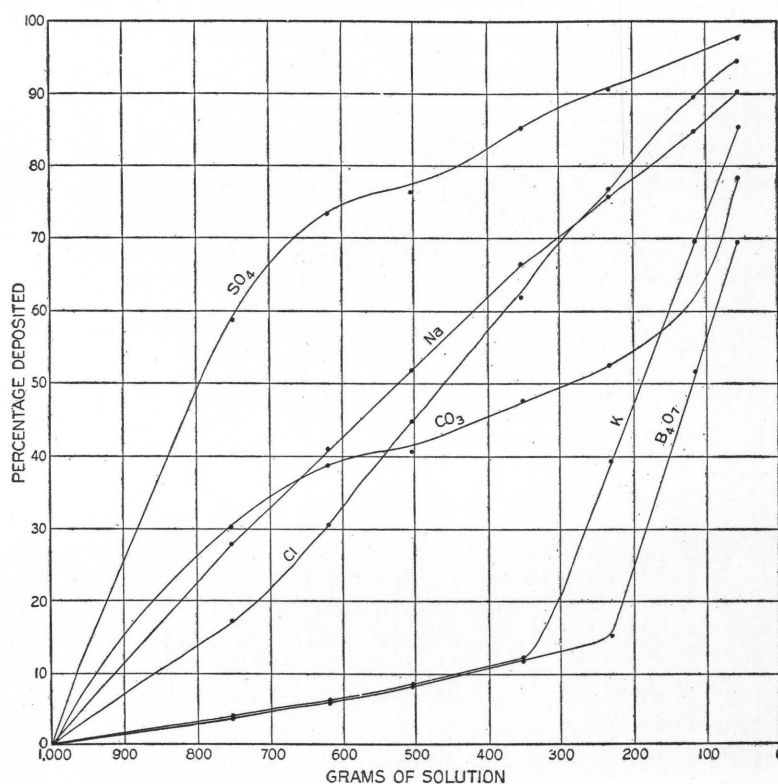
The solution that was separated from the crystals had a specific gravity of 1.399 at 30° C. and weighed 55 grams. This solution represents the final filtrate, indicated in Tables 1, 2, and 3 by the number 8.

TABULATION OF RESULTS.

Each of the fractions of crystals obtained in the experiments just detailed was analyzed, as was also the final filtrate. The results are given in Table 1 and have been used in computing the hypothetical combinations given in Table 2. The figures in Table 2 were obtained by calculating all the potassium to potassium chloride and the borate, carbonate, and sulphate radicles to the corresponding sodium salts and supplying enough sodium chloride to make the results add up to 100. Although this method of computation conceals the small error of closure, it was used because of its simplicity. The percentages of the several constituents deposited from solution as evaporation progressed have been calculated and are set forth in Table 3 and shown graphically in figure 1. The composition of the solution remaining after each stage in the evaporation has been computed from the quantity and composition of the various fractions of crystals, the composition of the final filtrate being used as a basis. The data so obtained, together with the composition of the original brine and that of the final mother liquor, are presented in Table 4. These values, which give the changes in the composition of the solution resulting through evapo-

ration, have been plotted and are shown graphically in figure 2.

