Utilization of Subsoil Brines: Potentialities and Problems

G. D. Bhat, R. B. Bhatt, U. P. Saraiya and M. M. Taquikhan
Central Salt & Marine Chemicals Research Institute
Bhavnagar, India

ABSTRACT

Subsoil brines are concentrated compared to sea brine and are rich in magnesium and bromine. The largest single source of subsoil brine in India is from the Rann of Kutch; besides this, subsoil brines are tapped on the sea coast, both east and west. Subsoil brines vary in density from 8° to 21° Bé (1.059 to 1.170 sp gr). Normally the multiple irrigation system is followed and Bharagara salt 2.5 cm-size cubes are produced by simple solar evaporation. Open wells are constructed 5 to 10 meters deep with bamboo reinforcements, and brine is bailed out by manual labour.

Requirements of huge quantities of salt both for human consumption and for industries have changed the pattern in the late seventies, and we now have bore wells 100 to 250 meters deep to obtain a copious supply of concentrated brine to be pumped out by submersible pump sets boosting salt production two to three times in the smallest area.

The paper deals with solar fractional crystallisation of subsoil brine and compares it with that of sea brine. Subsoil brines have solved the problem of getting large tonnage in a small area, thereby cutting down the overhead charges per tonne. However, it has some inherent problems; a few of these are discussed in the paper.

INTRODUCTION

The demand for salt is increasing day by day. Coastal land with suitable climatic conditions is not available in the same proportion as is the demand. The time has come when production per unit area will have to be increased by utilising all the available area and modern technology. Subsoil brines are concentrated compared to sea brine. Utilisation of subsoil brine is one of the answers to the same problem. Rann of Kutch is the largest single source for subsoil brine in the country and the density of brine varies between 8° and 21° Bé (1.059 to 1.17 sp gr). The brine supply is obtained from 10- to 30-meter-deep bore wells. Subsoil brines are also tapped on the East Coast, particularly at Tuticorin, which is between 8°-48′ north and 78°-11′ east and enjoys a similarly favourable climate. The maximum and minimum temperatures vary between 39°C and 29°C and 28°C and 20°C during summer and winter, respectively. The average annual rainfall in Kutch and Tuticorin is similar and varies between 500 and 600 mm, even though the seasons are different and Kutch is on the West Coast while Tuticorin is on the East Coast. The relative humidity is 50 to 60 percent in summer and 70 percent during winter months. The wind velocity varies between 30 and 40 km, and other conditions such as market transportation are also very favourable. Density of brine varies between 8 and 13° Bé (1.059 to 1.10 sp gr). The brines are tapped from 10- to 25-meter depth, but supply is not copious. Recently, subsoil brines are being tapped on the east and west seacoasts and brine of 8° to 16° Bé is obtained. Big salt works are being developed and are producing three to four times more salt than seawater-based salt works. The paper deals with utilisation of subsoil brines from greater depths, quality and yield of salt and a few problems associated with it.

SUBSOIL BRINES IN RANN OF KUTCH

The Rann of Kutch covers an area of about 5000 km^2 and is situated between 24°-40′ to 26°-6′ N and 68°-48′ to 71°-47′E and is a vast sandy track almost on sea level. There are several assumptions about the availability of brine in this area. The most acceptable theory is that the brine would have been formed because of solar evaporation of sea brine of isolated lagoons, bays or old arms of sea cut off partly or wholly by bars, silts or by seismic upheavels.

Salt was manufactured by open wells of about 3 meters in diameter and 6 to 10 meters in depth. These wells are supported with bamboo reinforcements and brine is bailed out by manual labour. Brine is usually found in the sand strata at about 6-meter depth. Above the sand strata there are different layers of clay and mud. In the beginning of the season, that is, in the months of September and October, open wells are dug. The interior of the wells is supported by bamboo and wooden posts. Brine is bailed out with the aid of a wooden post having a lever type arrangement. There is generally one well for each pan, but often because of a lower density or low recuperation rate two or three brine wells are required to be operated. These wells last for two or three years. However, every third year new wells are to be dug, because the recuperation rate is reduced and it is dangerous to enter the old wells to replace the old bamboo structure. Thus, construction of a new well is considered safe and economical.

Brine from the well is charged to the condenser area (25 m × 25 m size) at a rate of about 2500 litres per hour, or 15,000 litres per day. The salt crystalliser is constructed just parallel to the condenser, keeping a distance of 2 meters between the two. The size of the pan is generally kept at 80 m × 25 m, and each condenser provides brines to one salt crystalliser pan. Thus the ratio between the condenser crystalliser is usually 1:3. In the beginning the brine is charged to a depth of about 5 cms and salt crystals are broken with the aid of a wooden raker (Dautadi). The brine is charged to a depth of about 20 to 25 cms and allowed to evaporate. The salt crystals are raked daily and kept loose. The brine is charged at a slow rate and often 23° to 24° Bé brine is charged. Bittern is discharged twice in a season (January and May).

