Solution of Salt in a Horizontal Fracture System Between Wells

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ABSTRACT

Data is presented on experimental models involving the use of both vertical and horizontal fractures in two-well systems in which the fractures may exist initially adjacent to an insoluble or inert bed or located with massive salt above the fracture. Results of mathematical simulation and experimental model data are presented. Different solution patterns are developed depending on the mode of fracture system. Shape of cavities formed in massive salt sections are affected more by solution at the roof surface while cavities formed in which insoluble beds appear as roof members take on the appearance which is expected from vertical surface exposure.

Introduction and Purpose

Brine production is obtained in many areas through solution of salt beds which have been penetrated by wells that have been connected by leaching operations. In other cases direct communication between drilled wells is attempted by the hydraulic fracturing technique. When fractures are formed and washing of soluble beds continues in the fracture, the progressive growth of the cavity formed becomes of interest because of possible means of modifying washing procedures and possible subsidence caused by relatively large widths of cavities formed. Still another aspect of the importance of information concerning cavity growth is related to the question of future fractures emanating from other wells which may or may not be directed into a cavity.

This study was undertaken to determine, through the use of laboratory models, the general shape of cavity developed from an initial horizontal fracture between two wells and to develop a relationship between the growth of the cavity volume with time. Some idea as to the probable ultimate configuration was also believed possible as a result of the investigation.

Experimental Procedure

In order to determine the type of cavity produced between two wells connected by a fracture a system was devised to simulate the conditions to be expected in field operations. For this purpose salt blocks of various size were utilized. To establish the fracture, or path of the fluid introduced initially, a 1/32" to 1/16" thick metal plate was laid on a smooth surface salt block, and fixed in position by means of molding clay. The edges of the salt block were then raised by means of the same clay, and Hysol #R8-2038 with hardener H2-3475, obtained from the Hysol Corporation, Olean, New York, was poured on the surface of the salt. Preliminary to this, of course, the block of salt was levelled so that a uniformly thick coating of plastic material could be obtained. After the resin had hardened the molding clay was removed, and the metal plate, used to form the initial fracture condition, was taken very carefully from the salt surface so as not to extend the fracture in any manner. Later fractures were completed without the use of any metal strips or plates, and just sufficient amount of molding clay was placed to allow a fracture opening of about 1/16th inch in depth.

In order to seal the entire salt surface, other than the fracture, a piece of Lucite 1/4 inch thick was cut to the exact size of the salt block and was cemented to the block with Hysol. Inlet and outlet connections were provided in the plastic sheet to fit the particular fracture dimensions. No difficulty was experienced in obtaining complete coverage and sealing of the salt surface, though it was necessary to have the specimen block level, to employ a thin layer of Hysol solution for the final sealing, and to apply a small uniform load on the plastic plate.

After the Hysol had dried, the block was inverted and washing operations begun. In this manner, progression of solution of salt was that which would be possible with a fracture at the base of a soluble salt bed.

Water was used directly from the tap. A needle valve served as a means of regulating the flow rates and, in addition, a by-pass was provided to assure somewhat better control when fluctuations in pressure occurred. No difficulty whatsoever was encountered in establishing a uniform flow rate. The rate was measured by means of a rotameter placed in the line on the upstream side of the salt specimen, and direct measurement was made of the brine produced from the outlet well.

The amount of salt removed was determined from the volume of fluid flow during each definite time interval and the average specific gravity of the fluid during this time. At the end of each experiment brine was drained from the cavity. This volume was measured and the specific gravity determined. Finally, after drying, the insoluble material was removed and weighed. From the known specific gravity of this material (anhydrite) the volume of such was determined. Total volume was the sum of the volume of fluid drained and the volume of insoluble material. Further, a Plaster of Paris mold was made to give the configuration of the cavity, and a volume was also computed from the mold weight and determined specific gravity. In practically every instance the final volume of the cavity was established well within 10 per cent by the three means described.

A brief description of each leaching experiment follows. The results are tabulated to show the progression of each cavity during the period washed.

With some of the test blocks, in order to forestall a leak occasioned by a break or crack in the salt, the entire salt block was encased in Hysol. Another box, made of wood, was used to hold the salt. The Hysol was poured around the salt, and to a depth sufficient to cover the plastic plate used on top of the salt to seal the salt and furnish the fracture and well spacing.

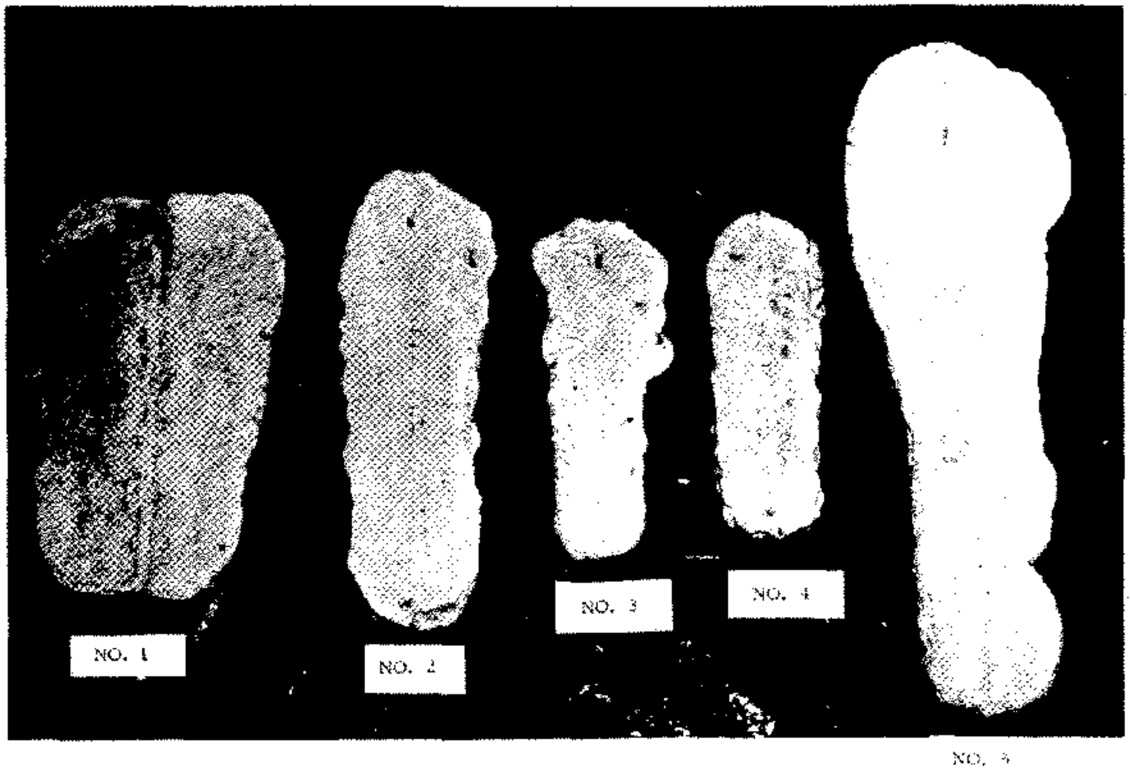
Experiment No. 1 was set up in the manne described and washing was continued for twenty two hours and twenty minutes. A cavity of 344 cc. was produced using a cumulative volume c water of 30,580 cc. A plaster mold of the cavit was prepared. This mold served well to measure th dimensions of the cavity formed and yielded a fin volume of 3240 cc.

