Diamond Alkali Brine Field at Mont Belvieu, Texas

by
M. L. Moore
Diamond Alkali Company
Mont Belvieu, Texas

ABSTRACT

The writer describes the location, drilling, production, logging, and protection of brine wells established in Barbers Hill salt dome at Mont Belvieu, Texas, by Diamond Alkali Company, in 1947.

Barbers Hill is a large, shallow salt dome located in the Texas Gulf Coastal plains in the general vicinity of other productive salt domes. The dome is oval in shape, covers an area of 1,718 acres and rises 45 feet above the surrounding prairie.

Diamond Alkali is the only chlorine-caustic producing company brining the dome at this time, while Texas Eastern, Gulf Oil, Tennessee Gas, Humble Oil and others have established LPG and other storage wells and attendant facilities in more recent times.

INTRODUCTION

In 1946 the Diamond Alkali Company began construction of a chlorine-caustic soda plant at Deer Park, Texas. One important factor contributing to this decision to build in this area was the close proximity and availability of relatively pure salt. This pure salt was located some seventeen miles northeast across the Houston Ship Channel in a salt dome known as Barbers Hill. The area was properly named since it rose some 45 feet above the surrounding prairie. Its location is 26 miles northeast of Houston and 11 miles north of Baytown, Texas.

GEOLOGY

Geological analysis tells us the Beaumont clays of the Pleistocene Age are exposed at the surface at Barbers Hill. The soil on the hill is very sandy generally, while the soil in the lowlands is clayey. The Beaumont clays, as found on and around the dome, are buff to grayish-black in color and become extremely sticky when wet. The clays range in thickness from 25 to 150 feet thick on the dome proper. By studying the evidence of the presence of an ancient stream which first established its course across this area, an imminent geologist established the upwarping of the Barbers Hill mound in the latter part of the Beaumont time but well before the end. Any photo-mosaic of the dome shows readily the outline of the hill by uplifted sand. The outline of the base of the hill corresponds closely with the caprock outline. The major axis is 12,000 feet long, located N 43° W and the minor axis is 9,200 feet long. The highest portion of the hill lies only 1,250 feet from the center of the dome. The dome covers 1,718 acres. On the dome proper, the clays are compact; on two outer edges and on the flanks, the clays are soft and loamy. In the early days, these clays were considered as a fine drilling mud base in oil well drilling.

The Lissie formation, also of the Pleistocene Age, underlies the Beaumont clays. The Lissie formation on the super dome structure is 600 to 700 feet thick and increases to 1,200 feet toward the flank. Its appearance, we are told, is definitely marked by the first sand break found below the Beaumont clays. This formation is characterized by non-marine gray sands and gravel with some gray, pink, and green calcareous clays. These extensive sands are intermingled with sandy shales and numerous boulders. All these sands are fresh water sands and generally are considered good sources. Our experience has been that water from the shallow sands around 100 to 200 feet contains considerably more hardness than water off the dome, and contain other detracting impurities such as trace of sulphides.

The "caprock," a cap-shaped formation covering the salt mass or "plug" and draping over the edges, rises to within 350 feet of the surface near the center of the dome. The caprock thickness varies from 850 feet near the dome center to a few feet at the dome edges. The term "rock" has evolved because the caprock is harder than the clays and sands in contact with it. It consists generally of two parts. The upper part is principally calcite or limestone and calcium carbonate. The lower part is principally calcium sulphate as gypsum, and is predominant to about 700 feet from the surface; anhydrous calcium sulphate (anhydrite) is predominant at greater depths down to the salt mass. These mineralized deposits are extremely irregular and occur rather as lenses, pockets, and concretions. The caprock is generally porous and cavernous, containing variable amounts of sulfur, pyrite, and calcite deposited in crystal form throughout the porous spaces. Some of the crystals have rounded edges, indicating solution by circulating underground waters. The sulphur is primarily in the elemental form and though present in some quantity, was not considered economically recoverable in 1922, when ten exploratory wells were drilled in search of it.