Nos. 1 to 8 in the tables represent the successive stages in the evaporation. The letter A refers to the crystals deposited from the hot solution during the process of evaporation; B has reference to the crystals depos-
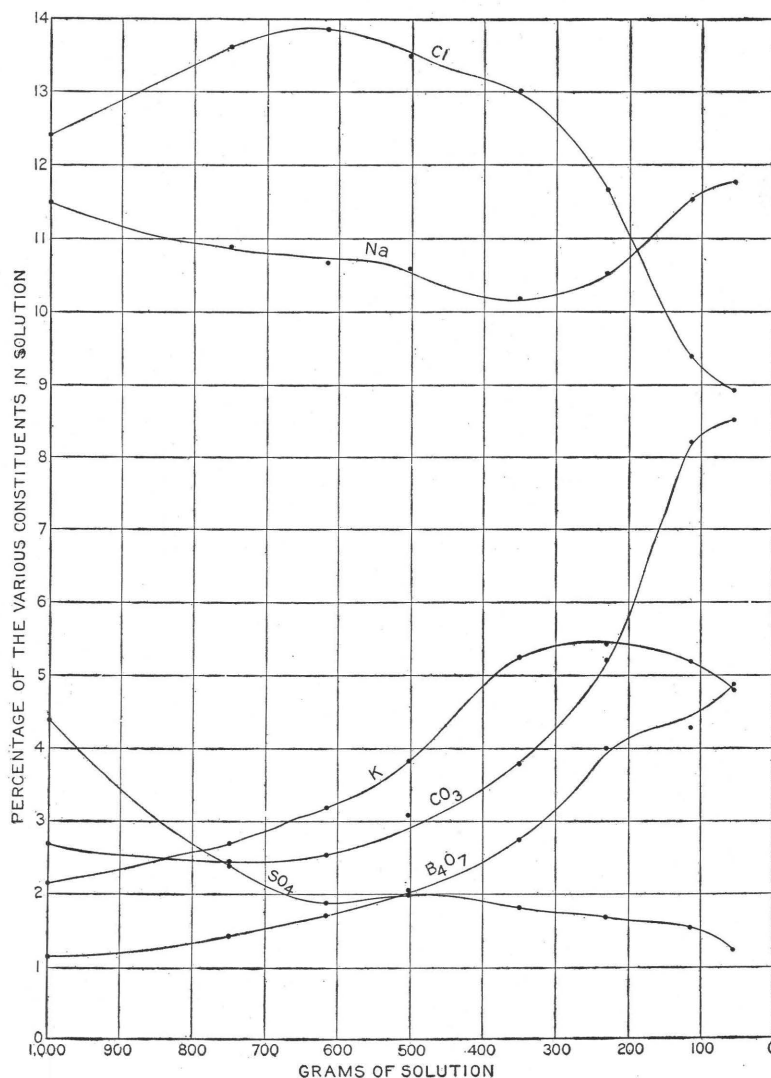

FIGURE 2.—Diagram showing the changes in the composition of the solution resulting through evaporation of brine from Searles Lake, Cal.

ited as the solution was cooled from 78° to 30° C.

TABLE 1.—*Percentage composition, in radicles, of the crystals deposited during fractional evaporation.*

	1 A	1 B	2 A	2 B	3 A	3 B	4 A	4 B	5 A	5 B	6 A	6 B	7 A	7 B	8
K	0.96	0.72	1.14	0.87	1.54	1.37	1.72	1.78	1.95	40.35	3.21	30.03	5.29	31.68	11.97
Na	35.45	38.61	36.51	38.71	37.28	37.94	37.00	37.58	37.27	8.87	36.04	12.87	35.60	12.14	29.36
Cl	14.73	59.92	30.22	59.43	50.99	58.99	45.20	58.98	46.76	47.92	44.03	31.10	21.64	32.51	22.33
SO$_4$	36.98	.22	23.51	.28	6.60	.47	10.49	.31	9.16	.39	8.55	1.03	6.71	.77	3.07
CO$_3$	11.34	.21	8.03	.31	2.90	.53	4.68	.52	3.99	1.36	6.54	5.57	26.83	4.96	21.23
B$_4$O$_7$	.54	.32	.59	.40	.69	.70	.91	.83	.87	1.11	1.63	19.40	3.93	17.94	12.04
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	a 100.00
H$_2$O by difference	7.60	3.89	6.74	3.18	8.64	6.36	11.72	2.34	8.21	9.60	8.67	35.21	23.59	28.99	59.91
Anhydrous salts: By summation	92.40	96.11	93.26	96.82	91.36	93.64	88.28	97.66	91.79	90.40	91.33	64.79	76.41	71.01	40.09
Ignited residue	92.20	95.70	93.05	96.40	91.50	93.30	88.40	97.60	92.20	90.35	91.00	64.15	76.10	71.20	40.80
Weight of crystals grams	75.00	19.11	28.93	14.30	21.52	13.56	41.01	8.88	28.81	14.31	24.68	29.37	19.22	10.41	....

a The solution also contained 0.22 per cent arsenic=0.55 per cent of the anhydrous salts.

TABLE 2.—*Percentage composition, in hypothetical combinations, of the crystals deposited during fractional evaporation.*

	1 A	1 B	2 A	2 B	3 A	3 B	4 A	4 B	5 A	5 B	6 A	6 B	7 A	7 B	8
KCl	1.83	1.37	2.17	1.66	2.93	2.61	3.28	3.39	3.72	76.90	6.12	57.25	10.08	60.37	22.80
NaCl	22.72	97.52	48.09	96.86	81.29	94.84	71.67	94.56	74.56	18.68	67.57	6.28	27.49	6.54	19.58
Na$_2$SO$_4$	54.75	.33	34.81	.41	9.77	.70	15.51	.46	13.56	.58	12.65	1.53	9.94	1.14	4.54
Na$_2$CO$_3$	20.00	.37	14.17	.55	5.12	.94	8.26	.52	7.04	2.40	11.55	9.84	47.40	8.75	37.50
Na$_2$B$_4$O$_7$	.70	.41	.76	.52	.89	.91	1.18	1.07	1.12	1.44	2.11	25.10	5.09	23.20	15.58
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

TABLE 3.—*Percentages of the constituents deposited during fractional evaporation.*

[The first column for each constituent gives the percentage deposited at each stage; the second column gives the total percentage.]