Experiment No. 2, the block for this test was pre pared and totally enclosed in plastic as befor Initial fracture was one inch by sixteen inche While washing, air kept leaking in through th bypass valve. Both valves were replaced and the a was purged from the cavity and the mining cor tinued for an elapsed time of seven hours and fi teen minutes. A cumulative volume of 36,445 cc of water was used producing a cavity of 1541.4 cc A plaster mold was made of the cavity and th dimensions recorded. Total final volume of mol was 1515 cc., an excellent agreement with th value obtained from the washing data. See photo graph showing molds of various cavities formed b using this procedure.

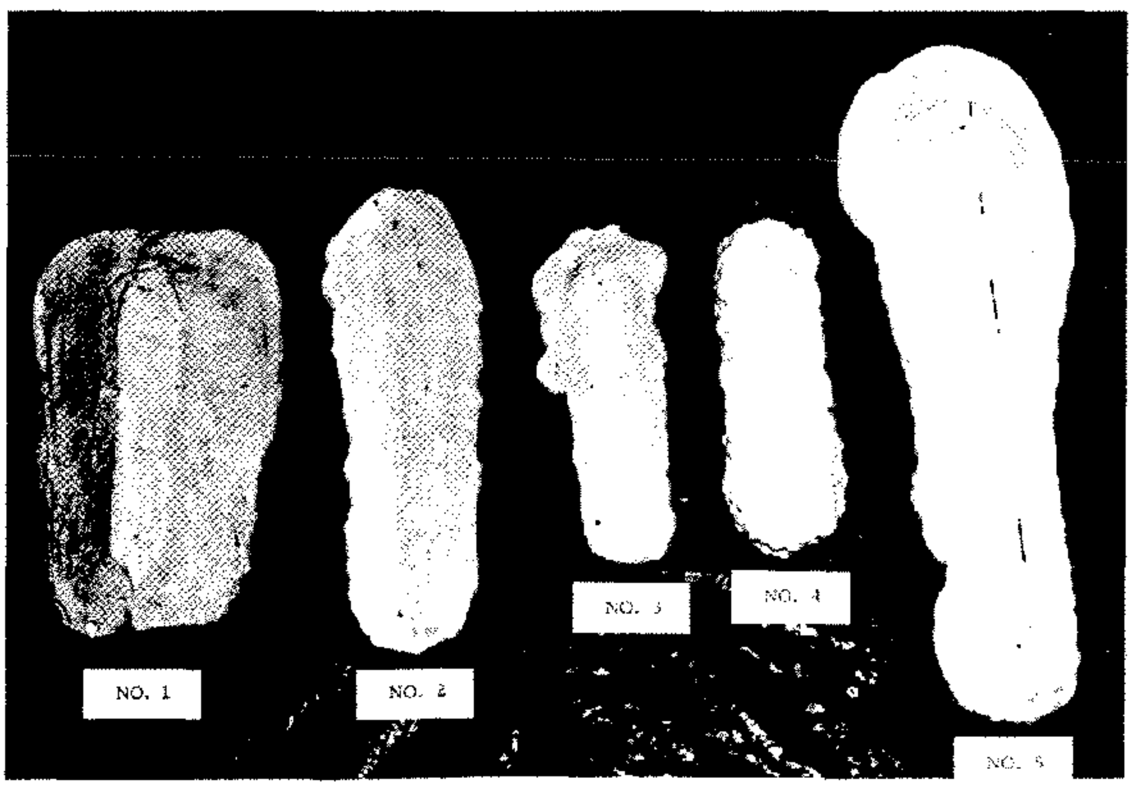
Experiment No. 3 was conducted with a block hav ing a two-inch by ten-inch initial fracture. Th block appeared to be massive and it was decided t try to run the experiment without sealing it in plas tic. The block was set up, but after 1600 cc. o water were circulated it was found a crevice leal existed. The block was sealed in plastic and wa again set up and leaching continued. The cavity was formed with an elapsed time of five hours. A total volume of 9895 cc. of water was used produc ing a cavity of 850.0 cc. A plaster mold of the cavity was made and the dimensions recorded. The solution of salt which resulted from fluid following the fracture was quite evident as a projection or one side of the mold. Volume determined from mold was 740 cc.

Experiment No. 4, in which for the first time a low-grade potash ore was used, was set up in a block with an initial fracture one inch by ten inches. This block again appeared to be massive and was set up without sealing it in plastic. The block was set up and mined, using fresh water. Solution of the potash salt was continued for five hours and thirty minutes using 10,860 cc. of water. A cavity having a calculated volume of 1050 cc. was formed. A plaster mold showed a volume of 935 cc. Very good symmetry was observed. The physical dimensions were recorded from the mold.