The salt mass is very roughly circular in horizontal cross section with the major axis and sides very nearly vertical, so it is quite often referred to as a plug. Actually, the plug is slightly mushroomed and has overhanging salt and caprock on the north, east and south flanks. Much of the crude oil produced at Barbers Hill was found in flank sands located beneath these overhangs.

The salt in the plug is believed to have been deposited in horizontal layers intermingled with bands of anhydrite. It rose from a depth of some 30,000 feet, piercing other formations as it moved upward, and attempting to minimize friction by assuming the shape of minimum surface per unit volume. This friction, however, was very great and the time of rise extensive, so this salt was cold worked, recrystallized and strengthened. This produced a salt with low porosity and permeability, and small moisture content. Analysis of core samples showed very negligible free water. The anhydrite beds were extended in extreme cases to filaments.

OIL HISTORY

In 1889, Mr. E. W. Barber found inflammable gas while digging a 65 foot water well on his property near the top of the mound. The well produced a small quantity of gas for many years. Following the discovery of oil at Spindletop near Beaumont, some 90 miles away, on January 1, 1901, Barbers Hill began to receive the attention of the early operators. Early wells were drilled above and into the caprock. Then drilling was extended to the slopes and the first producing well was completed in 1918, after 16 years of drilling, on the southern slope. It produced 70 barrels a day of crude for only 15 months. In 1924, 120 tests had been drilled, of which only 20 were producers. Development, with possibly a single exception, had not penetrated deeper than the Miocene formation. Production had been obtained principally on the southwest flank and amount to only about 800,000 barrels, not enough to make the ventures worthwhile. In the following years, other producing sands were discovered around the periphery of the dome and production increased sharply. Drilling reached its peak in 1930, 31, and 32, then gradually declined. The field has produced 110,500,000 barrels of crude to date and is still producing.

BRINE WELLS

<u>No. 1 Brine Well</u>

Initially, two brine wells were developed. Drilling was started on No. 1 brine well on July 21, 1947. The drilled hole diameter was 22 inches for 711 feet, into which was cemented a 18 inch O. D. x 3/8 inch x 5/16 inch wall casing. The extended drilled hole diameter was

17 inches for 1, 060 feet and 13 5/8 inches O. D. x 54. 4 lbs/foot casing was cemented in for the final depth. The major difficulty experienced was the loss of drilling mud circulation several times due to cavities or crevices. Several hundred bags of cement were used to plug these leaks. 1, 600 sacks of cement were required to cement the 18 inch casing and 1, 350 sacks of cement were required to cement the 13 3/8 inch casing. Core material varied with depth as shown on the following table:

Depth Strata	Each Strata	Formation
22'	22'	Soil and Clay
75	53	Sandy Clay
113	38	Sand
125	12	Sandy Clay
156	31	Sand
255	99	Sand and Sandy Shale
278	23	Shale
320	42	Sandy Shale
400	80	Broken Sand
420	20	Shale
491	71	Broken Sand
522	31	Hard Sand and Rock
553	31	Sand and Shale
584	31	Sand and Rock
614	30	Sand and Shale
646	32	Sand and Boulders
706	60	Sand and Boulders
711	5	Rock
725	14	Sandy Shale and Boulders
730	5	Sandy Shale Boulders -- Lost Returns
733	3	Sandy Shale Boulders
741	8	Sandy Shale Boulders -- Cored
751	10	Sandy Shale Boulders
757	6	Anhydrite -- Cored
760	3	Broken Rock
763	3	Rock and Boulders
770	7	Rock
783	13	Sand and Boulders
788	5	Rock
801	13	Sand and Anhydrite
870	69	Anhydrite -- Broken
944	74	Anhydrite
970	26	Anhydrite and Sulphur
1360	390	Hard Anhydrite
1380	20	Anhydrite and Sand
3400	2020	Salt and Sand

A temperature log was run at this point to assure that no voids existed behind the 13 3/8 inch casing. A rapid change of temperature would indicate a void. Salt was found at 1, 360 feet. An 8 3/8 inch hole was drilled to a 3, 400 foot depth and a water injection tubing or "string" installed to a depth of 3, 341 feet. The water tubing or "string" was made up of 1, 809 feet of 6 5/8 inch O. D. galvanized tubing and 1, 531 feet of 5 9/12 inch O. D. tubing, joined by a swedge. The bottom of the 5 9/16 inch tubing was closed off and 36 one inch diameter holes were burned in the bottom three feet of tubing. The well was completed on November 4, 1947, and was placed in production in April, 1948, at a rate of 75 gpm. Brine of the following quality was produced.