The size of 'Baragara' salt crystals is about 1.5 to 2.5 cms. The crystals are very hard with no voids inside. This type of manufacturing method, known as multiple irrigation system, is advantageous in reducing magnesium content due to compactness as well as lesser surface area. The yield of salt per acre of crystallising area is about 600 metric tonnes. The hardness of salt crystals due to presence of manganese in the brine and development of crystals below the brine are both helpful in forming bigger and more compact crystals. Each salt unit consists of one or two open wells, a condenser and a crystalliser, and is operated by a family. There are a number of such units operated in the Rann area producing 6 to 8 lakh tonnes of salt. The composition of sea brine and subsoil brine is shown in Tables 1 and 2 and the composition of sodium chloride produced from sea and subsoil brines is tabulated in Table 3.

TABLE 1

Composition of Sea Brine During Salt Separation

Density °Bé	14.5	20	24.1	25.6	27.2	29	30
$CaSO_4$	0.47	0.36	0.16	0.12	0.06	0.03	0.007
$MgSO_4$	1.00	1.50	1.92	2.00	4.13	6.60	7.60
$MgCl_2$	1.58	2.30	2.90	3.15	6.38	10.50	12.10
NaCl	13.05	19.11	24.74	26.70	22.47	15.40	13.00
KCl	0.30	0.45	0.63	0.68	1.40	2.30	2.50
Percentage Separation of $CaSO_4$			74.46		98.51		

TABLE 2

Composition of Subsoil Brines During Salt Separation

	14° Bé	19° Bé	24.1° Bé	25.40° Bé	26.80°	29° Bé
$CaSO_4$	0.75	0.55	0.49	0.34	0.19	0.01
$MgSO_4$	0.10	0.16	0.20	0.33	0.57	0.83
$MgCl_2$	2.34	4.42	6.40	9.06	12.22	25.72
NaCl	11.78	17.75	22.25	22.57	12.77	6.16
Percentage separation of $CaSO_4$			34.66		98.18	

TABLE 3

Composition of Salt Produced from Sea and Subsoil Brines

	Sea Salt	Subsoil Brine Salts		
	Bhavnagar.	Tuticorin	Kharaghoda.	Bhavnagar.
NaCl	97.36–98.2	92.20–95.50	96–98	95–98
$CaSO_4$	0.27–0.60	1.87–0.30	1.55–0.71	1.27–0.30
$MgSO_4$	0.05–0.50	1.19–0.55	0.37–0.21	0.04–9.6
$MgCl_2$	0.30–0.70	2.74–0.70	1.13–0.40	2.74–0.5
Insolubles	0.04–0.10	0.05–1.73	1.40–0.10	0.05–1

A Change in Outlook

As the requirements of salt increased by leaps and bounds both for human consumption and for requirements for the industry, Kutch and Titicorin accepted the challenge, and modernisation and mechanisation were introduced in the late 70s. Credit must also be given to the Government, which helped in development of the cooperative movement by liberalising short-term and long-term loans. In Tuticorin, as well as in Kutch, centrifugal pumps were installed to pump brine from 20 to 30 meters depth by lowering the pump sets below the ground level by 2 to 3 meters. The lowering of bore wells and use of pump sets boosted the production in a short time without increasing the area. These results encouraged some large unit entrepreneurs to sink bore wells to greater depths, such as 150 to 250 meters. In order to understand this thinking let us consider a concrete case.

A Case Study of Bharat Salt Works

Bharat Salt and Industrial Works is situated in Bhavnagar between 21°-09′ North and 71°-51′ East in Gujarat State (India). The Bharat Salt and Industrial Works Ltd. was started in 1963 when the final lease deed for 750 acres (303.5 hectares) was finalised. Earlier production in the same area was barely 20,000 to 25,000 tonnes per season. Management took a bold step in drilling fourteen bores of 50 to 60 cms outer diameter and 150 to 250 meters depth. Casing pipe of 20 to 30 cms outer diameter in pieces of 2.5 to 3 meters length are either welded or jointed by threaded couplings. Slotted casing pipes are so arranged in between as to fix them in front of the sand strata. Three to 5 cms diameter gravel or holders are put between the bore hole and the casing pipe to obtain a regular supply of brine and also act as a sieve. Casing pipe is usually of galvanised iron so as to last longer against corrosion effects. The casing pipe was fitted to the entire depth because no hard rock is found in this area even up to 600 meters depth. Soil strata consisting of alternate layers of sand and clay are shown in Table 4.