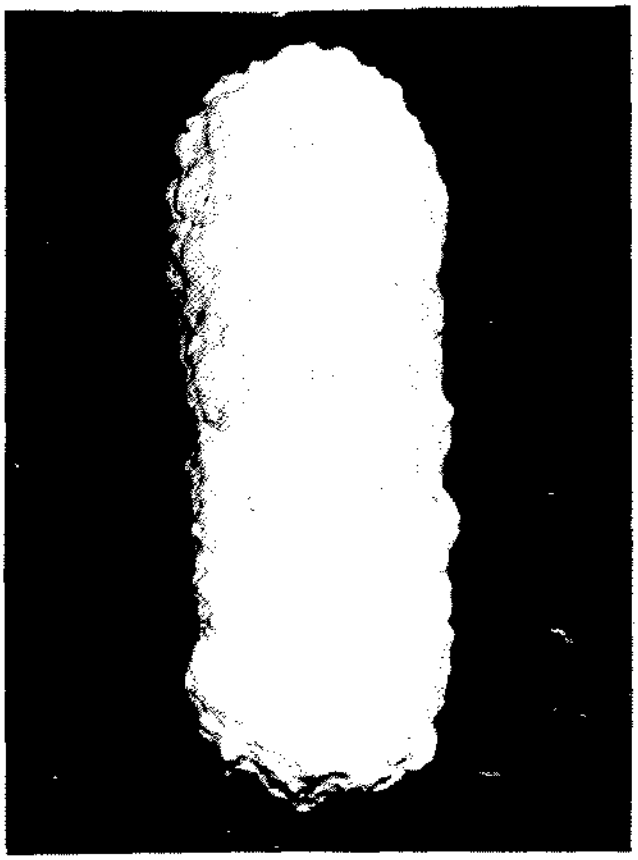
Experiment No. 5 was run on a block with an initial fracture of four inches by twenty-three



Plaster molds of leached cavities–top view.



Plaster molds of leached cavities–bottom view.



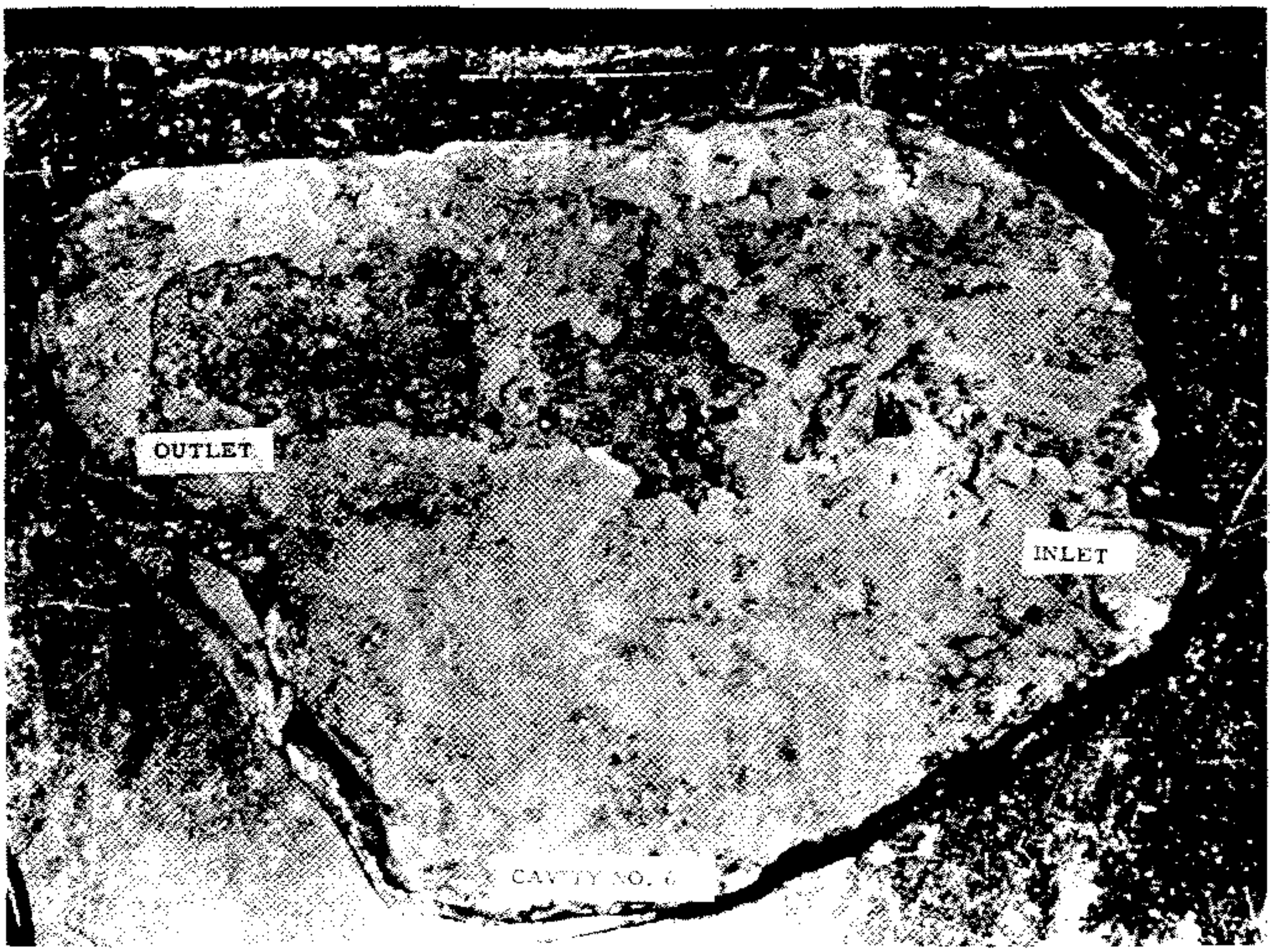
Plaster mold of Cavity No. 4—note symmetry.

inches with a distance of twenty-one inches between wells. The mining was continued for a period of sixteen hours and ten minutes. A volume of 34,670 cc. of fresh water was used to produce a calculated cavity volume of 3847.2 cc. A plaster mold was made of the cavity from which the physical dimensions of the cavity were recorded. The measured volume from the mold was 3660 cc. This cavity was the largest formed and also represented the cavity having the longest course between wells. A photograph of the cavity mold shows the details of the configuration. As in the case of each cavity formed, the roof (top) of the cavity was perfectly smooth.

Experiment No. 6 was conducted with a one-and-one-half inch slab of potash ore with a one-inch by ten-inch fracture. The slab was completely sealed in plastic and set up and mined by circulating salt water with a specific gravity of 1.118. The water was supplied by a gravity flow system from a storage reservoir. The leaching was continued for five hours and fifty-five minutes using 11,440 cubic centimeters of salt water. A cavity of 545 cc. wa produced. The cavity was irregular due to fractur in the potash ore slab and a mold of the cavity wa not made. A photograph showing the irregulariti found near the inlet end and toward the middle o the cavity is included. It appears some selecti solution of sylvinite (sylvite) may have taken plac However, the same pattern was developed as in pr vious instances, namely a flat, smooth roof an widening of the initial fracture width. Apparentl the use of salt water as a circulating medium do not change the basic mechanism of solution, bu as expected, greater volumes of brine must be ci culated to remove a unit volume of ore.