Sulfate as Na_2SO_4	4.605
Calcium as Ca	1.310
Magnesium as Mg	.003
Bicarbonate as HCO_3	.244
Chloride as Cl	183.3
Chloride as NaCl	302.6
Sp. Gr. at 20/4° C (Pycnometer)	1.1983
pH (Beckman)	7.05
Milligrams/liter, Iron as Fe	.02

Salt plug core samples analyzed from 8.5 - 22.47% anhydrite, averaging 13.3% by weight, and 77 to 96% NaCl, averaging 86.5% by weight.

No. 2 Brine Well

The number two brine well specifications, drilling and brining were very similar to that of the number 1 well. It was completed in 1948.

BRINE LINE

Seventeen miles of 10 inch cast iron pipe were coated, wrapped and buried between Barbers Hill and the production facilities at Deer Park, to transport the brine from producer to consumer. Cast iron was chosen for its corrosion resistance to brine and the soil, and has performed well; however, today we would probably favor steel because it is more economical to purchase and install, would have no joints to fail, and has adequate brine corrosion resistance. The cast iron was laid in 18 foot lengths, utilizing approximately 5,000 mechanical joints. This industrial artery crosses several streams, a lake and the Houston Ship Channel. Under the Ship Channel, it has a ball joint instead of the mechanical joint, to allow more flexibility.

BRINING OPERATION

It would be well here to discuss the operational details of brining. In the normal brining procedure, water is produced from nearby wells and pumped into a storage reservoir. Water from the reservoir is injected under approximately 300 psig into the bottom of the brine well cavity through the 5 6/16 inch water tubing. The salt crystals are dissolved, producing brine of a specific gravity of 1.195 to 1.198 at 60° F/60° F. Most of the anhydrite and other waste materials fall to the bottom of the cavity, gradually filling it in. The brine is removed from the cavity through the annulus between the water tubing and the smaller casing, and piped to a brine reservoir.

These first brine wells were not equipped with check valves in their water supply piping, so a well outage allowed backflow due to the imbalance of weight of the brine and water columns. This backflow caused the water injection string to be filled partially with the waste anhydrite or "sand in," plugging it off. The installation of check valves effectively solved this problem for a time. Then the check valves failed from corrosion and this condition was discovered when an emergency outage occurred, and the wells "sanded in." The moral to this story is -- check your check valves.

When a well outage is planned, it has been found advantageous to forward flow the brine wells with brine, instead of water, when the ambient temperature is above about 60° F, in order to equalize quickly the two column pressures. If this procedure is followed when the ambient temperature is much below 60° F, under our conditions, salt crystals may form and plug the piping. This type of plugging has happened.

If for some reason, such as a leaking check valve, backflow occurs during a well outage, the water string may become plugged or "sanded in." When this happens, 400 psig pressure is applied and removed as rapidly as possible several times in an attempt to dislodge the pluggage in forward flow. If this procedure fails to unplug the well, it may be possible to clear the well by backwashing with brine under as much pressure as the well can safely take. If water is used and the cavity is unprotected, salt will be dissolved from the cavity roof and eventually jeopardize the well. Another more expensive method of solving the pluggage problem is to shoot off the water tubing above the plugged zone. We would recommend that this be done periodically and coincidentally with planned outage.

On October 11, 1948, following an outage, the #1 well could not be operated due to "sanding in" of the water string. A rig was moved in to raise the tubing but sufficient buildup of anhydrite had occurred around the lower end of the water string to make raising impossible without risking loss of tubing. Pulling rigs were changed twice and considerable time was spent in backwashing to clear this plug. The bottom 500 feet of the water string was found to be "sanded in." The tubing could not be released from anhydrite wedging under pressure from two 50 ton hydraulic jacks, so the tubing was shot off with a "collar-buster" shot, an explosive charge set off at a piping collar. The tubing was released and shot upward about 2 inches. It then was easily removed by the well rig. The tubing was perforated with 48 core shots approximately 70 feet from the bottom. Test flowing indicated that a considerable amount of sand was still being encountered, so 120 additional core shots were made throughout the 50 feet above.