Stage.	K.		Na.		Cl.		SO$_4$.		CO$_3$.		B$_4$O$_7$.	
1 A	3.19	3.19	21.44	21.44	8.23	8.23	58.50	58.50	29.88	29.88	3.36	3.36
1 B	.62	3.81	6.19	27.63	8.90	17.13	.09	58.59	.15	30.03	.55	3.91
2 A	1.48	5.29	8.59	36.22	6.60	23.73	14.47	73.06	8.25	38.28	1.45	5.36
2 B	.57	5.86	4.68	40.90	6.65	30.38	.09	73.15	.15	38.43	.55	5.91
3 A	1.43	7.29	6.40	47.30	8.10	38.48	2.97	76.12	2.17	40.60	1.27	7.18
3 B	.81	8.10	4.20	51.50	6.05	44.53	.14	76.26	.27	40.87	.82	8.00
4 A	2.95	11.05	11.68	63.18	13.22	57.75	8.68	84.94	6.43	47.30	3.00	11.00
4 B	.71	11.76	2.84	66.02	4.13	61.88	.07	85.01	.19	47.49	.64	11.64
5 A	2.48	14.24	8.61	74.63	10.00	71.88	5.52	90.53	3.99	51.48	2.09	13.73
5 B	24.85	39.09	1.00	75.63	5.01	76.89	.11	90.64	.68	52.16	1.27	15.00
6 A	3.43	42.52	7.08	82.71	8.02	84.91	4.38	95.02	5.63	57.79	3.36	18.36
6 B	27.22	69.74	2.14	84.85	4.79	89.70	.46	95.48	4.03	61.82	33.51	51.87
7 A	3.71	73.45	4.56	89.41	2.57	92.27	2.26	97.74	14.97	76.79	5.28	57.15
7 B	11.14	84.59	.79	90.20	1.94	94.21	.14	97.88	1.41	78.20	12.09	69.24
8	12.57	97.16	5.66	95.86	3.98	98.19	1.55	99.43	17.80	96.00	24.20	93.44

TABLE 4.—*Changes in the composition of the solution during fractional evaporation.*

Stage.	Solution after evaporation (grams).	Specific gravity at 30° C. / 20° C.	Percentage composition of the solution (calculated).							Potassium in total salts (per cent).	K/Na ratio.
			K.	Na.	Cl.	SO$_4$.	CO$_3$.	B$_4$O$_7$.	Total.		
Original solution [a]	1,000	1.292	2.10	11.46	12.37	4.38	2.63	1.10	34.04	6.16	0.18
1	750	1.278	2.69	10.88	13.60	2.39	2.41	1.40	33.37	8.06	.25
2	617	1.282	3.19	10.66	13.85	1.87	2.55	1.67	33.79	9.44	.30
3	502	1.295	3.84	10.57	13.46	2.03	3.10	2.00	35.00	10.97	.36
4	351	1.318	5.26	10.17	13.04	1.81	3.79	2.74	36.81	14.30	.52
5	230	1.351	5.45	10.50	11.66	1.68	5.22	4.01	38.52	14.15	.52
6	114	1.386	5.20	11.54	9.39	1.53	8.21	4.29	40.16	12.95	.45
7 [a]	55	1.399	4.80	11.77	8.95	1.23	8.51	4.83	40.09	11.97	.41

[a] Values determined by actual analysis.

DISCUSSION.

Before discussing the results presented in the tables, it will be well to recall the fact that before the fractional crystallization began sodium chloride and borax had been deposited from the brine on standing at 22.5° C. Although undetermined factors make deductions inconclusive, the facts indicate that when the temperature is lowered these constituents must separate from the solution in order that equilibrium may be attained for the new conditions. It might be inferred that by lowering the temperature still further larger amounts of sodium chloride and borax would leave the solution. However, as the solubility of sodium sulphate decreases rapidly when the temperature is lowered below the transition point, this constituent might separate out in large amounts at low temperature. In principle the same argument may be applied to the potassium chloride and sodium carbonate contained in the brine. The final equilibrium at any temperature is dependent on the solid phases which separate and must therefore be determined experimentally.