Experiment No. 7, again utilizing potash ore, wa set up and run on a block using an initial fractur width of seven inches, with a distance of eleve inches between wells. The washing with fresh wate took five hours and forty-one minutes usin 19,250 cc. of fresh water. A cavity of 2160 cc. wa

Plaster mold of Cavity No. 5—bottom view.



Note ragged, uneven solution at inlet and smooth roof at outlet.

formed. The block was not sealed in plastic and an air leak developed along a small fracture. The air leak was plugged with clay and was stopped for two to three hours but finally caused the mining to be terminated. The cavity was measured and the measurements recorded and several pictures of the cavity made. The typical configuration was obtained. The effect of having a larger initial width-to-length ratio of the fracture is to decrease the time required to reach a particular saturation of brine. This means, of course, that with a wide fracture existing between wells, a greater amount of salt (potash) could be removed in the early stages of washing. It would mean further that greater volumes of water could be employed initially and throughout the leaching operations.

MATHEMATICAL ANALYSIS

The objective was to obtain a function for volume of salt removed as a function of time so that at any time the rate of removal and the cavity may be predicted.

The experimental work performed indicated the concentration of salt solution is constant along any horizontal plane, resulting in a flat roof and flat floor for the cavity, with all progression being in the positive and negative vertical directions. The approach to the solution of the problem then centered on finding the curve for the outline of the cavity as viewed from above and then to integrate this function over the thickness of the cavity to obtain the volume.

Cavity No. 7 before leaching.

Cavity No. 7 after leaching.

First in line in this approach was the streamline analogy. It was felt that since concentration was constant on any horizontal plane, a model based on the source-sink analogy of fluid mechanics would closely approximate the outline shape. It did indeed do this fairly well for fluid velocities in a suitable range; however, the streamline function resisted integration and so was abandoned.

The next approach was to analyze the cavities leached in the laboratory and to develop equations which represented the configuration with time of washing. All cavities leached had approximately the same shape given below.

The volume was calculated first by approximating the darkened lines in Figure 1(b) and Figure 1(c) by parabolas and then integrating over the outline indicated in Figure 1(a).

For the parabola approximating the curve in Figure 1(c), the assumption was made that

$$Y = a_1 X^2 + b' X + c_1$$

where:

$$Y(a) = b, \; Y(a) = 0, \; Y(c) = 0$$

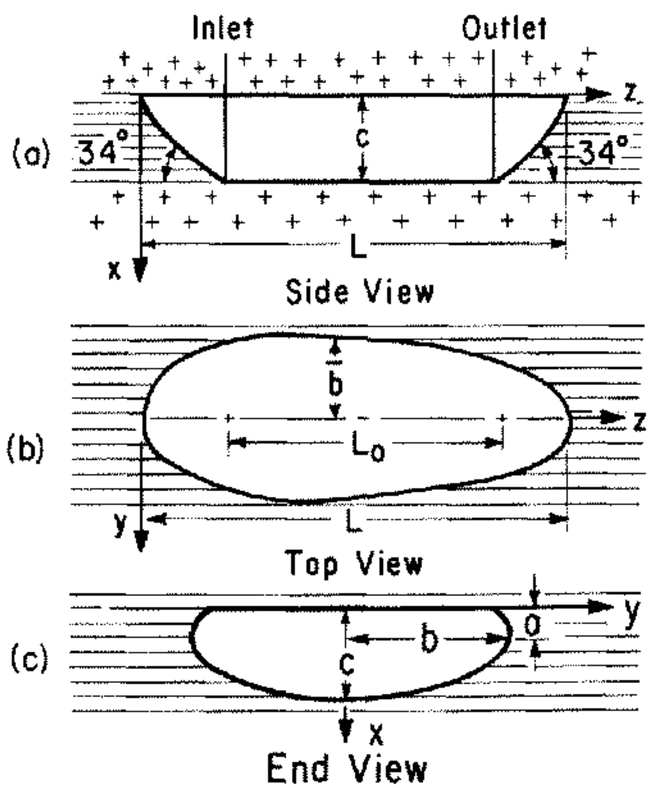


Figure 1. Section taken half way down the length of the cavity: $z = L/2$

This results in three linear equations

$$b = a_1 a^2 + b_1 a + c_1$$

$$2a_1 a + b_1 = 0$$

$$a_1 c^2 + b_1 c + c_1 = 0$$

whose solution is

$$a_1 = \frac{-b}{(a-c)^2}, \quad b_1 = \frac{2ab}{(a-c)^2}, \quad c_1 = \frac{bc\,(c-2a)}{(a-c)^2}$$

and thus the approximating parabola is

$$Y = \frac{1}{(a-c)^2} \left[-bX^2 + 2abX + bc\,(c-2a) \right]$$

Likewise the equation for the curve indicated in Figure 1(b) was approximated by

$$Z = \frac{L}{Zb^2} \; Y^2$$

and the area given for the top is

$$A = \frac{4}{3} \bar{b} L$$

where $\bar{b}$ is the variable representing the half-width as one moves up and down the thickness (at $Z = \frac{L}{2}$); $\bar{b}\,(a) = b$

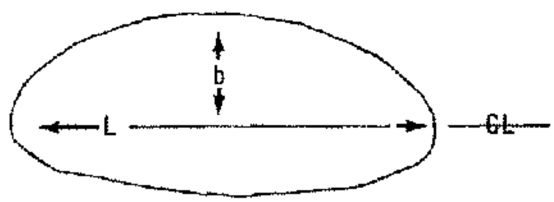
The volume for the complete cavity then is given by

$$V = \frac{8}{3(a-c)^2} \left\{ \int_0^c \frac{-bLX^2\,dX}{2} + \int_0^c abLXdX + \int_0^c \frac{bc}{2} (c-2a) \; LdX + \int_0^c b \tan 34^\circ \; X^3 \; dX - \int_0^c 2ab \tan 34^\circ \; X^2 \; dX - \int_0^c bc\,(c-2a) \tan 34^\circ \; X \; dX \right\}$$

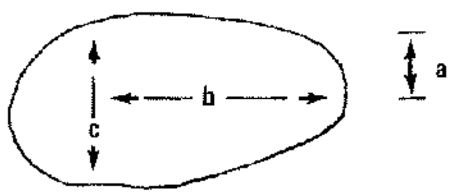
or

$$V = \frac{4\ bc^2\ L}{3\,(a\text{-}c)^2}\ [\frac{5c}{3} - 3a] \pm \frac{8\ bc^3\ \tan 34°}{3\,(a\text{-}c)^2}\ [\frac{a}{3} - \frac{c}{4}]$$

where a, b, c, L are the dimensions indicated below



Top View



Cross Section

In the following examples application of this formula is made for cavities washed in the laboratory to indicate the precentage error.