No. 3 Brine Well

A third brine well was drilled in 1952 to the same overall brining depth of 3,400 feet. As an additional corrosion protection, three casings were used instead of two. The additional casing was a 20 inch O. D. T and C 0.438 inch wall pipe at 44 lbs, cemented into a depth of 710 feet.

In 1954 it was decided to locate the top of the cavity in each of the three wells because major loss of salt in this area could lead to very serious consequences, the gravest of which would be the loss of the well. A Neutron log was run. The logging tool was small enough to pass through the water injection string, so the only disassembly necessary was the removal of the 90° flanged ell at the well head. As the logging tool was lowered, neutron bombardment of the materials surrounding the casings occurred and the quantity of returning neutrons varied with the type of material. The logs showed a roof loss of 97 feet, 243 feet, and 47 feet respectively by increasing well number.

On July 20, 1955, the No. 3 well showed indications of having been violently displaced, with small piping broken off and flowing brine of 1.040 specific gravity. This indicated a loss of water tubing. When a rig was moved in and the tubing pulled, it was discovered that the bottom 1,520 feet of tubing was missing, apparently becoming unscrewed at a coupling where threads were still quite useable. A sonar cavity definition survey was made, with distances recorded on 90° angles at each 10 feet of depth. The resultant cavity as defined was disappointingly short of the calculated cavity and disappointing in indicated shape. It was large in the middle and small on each end. The accuracy of the survey was considered suspect. A Neutron log was run on August 26th to define the roof and bottom hole depth.

In August 1956, a sonar caliper survey was made of the No. 2 well cavity concurrently with the cutting off of 243 feet of the 13 3/8 inch casing which was hanging free in the well cavity. Here again the defined cavity did not agree with the calculated cavity. A Neutron and gamma ray log was run to locate the top of the cavity and it was found at 1,622 feet, indicating no change since 1954. At this point 2,200 feet of 9 5/8 inch tubing was installed as a "floating liner" or brine exit piping, to be used for brine eduction instead of the well casing. The purpose of this liner was to afford control of the brining operations, keeping it away from the cavity roof, and allowing cavity diameter control within limits by raising or lowering the liner. Additional roof protection was planned by injection of approximately 25,000 gallons of natural gasoline, and the injection actually took place in January of 1957. A radio-active tracer, iodobenzene, was added to the gasoline to allow a gamma ray logging of the gasoline during injection. Utilizing the gamma ray readings corresponding to known increments of gasoline pumped in the well cavity, the average diameter at each elevation was calculated. An inhibitor was added to the gasoline to protect from sulfur corrosion.

The same general procedure of floating liner installation and gasoline protection was applied to the No. 1 well in the same year, except that the floating liner was extended only 43 feet below the end of the well casing, as compared to 580 feet for the No. 2 well. This was done in an attempt to evaluate the floating liner brining procedure in already existing wells.

In July 1957, a cavity definition logging was made in the No. 3 well with a sonar caliper. This logging was made similarly to those made in the No. 1 and 2 wells, except that readings were taken with an improved tool tested in our brine storage tanks for accuracy. Readings were recorded each 5° as the tool was rotated through 360° at each elevation. The cavity as defined by this survey was very close in volume to that which calculation defined, based on salt removed. The cavity was much more uniform than those defined for the other two wells. The top of the cavity was located at 1, 839 feet and the end of the casing at 1, 855 feet; so the casing extended into the cavity some 16 feet, indicating very little change since 1956. It was decided to leave this casing extension and place the gasoline blanket behind it. Thus each well would have a somewhat different brining control in that the No. 2 well had a relatively long floating liner, the No. 1 well a relatively short floating liner, and the No. 3 well none at all. This arrangement, then, should afford an indication of the best arrangement in the next few years. The injection of only 11, 978 gallons of gasoline filled the cavity top to within 20 inches of the end of the casing, proving a very narrow cavity. It had been anticipated that 40, 000 gallons might be needed, based on the history of the other wells. When the water tubing was set back in this well, forward water flow could not be obtained, so the tubing was shot off 27 feet above the anhydrite.