Suction or column pipes are of mild steel, painted inside and outside with anti-corrosive paint. The size of the suction pipe and the attached submersible pump set depends on the availability of the brine and varies between 7.5 cms to 15 cms outer diameter. Small pieces of 2.5 to 3 meter length previously coated with anti-corrosive paint are connected by threaded couplings. The submersible pump set is attached at the end of this column pipe and 20 HP to 50 HP capacity motors are in use. The column pipe is inserted only up to 60 to 70 meters with a submersible pump set at the end. The brine table is at a distance of about 25 meters but remains stable at about 50 meters when the pump is in operation. The pump set is energised through a control board placed in a small 4 m × 4 m room provided just near the bore well site.

The cost of drilling a bore well alone varies between Rs.17 and 25 ($2 and $3) per running meter. The cost of casing pipe varies between Rs.25 and 30 ($3 and $4) per running meter, and column pipe with couplings, etc., costs Rs.20 ($2.50) per running meter. The pump set with submersible motor and other accessories costs additional Rs.25,000 to 60,000, depending upon horsepower, which depends on density of brine and depth, etc. Thus cost of each bore well with pumping set, etc., works out to an average of Rs.0.25 million ($30,000).

Fourteen such bore wells were prepared, but only seven are in operation. Other wells are not in use either because of a low recuperation rate or damage caused by corrosion. The bore wells work 'round the clock for a period of 7½ to 8 months and on an average supply 12° Bé brine. Composition of brine is reported in Table 5. Pumping capacity of each bore varies but on the average supplies 15,000 to 20,000 gallons per hour (68,000 to 91,000 kilo litres per hour), and each bore well produces 18,000 to 20,000 metric tonnes of salt per season of 200–220 working days.

Method of Salt Production

Bore well operation starts in the beginning of October and brine is circulated in the circuit through various condensors. It is charged to crystallisers only when it reaches 25° Bé. The depth of brine in the crystallisers is maintained between 20 and 25 cms throughout the season. After a layer of salt of about 3 cms is formed, the crust is broken with a raker operated lengthwise and widthwise for a week. This operation has two advantages: 1) it allows new faces to grow to form large size crystals; 2) the loose salt bed helps to keep the remaining upper layers away from the bottom of the pan. This is very useful in harvesting salt. The whole crust, which is not in contact with the bed, comes out as a slab. This saves man-hours and prevents contamination of salt crystals with mud particles. Deep charging helps the crystal growth, reduces mother liquor

TABLE 4

Soil Strata and Other Information on Bore Wells—Bharat Salt Works

Date of Starting	Brine 1	Brine 2	Brine 3	Brine 4	Brine 5
Casing pipe size	8″	12″	8″	12″	12″
Column pipe size	5″	6″	3″	3″	6″
Bore hole size	20″	20″	20″	20″	20″
Total depth	620′	550′	465′	744′	530′
Column pipe	190′	220′	190′	200′	200′
Temp. of brine	31°C	30°C	31°C	32°C	29°C
Clay	0–90′	0–90	0–80	0′–45′	0–′–62
Sand	90–115	90–115	80–116	45′–65′	62–83
Clay	115–160	115–128	116–150	65′–90′	83–87
Sand	160–170	128–144	150–170	90′–120′	87–99
Clay	170–175	144–200	170–180	120–195′	99–114
Sand	175–240	200–244	180–250	195′–240′	114–140
Clay	240–260	244–318	250–290	240′–390′	140–194
Sand	260–282	318–343	290–350	390–405	194–225
Clay	282–325		350–376	405–470	225–284
Sand	325–368		376–386	470–490	284–300
Clay	368–430		386–392	490–632	300–359
Sand	430–448		392–416	632–665	359–385
Clay	448–580		416–448	665–695	385–414
Sand	580–595		448–516	695–734	414–435
Clay	595–610		516–525		435–490 Clay
					490–52 Sand
Total Clay	412	233		332	337
Total Sand	198	110		202	

TABLE 5

Analysis of Brine Samples Bharat Salt Works—Bhavnagar (Percent w/v)

	Brine 1 5" bore Near pole 77 Outside factory on sea	Brine 2 6" bore Near pole 78	Brine 3 6" bore No. 3 From factory Near pole 17	Brine 4 5" bore No. 6 From factory Near pole 27	Brine 5 5" bore No. 7 Near pole 42
$CaSO_4$	0.957	0.620	0.591	0.849	0.621
$MgSO_4$	0.056	Absent	0.389	0.064	0.416
$CaCl_2$	—	0.440	—	—	—
$MgCl_2$	1.028	0.642	1.489	1.500	2.004
$NaHCO_3$	0.015	Absent	0.015	0.015	0.015
KCl	0.066	0.040	0.195	0.125	0.180
pH	6.7	6.9	7.1	6.9	6.8
T.D.S.	12.94	16.72	20.32	18.02	20.50
Ca^{2+}	0.282	0.341	0.174	0.250	0.183
Mg^{2+}	0.274	0.164	0.459	0.396	0.596
SO_4^{2-}	0.720	0.438	0.727	0.650	0.770
Cl^-	6.950	6.230	9.480	8.548	9.630
HCO_3^-	0.011	0.008	0.011	0.011	0.011
CO_3	Absent				

adherence and improves the salt's appearance, quality and compactness.