Cavity No. 1

$$V = \frac{4\ bc^2\ L}{3\,(a\text{-}c)^2}\ [\frac{5}{3}\ C - 3a] + \frac{8\ bc^3\ \tan 34°}{3\,(a\text{-}c)^2}\ \frac{a}{3} - \frac{c}{4}]$$

where

$a = \frac{5}{16}$ inches, $b = \frac{77}{16}$ inches,

$c = \frac{22}{16}$ inches, $L = \frac{266}{16}$ inches.

$V = 3200$ cc

The measured volume was 3250; the predicted volume is 3200 cc. % error is = 1.6%.

Cavity No. 2

Where

$a = \frac{5}{16}$ inches, $b = \frac{44}{16}$ inches,

$c = \frac{19}{16}$ inches, $L = \frac{306}{16}$ inches.

$V = 1670$ cc

The measured volume was 1470 cc.; the predicted volume is 1670 cc. % error is = 14%.

Cavity No. 3

Where

$a = \frac{6}{16}$ inches, $b = \frac{33}{16}$ inches,

$c = \frac{21}{16}$ inches, $L = \frac{227}{16}$ inches.

$V = 1000$ cc

The measured volume was 817 cc.; the predicted volume is 1000 cc. % error is = 22%.

Cavity No. 4

Where

$a = \frac{8}{16}$ inches, $b = \frac{36}{16}$ inches,

$c = \frac{22}{16}$ inches, $L = \frac{218}{16}$ inches.

$V = 918$ cc

The measured volume was 935 cc.; the predicted volume is 918 cc. % error is = 1.8%.

<u>Cavity No. 5</u>

Where

$$a = \frac{12}{16} = .75 \text{ inches,} \qquad b = \frac{96}{16} = 6 \text{ inches,}$$

$$c = \frac{29}{16} = 1.80 \text{ inches,} \qquad L = \frac{368}{16} = 22.8 \text{ inches}$$

$$V = 4000 \text{ cc.}$$

Measured volume was 4175 cc.; predicted volume is 4000 cc. % error = 5%.

In order to make this volume (V) function a function of time, it was necessary to determine experimentally how a, b, c, and L depend on time. Once this had been accomplished, the resulting formulas were substituted into the volume (V) function resulting in the desired relationship of volume (V) as a function of time.

First the b values were plotted versus time to get the form of the curve relating b, c, a, and L, to t. This graph (Figure 2) indicates these dimensions are linear functions of time.

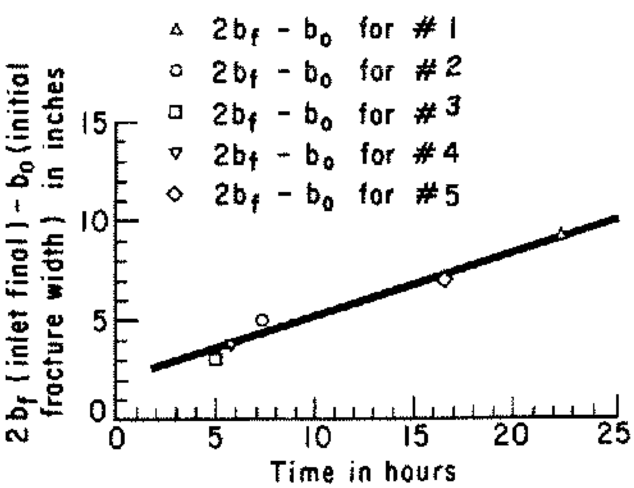


Figure 2.

On the basis of Figure 1 we may assume, since $b_{(t)}$ is a linear function that

$$2b(t) = b_1 t + b_o$$

where b_o is the initial fracture width. Also, b_1 is the slope of the line in Figure 1 and is seen to be

$$\frac{5}{16} \text{ in/hr. or } 0.026 \text{ ft/hr.}$$

b(t) then is given by

$$b(t) = 0.013t + \frac{b_o}{2}$$

Likewise L(t) is given by

$$L(t) = 0.013t + L_o$$

If the water is near saturation at the outlet the experiment shows that c changes at the ratio $\frac{11}{32}$ of the rate of change of L. Thus:

$$c(t) = 0.0045t$$

Also, *a* changes at the ratio $\frac{4}{15}$ as fast as does c.

Therefore:

$$a(t) = 0.0012t.$$

The volume in cubic feet as a function of time then is given by

$$V(t) = \left[\frac{4\left(0.013t + \frac{b_o}{2}\right)(0.0045t)^2 \ (0.013t + L_o)}{3(-0.0033t)^2}\right]$$

$$\left[\left(\frac{5}{3}\right)(0.0045t) \cdot 3(0.0012t)\right]$$

$$+ \left[\frac{16\left(0.013t + \frac{b_o}{2}\right)(0.0045t)^3}{9(-0.0033t)^2}\right]$$

$$\left[\frac{0.0012t}{3} \cdot \frac{0.0045t}{4}\right]$$

Simplifying,

$$V(t) = \left[\left(\frac{10.4}{10^3}\right) \left(0.013t + \frac{b_0}{2}\right) \left(0.013t + L_0\right) (t) \right]$$

$$- \left[\left(\frac{11.2}{10^6}\right) \left(0.013t + \frac{b_0}{2}\right) (t)^2 \right]$$

As an example, assume a calculation of the volume removed after 100 hours from an initial cavity defined by: $b_o = 50$ feet, $L_o = 400$ feet.

$$V(100) = \left(\frac{10.4}{10^3}\right) \left[(0.013)(100) + \frac{50}{2} \right] \left[(0.013)(100) \right.$$

$$\left. + 400 \right] - \left[\left(\frac{11.2}{10^6}\right) \left(1.3 + \frac{50}{2}\right) (100)^2 \right]$$

$$V(100) = 10{,}976 - 2.83 = 10{,}973 \text{ ft}^3$$

Two methods were employed to determine surface areas. The first method was based on a model with flat sides such as occurred when insoluble material was present, and the other was based on a prolate spheroid.