In May 1959, sonar caliper cavity surveys were made in both the No. 1 and No. 2 brine wells and a photon log found no change in the gasoline-brine interface. The total volume of the cavities as defined by the sonar caliper log compared very closely with volume as calculated from salt removed. These findings proved that the earlier surveys were in error. One theory for the error of earlier surveys was that the true cavity dimensions cannot be defined adequately by readings recorded each 90° of the tool rotations. The later survey recorded dimensions each 5° of the tool rotation. This theory was very plausible because the cavity proved to be oblong in cross section rather than circular.

In August 1961, photon logs were run on all three wells to determine the cavity roof and gasoline-brine interface. The No. 1 well log showed the "loss" of 1.7 feet of gasoline but no measurable change in the cavity roof. The No. 2 well log, on a scale of 5 inches of log per 100 foot of depth, showed no changes. On an expanded scale, of 25 inches of log per 100 foot of depth, a photon log indicated a "loss" of .8 foot in the gasoline-brine interface. The No. 3 well log indicated no brine-gasoline interface. Successive logs indicated the same condition. 110 gallons of gasoline containing the radio-active tracer iodobenzene was pumped down the water string. No trace of the radio-activity was found. 7, 000 gallons of radio-active gasoline were pumped into the well through the annulus. No trace of the gasoline was found. It was thought at this point that a serious cave-in had occurred sufficiently removed from the casing to escape detection, or the gasoline was escaping through a fissure. The latter possibility would be very serious. It was decided to transfer all the gasoline from the No. 1 well into the No. 3 well. A salinity log verified the cavity roof at 1802 feet and the top of the salt at 1, 342 feet. 25 MC of iodobenzene was added to the first few hundred gallons of gasoline and pumped down the water string. The gamma ray detector was lowered to 2, 800 feet in an attempt to log the radio-active gasoline as it rose in the brine. The gasoline was not detected. 8, 000 additional gallons were transferred from No. 1 well to No. 3 well. Salinity logs did not locate any tagged gasoline at the roof elevation of 1, 802 feet. The remaining 12, 000 gallons of gasoline in No. 1 well were transferred to the No. 3 well and salinity logs again found no trace of radio-activity or gasoline. Later in the evening, a gasoline layer so thin as to be questionable, was located. 12, 000 gallons of gasoline was transferred from the No. 2 brine well cavity and a gamma ray log confirmed its presence in sufficient quantity to protect the roof.

The brine wells will be produced until a cavity diameter of approximately 400 feet is reached. 200 foot thich cavern walls will be maintained between wells to minimize possibility of subsidence. A brining cost study limits well depth to about 4, 000 feet for most economical operation, but for a 25% increase in cost, the well brining depth of new wells could be increased sufficiently to double the well life. One limitation imposed on depth, if a floating is necessary, is the maximum length a floating liner can extend and sustain its own weight. For a 13 3/8 inch liner, 0.514 inches thick, this maximum depth is about 6, 000 feet; for a 9 5/8 inch liner, 0.545 inches thick, this maximum depth is about 8, 000 feet. Another limitation is the operating pressure must not exceed 1, 500 psig, beyond which we are told the overburden might be lifted in a manner very similar to that done purposely when hydro-tracing a tight oil bearing formation.

GENERAL

Atop Barbers Hill sits a small village named Mont Belvieu, with numerous small property owners. Over the years, there have been dreams of oil production on the dome, but development occurred mainly on the edges. Recently, property on the dome has become more valuable, because major pipeliners and other storage seekers have been bidding for a share of this giant salt plug. Today the dome is being gradually taken over by stockpilers such as Texas Eastern Transmission, Gulf Oil Corporation, Warren Petroleum, Texas Natural Gas, and Texas Butadiene.