PROBLEMS ASSOCIATED WITH BORE WELLS

Capital Expenditure

Drilling a bore well 150 to 250 meters deep involves huge capital expenditures. It is also associated with many uncertainties, such as whether or not copious brine of higher density (15 to 20° Bé) is struck, or touching a sweet water stream, thus getting dilute brine of 5° to 7° Bé, which is uneconomical for pumping from such depths. Even after touching a good brine source it is not always certain that a bore well will give a continuous brine supply. Average life of a bore well is considered to be only 3 to 4 years, and the entire cost is to be recovered within that time by selling salt in a competitive market.

Cost of Pumping

Pumping brine from an 80-meter depth requires three-phase electric power connections. Thus extension of an electric power supply at different places in the salt works or taking a line from a nearby area is also costly. Diesel pumping is out of the question. The average electric bills of Bharat Salt Works producing 1 to 1.2 lakh tonnes of salt indicate that Rs.7 to 8 per tonne of salt is required for pumping brine. Seawater-based salt works working on tidal waters are at an advantage in this respect.

Corrosion Problem

Usually galvanised iron casing pipes and mild steel column pipes are in use. However, the corrosion problem is so severe that in a short time, such as 3 years, the casing pipe, the column pipes and even the pumpsets are worn out and are irreparable. The pump sets often fall into the well due to severe corrosion and are then difficult to take out. Colouring pumping sets and column pipe in off season improves life to a very little extent. Cathodic protection of the assembly is being tried at certain places and results are awaited. PVC and high density polyethelene pipes are being tried at one of the salt works. It is costly, but results are encouraging.

Unanswered Questions

Running a huge salt works on bore well brine raises many unanswered questions and challenges in the entrepreneur's mind, and answers to all these are not always true and exact. Some of the questions are as follows

a) *What is the age of the brine, what quantity of brine is available and how long will it last?* Estimation of carbon 14 in the brine samples may throw some light on the age of the brine, but estimation of exact quantity of brine is difficult to assess.

b) *What is the effect of changes in monsoons?* Does a monsoon of the region and previous year have any relation on the availability of brine? One of the observations is that after a monsoon there is no dilution or change in density of brine. However, for bore wells up to 30 meters depth it has been ascertained that they yield less brine if the previous season is dry.

c) *What is the effect of continuous pumping?* Pumping continuously for years 12° to 13° Bé brine on a seacoast near the tidal boundary points out the availability of brine pockets due to sesmic disturbance in the past. Continuous replenishment of brine through seawater and its rise in density is not clearly understood.

d) *What is the composition of subsoil brines?* Subsoil brines are always deficient in total sulphate and potassium ions. On the other hand, concentration of calcium, magnesium and bromine is usually more. Composition varies from place to place and the formation of calcium chloride and absence or intermediate concentration of magnesium sulfate in subsoil brines are often witnessed. The exchange properties of soils and various clays and minerals, the effect of organic matter, sulfate reducing bacteria and kinetics of various reactions may throw a light on its composition and give useful information for future developments.

e) *Will the bore well die out or drop in output?* There is always a fear in the mind of the salt manufacturer that his bore well may become dead at any time. That could happen for various reasons, such as fall in recuperation rate, change in brine stream, corrosion, slipping of silt and blocking passage and others. There is also a fear that he may have to lower his pumping assemblies after a few years, in addition to usual power failure, voltage drops, etc.

f) *Will cracks develop?* It also has been observed that big cracks are developed in surrounding areas and there is a fear of sinking the ground level.

g) *What will be the quality of salt?* A few samples of salt were analysed and are reported in Table 3. It is observed from brine analysis Tables 1 and 2 that subsoil brines contain more magnesium chloride and less or no magnesium sulfate compared to sea brine at similar density. As sulfate content of brine is less, the calcium sulfate remains in solution with the result that calcium sulfate separates out with salt. The graph clearly indicates the difference between seawater evaporation and subsoil brine evaporation and explains how $CaSO_4$ concentration varies with sea salt and in subsoil brine salt.

Washing of calcium sulfate from salt poses a problem because of its very low solubility and its inclusion in the salt crystal. Naturally this type of salt is not preferred by the (chlor) alkali industry and has no foreign market.

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