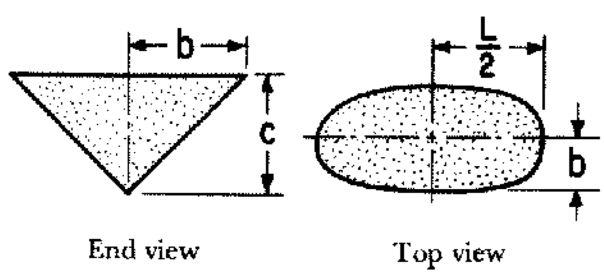


Figure 3.

Surface area for the slab side model is given by:

$$S.A. = \pi\, b \frac{L}{2} + 2L \sqrt{b^2 + c^2}$$

Where the first term gives the surface area of the elliptical top and the second term gives the surface area of the sides.

For the prolate spheroid model the surface area is given by

$$\text{SURFACE AREA} = \pi \left(\frac{Lb}{2} + b^2 + \frac{Lb}{2\epsilon} \sin^{-1} \epsilon \right)$$

Where:

$$\epsilon = \frac{\sqrt{L^2 - 4b^2}}{L}$$

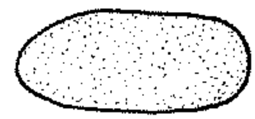


Figure 4.

It should be pointed out that this model is good only in the latter stages of the washing when the cavity does begin to assume the shape of half a prolate spheroid.

Summary

1. A study has been made in the laboratory by leaching salt blocks in which horizontal fractures connected two wells.

2. Fracture width and length were varied. The minimum fracture width was 1 inch. The corresponding length was 10 inches. The maximum width of fracture was 7 inches with 12 inches between wells. Maximum length between wells was 23 inches, corresponding fracture width was 4 inches.

3. The resulting configuration of cavity formed may be described in mathematical terms which permit prediction of the volume of cavity formed with time.

4. When the initial fracture width is relatively large in comparison with the length between wells practically all the solution of salt takes place on the roof of the cavity, and relatively little widening of the cavity occurs with time.

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CAVITY WASHING TEST: No. 1
SOURCE OF SALT: Hockley Salt Mine, United Salt Company, Houston, Tex.
CONDITION OF TEST: Fracture, 10" long, 1" wide
MANNER OF TEST: Inlet and outlet at bottom of fracture
RECAPITULATION OF DATA

Time Interval Min.	Vol. of Water cc per time interval	cumulative	Flow Rate cc/min	Specific Gravity Outlet Brine	Calculated Vol. Salt Removed "cc/stage	Cumulative Volume of Cavity cc	Vol. Water / Vol. Cavity formed
	700 cc getting set up						
60	960	1,660	16	1.107	125	125.0	7.6
60	900	2,560	15	1.138	86.5	211.5	10.4
60	900	3,460	15	1.148	97.2	308.7	9.2
60	900	4,360	15	1.150	97.2	405.9	9.2
60	870	5,230	14.5	1.152	95.5	501.4	9.1
	400 cc used setting up						
60	855	6,485	14	1.160	140.5	641.9	8.8
60	870	7,355	14.5	1.156	94.0	735.9	8.30
60	900	8,255	15	1.157	99.0	834.9	9.1
60	1,450	9,705	22	1.150	157.0	991.9	9.2
60	1,075	10,780	18	1.146	114.0	1,105.9	9.4
60	1,100	11,880	18.5	1.150	119.0	1,224.9	9.2
60	1,090	12,970	18	1.153	120.0	1,344.9	9.0
60	985	13,955	16.5	1.155	107.5	1,452.4	9.1
20	1,000	14,955	20	1.170	120	1,572.4	8.3
60	825	15,780	15	1.156	90.0	1,662.4	9.1
60	925	16,705	20	1.140	92.5	1,754.9	10.0
120	1,875	18,580	20	1.137	178.5	1,933.4	10.5
60	1,450	20,030	20	1.131	133.5	2,066.9	10.8
30	750	20,780	20	1.123	64.0	2,130.9	12.7
	Drained 2650 cc			1.133	244.0	2,474.9	10.8
60	1,350	24,780	20	1.156	147.0	2,621.9	9.2
60	1,000	25,780	20	1.165	Shut in	2,733.4	9.0
60	900	26,680	20	1.182	114.0	2,847.4	7.9
30	650	27,330	20	1.178	83.5	2,930.9	7.8
	3,250	30,580		1.162	374.0	3,304.9	8.7
				Dried and weighed 400 gm anhydrite			
				Insoluble material 135.5		3,440.4	

Volume (mold) = 3,240 cc
Length = 16.25 inches Height at inlet = 2-1/4 inches
Width at inlet = 10.25 inches Height at inlet = 2-7/8 inches
Width at outlet = 8.00 inches
Width at midpoint = 9.25 inches

CAVITY WASHING TEST: No. 2
SOURCE OF SALT: Hockley Salt Mine, United Salt Company, Houston, Tex.
CONDITION OF TEST: Fracture, 1" Wide 16" Long
MANNER OF TEST: Inlet, Outlet at bottom of fracture
RECAPITULATION OF DATA