By reference to the tables it will be seen that more than 58 per cent of all the sulphate originally present in the brine was deposited from the hot solution in the first fraction of crystals, which is composed of nearly 55 per cent of sodium sulphate, large amounts of carbonate and chloride, and only small amounts of borate and salts of potassium. In the other fractions of crystals that were deposited from the hot solution as evaporation progressed the sulphate radicle is a chief component. When the brine had been reduced to half its original volume, more than 76 per cent of all the sulphate had been deposited, and in the final filtrate less than 2 per cent of it remained. It is significant that only small quantities of sulphate were found in the several fractions of crystals deposited as

the solution was cooled from 78° to 30° C. These facts point to the conclusion that sodium sulphate is less soluble in the hot solution than it is at 30° C., a conclusion which is in accord with experimental data on the solubility of sodium sulphate in pure water.

The behavior of the carbonate radicle was somewhat like that of the sulphate. A large portion came down in the first crop of crystals and in all the succeeding fractions that were deposited from the hot solution during evaporation (marked A in the tables). However, a considerable amount separated out during cooling from 78° to 30° C. in fractions 6 B and 7 B, and nearly 18 per cent of the total amount in the original brine remained in the final filtrate. The results are somewhat difficult to interpret but point out clearly that the carbonate is at least as soluble in the cold solution as in the hot until about the fifth stage in the evaporation. Then, in the presence of a greater concentration of potassium, the carbonate is much more soluble in the hot solution.

At this point it seems pertinent to call attention to an experiment conducted by the writer with the view of showing the possibility of removing the carbonate from the brine by the action of carbon dioxide. This gas was passed at the rate of several bubbles a second through 100 grams of the brine at room temperature. No visible action was apparent for some time. Finally a precipitate began to form and to adhere to the bottom and sides of the container. After about six hours no further action was perceptible and the reaction appeared to be completed. The residue, which was filtered from the solution through a tared Monroe crucible, weighed 5.85 grams. It was analyzed with the following results:

Analysis of precipitate produced through action of carbon dioxide on brine.

Na	26. 27
K	. 68
Cl	4. 28
SO_4	. 65
CO_3	4. 13
HCO_3	53. 36
B_4O_7	1. 06
H_2O (by difference)	9. 57
	100. 00

The solids which separated through the action of carbon dioxide on the brine contained 73.6 per cent of sodium bicarbonate and 9.57 per cent of water. The original brine contained 2.63 per cent of CO_3, and so the deposition represents 67.5 per cent of all the carbonate originally present in the brine.

Small amounts of borate separated from the hot solution and also during cooling in all the fractions of crystals, but at the beginning of the sixth stage in the evaporation, when only 114 grams of the solution remained, the total quantity of borate that had been deposited was only about 18 per cent of the amount originally present. More than 45 per cent of the borate separated in the two fractions 6 B and 7 B as the solution was cooled from 78° to 30° C., and more than 24 per cent remained in the final filtrate. The results show that the borate became more soluble in the solution as the concentration of the potassium and carbonate radicles increased and that of chloride and sulphate decreased.

Although potassium separated in increasing amounts in all the succeeding fractions of crystals up to the fifth stage, only about 8 per cent of that originally present was lost from solution by reducing it to half the original volume and increasing the concentration of the potassium to nearly 4 per cent. This loss is somewhat higher than that recorded in the experiments with artificial potash brines.[1]

More than 60 per cent of all the potassium was deposited on cooling the solution from 78° to 30° C. in fractions 5 B, 6 B, and 7 B, and 12.57 per cent remained in the final filtrate. Residue 5 B, representing 24.85 per cent of all the potassium in the original brine, contained the equivalent of 76.9 per cent of potassium chloride, with sodium chloride as the principal impurity. Residues 6 B and 7 B, representing more than 48 per cent of all the potassium in the brine, contained 57 and 60 per cent, respectively, of potassium chloride, but in these residues carbonates and borates are the chief impurities.

The data here recorded indicate that carefully controlled fractional evaporation and crystallization, possibly combined with other treatment, promise much as a means of obtaining potassium from brines similar to that of Searles Lake. A wider range of temperature suggests itself at once, and other possibilities are apparent. However, many points in regard to the behavior of the constituents of the brine under varying conditions remain to be studied before the problem can be adequately discussed.

[1] Hicks, W. B., Evaporation of potash brines: U. S. Geol. Survey Prof. Paper 95, pp. 65–72, 1915 (Prof. Paper 95–E).