Time Interval Min.	Vol. of Water cc per time interval	cumulative	Flow Rate cc/min	Specific Gravity Outlet Brine	Calculated Vol. Salt Removed cc/stage	Cumulative Volume of Cavity cc	Vol. Water / Vol. Cavity formed
15	1,000	--	--	--	start up, flushed air from system, set rate		
15	800	1,800	53	1.047	25.8	25.8	31
15	1,750	3,550	117	1.058	73.0	98.8	24
15	2,150	5,700	143	1.048	77.0	175.8	28
15	1,450	7,150	97	1.040	41.5	216.3	35
Flushed out with air, 1,500 ml, no data taken, Sp. Gr. of solution was 1.041							
		(8,650)					
8	725	9,375	91	1.034	17.5	233.8	41
28	Flushed with air, 1,100 ml, no data taken, changed valves while shutdown						
		(10,475)					
17	1,400	11,875	82	1.022	21.6	255.4	65
15	1,060	12,935	71	1.022	14.0	269.4	75
5	1,100	Flushed air out of cavity, no data taken					
		(14,035)					
10	910	14,945	91	1.034	22	291.4	41
15	1,310	16,255	87	1.029	27	318.4	48
15	1,350	17,605	90	1.015	14.5	332.9	92
30	3,800	21,405		Tried to flush out air, connection broke, repaired, tried to flush air second time			
5	460	21,865	92	1.017	63.3	396.2	-) air
				1.017			-) in
10	980	22,845	98	1.012			-) cavity
Shut down, awaiting assistance in attempt to remove all air from cavity							
10	1,000	23,845	Flushed out system, no data taken				
				(1.074)			
10	600	24,445	60	1.090	39.5	435.7	15
10	750	25,195	75	1.110	83.0	518.7	9
15	1,150	26,345	76	1.115	95.0	613.7	12
15	1,150	27,495	77	1.114	93.5	707.2	12
15	1,100	28,595	73	1.113	90.5	797.7	12
15	1,130	29,725	75	1.114	92.5	890.2	12
15	1,170	30,895	78	1.116	100.0	990.2	12
15	1,450	32,345	96	1.114	120.5	1,110.7	12
15	1,150	33,495	76	1.112	95.0	1,205.7	12
15	1,100	34,495	67	1.111	87.0	1,292.7	13
15	970	35,365	65	1.098	70.5	1,363.2	14
15	1,080	36,445	72	1.097	79.5	1,442.7	14
15	Drained 1,400 ml, Sp. Gr. 1.062, Stopped test				61.5	1,504.2	
				Dried and weighed 110 gm anhydrite			
				Insoluble material	37.2	1,541.4	

CAVITY WASHING TEST: No. 2 (Continued)

Cavity Dimensions after making plaster of Paris mold:

Width at inlet end = 6"

Width at outlet end = 5-1/4"

Depth = 1-1/8", uniform over length

Width at midpoint = 5-1/2"

Length over-all = 19"

Volume (from mold) = 1,515 cc

CAVITY WASHING TEST: No. 3
SOURCE OF SALT: Hockley Salt Mine, United Salt Company, Houston, Tex.
CONDITION OF TEST: Fracture 2" Wide, 10" Long
MANNER OF TEST: Inlet, Outlet at bottom of fracture
RECAPITULATION OF DATA

Time Interval Min.	Vol. of Water cc per time interval	Vol. of Water cc cumulative	Flow Rate cc/min	Specific Gravity Outlet Brine	Calculated Vol. Salt Removed cc/stage	Cumulative Volume of Cavity cc	Vol. Water / Vol. Cavity formed
Set up and purged air, ran in 100 ml, allowed to set 24 hours							
Started to run, found air leak, fractured salt segment, total of 1,600 ml run, Sp. Gr. = 1.032, shut down to seal fracture					(37)	(37)	-
Sealed block of salt in Hysol							-
Started up again							-
10	500	2,100	50	1.045	16.6	53.6	30
15	460	2,560	31	1.066	22.0	75.6	21
20	590	3,150	30	1.098	41.6	117.2	14
30	800	3,950	27	1.117	67.2	184.4	12
30	860	4,810	29	1.125	78.0	262.4	11
30	860	5,670	29	1.128	79.5	341.9	11
30	790	6,460	26	1.129	73.8	415.7	11
60	1,620	8,080	27	1.132	155.0	570.7	10
30	680	8,760	22	1.135	66.0	636.7	10
30	720	9,480	24	1.137	71.5	708.2	10
15	415	9,895	28	1.139	41.5	749.7	10
Stopped test, drained 810 cc of fluid, Sp. Gr. = 1.130					67.5	817.2	-
				Dried and weighed 100.3 gm anhydrite			
				Insoluble material	33.7	850.9	

Cavity dimensions after making plaster of Paris mold:

Width at inlet end = 5-1/2" Depth = 1-5/16"

Width at outlet = 3-5/8" Length over-all = 14"

Width at midpoint = 4-1/8" Volume (from mold) = 740 cc

CAVITY WASHING TEST: No. 4
SOURCE OF SALT: Low Grade Potash Ore—New Mexico
CONDITION OF TEST: Fracture 1" Wide, 10" Long
MANNER OF TEST: Inlet, Outlet at bottom of fracture
RECAPITULATION OF DATA

Time Interval Min.	Vol. of Water cc per time interval	cumulative	Flow Rate cc/min	Specific Gravity Outlet Brine	Calculated Vol. Salt Removed cc/stage	Cumulative Volume of Cavity cc	Vol. Water / Vol. Cavity formed
5	540	540	108	1.052	20.4	20.4	27
10	420	960	42	1.062	18.2	38.6	23
15	460	1,420	31	1.083	27.6	66.2	17
15	450	1,870	30	1.102	33.2	99.4	14
15	460	2,330	31	1.112	37.4	136.8	12
15	460	2,790	31	1.117	39.1	175.9	12
15	440	3,230	29	1.121	38.6	214.5	11
15	460	3,690	31	1.125	41.6	256.1	11
15	445	4,135	30	1.129	41.7	297.8	11
15	460	4,595	31	1.130	43.6	341.4	10
15	460	5,055	31	1.132	43.9	385.3	10
15	450	5,505	30	1.135	43.9	429.2	10
15	450	5,955	30	1.138	44.8	474.0	10
15	650	6,605	43	1.140	66.0	540.0	10
15	350	6,955	23	1.142	35.8	575.8	10
30	850	7,805	29	1.145	98.5	665.3	8.6
30	860	8,665	29	1.149	93.0	758.3	9
30	880	9,545	29	1.150	95.5	853.8	9
15	465	10,010	31	1.151	50.8	904.6	9
15	850*	10,860	30	1.146	89.5	994.1	9
Drained an additional 600 cc of brine, Sp. Gr.				1.130	56.5	1,050.6**	

No insoluble material present.

Width at inlet end = 4-7/8"

Width at outlet end = 4-1/4"

Width at midpoint = 4-1/2"

Depth, uniform = 1-3/8"

Length = 13-5/8"

Volume from mold = 935 cc

*Test stopped because of air leak caused by breakthrough at top of cavity which caused high flow just at end of last wash period of 15 min.

**Considering rate of flow to be normally 450 cc durg the 15 minute period, this would mean 400 cc of last 850 cc was drainage from cavity, thus volume of fluid, by drainage, would be 400 + 600 = 1,000 cc.

CAVITY WASHING TEST: No. 5
SOURCE OF SALT: Hockley Salt Mine, United Salt Company, Houston, Tex.
CONDITION OF TEST: 4" x 23" Channel, 21" between wells
MANNER OF TEST: Inlet, Outlet at bottom of fracture
RECAPITULATION OF DATA

Time Interval Min.	Vol. of Water cc per time interval	Vol. of Water cc cumulative	Flow Rate cc/min	Specific Gravity Outlet Brine	Calculated Vol. Salt Removed cc/stage	Cumulative Volume of Cavity cc	Vol. Water / Vol. Cavity formed
17	700	700	-	1.053	27.1	27.1	26.5
13	580	1,280	44.6	1.050	21.2	48.3	26.6
15	500	1,780	33.3	1.052	19.9	68.2	25.1
15	420	2,200	28.0	1.069	20.9	89.1	20.1
15	510	2,710	34.0	1.089	32.9	122.0	15.5
15	465	3,175	31.0	1.103	34.7	156.7	13.4
15	475	3,650	31.7	1.110	37.7	194.4	12.7
15	450	4,100	30.0	1.116	37.8	232.2	11.9
15	445	4,545	29.6	1.120	38.6	270.8	11.5
15	410	4,955	27.3	1.124	36.7	307.5	11.2
15	500	5,455	33.3	1.129	46.6	354.1	10.7
15	510	5,965	33.9	1.132	49.5	403.6	10.3
30	950	6,915	31.7	1.135	92.0	495.6	10.3
30	935	7,845	31.2	1.139	93.9	589.5	9.96
30	950	8,800	31.7	1.145	98.6	688.1	9.7
30	950	9,750	31.7	1.150	103.0	791.1	9.2
30	930	10,680	31.0	1.152	102.0	893.1	9.1
30	875	11,555	29.2	1.150	94.8	987.9	9.2
10	320	11,875	32.0	1.150	34.7	1,022.6	9.2
15	540	12,415	36.0	1.164	64.1	1,086.7	8.4
15	475	12,890	31.7	1.165	56.7	1,143.4	8.4
15	450	13,340	30.0	1.160	52.1	1,195.5	8.6
15	485	13,825	32.3	1.154	54.0	1,249.5	9.0
30	880	14,705	29.3	1.153	97.6	1,347.1	9.0
30	930	15,635	31.0	1.153	103.0	1,450.1	9.0
30	1,080	16,715	36.0	1.152	118.6	1,568.7	9.1
30	1,070	17,785	35.7	1.149	115.7	1,684.4	9.2
30	1,010	18,795	33.7	1.147	107.8	1,792.2	9.4
30	990	19,785	33.0	1.149	106.9	1,899.1	9.3
30	930	20,715	31.0	1.151	101.5	2,000.6	9.2
30	1,020	21,735	34.0	1.151	112.5	2,113.1	9.1
30	1,200	22,935	40.0	1.150	131.5	2,244.6	9.1
30	1,360	24,295	45.3	1.146	143.8	2,388.4	9.4
30	1,290	25,585	43.0	1.143	133.4	2,521.8	9.6
30	1,310	26,895	43.7	1.144	136.5	2,658.3	9.6
30	1,500	28,395	50.0	1.144	156.5	2,814.8	9.6
30	1,320	39,715	44.0	1.144	138.5	2,953.3	9.5
30	1,275	30,990	42.5	1.145	134.2	3,087.5	9.5
30	1,230	32,220	41.0	1.146	130.5	3,218.0	9.4

CAVITY WASHING TEST: No. 5 (Continued)

Time Interval Min.	Vol. of Water cc per time interval	cumulative	Flow Rate cc/min	Specific Gravity Outlet Brine	Calculated Vol. Salt Removed cc/stage	Cumulative Volume of Cavity cc	Vol. Water / Vol. Cavity formed
30	1,200	33,420	40.0	1.147	128.0	3,346.0	9.4
30	1,250	34,670	41.7	1.147	133.2	3,479.2	9.4
Drained 3,700 cc of water, Sp. Gr.				1.139	368	3,847.2	
				Insoluble material	328	4,175.2	

Volume from mold = 3,660 cc

Width at inlet = 9 inches

Width at outlet = 4-1/2"

Width at midpoint = 6 inches

Length overall = 28"

Depth, uniform = 1-7/8"

CAVITY WASHING TEST: No. 6
SOURCE OF SALT: Potash Ore, low grade, New Mexico
CONDITION OF TEST: 1" x 10" cavity, 10" between wells
MANNER OF TEST: Used salt water as fluid S.G. 1.118, Inlet and Outlet at bottom of fracture
RECAPITULATION OF DATA

Time Interval Min.	Vol. of Water cc per time interval	cumulative	Flow Rate cc/min	Specific Gravity Outlet Brine	Calculated Vol. Salt Removed cc/stage	Cumulative Volume of Cavity cc	Vol. Water / Vol. Cavity formed
10	400	400	40.0	1.118	0	0	165
15	430	830	28.6	1.126	2.6	2.6	165
30	1,025	1,855	34.2	1.140	16.1	18.7	63.7
30	930	2,785	31.0	1.152	24.4	43.1	38
30	1,000	3,785	33.3	1.162	31.8	74.9	31.2
30	920	4,705	30.7	1.168	32.7	107.6	28.6
30	920	5,625	30.7	1.169	33.2	140.8	28.7
30	780	6,405	26.0	1.172	36.1	176.9	21.3
30	940	7,345	31.3	1.174	34.3	211.2	27.4
30	900	8,245	30.0	1.174	36.5	247.7	24.6
30	840	9,085	28.0	1.175	34.5	282.2	24.3
30	970	10,055	32.3	1.176	40.7	322.9	23.8
30	840	10,895	28.0	1.176	35.2	358.1	23.8
	545	11,440	-	1.169	20.1	378.2	27.1

Drained Cavity

Checked S.G. 8/11/65 at 1.119

Volume of cavity from amount drained at end of test = 545 cc

No mold made, see picture

Width at inlet = 3-1/4" Depth at inlet = 1-1/2"

Width at outlet = 2-3/4" Depth at outlet = 3/8"

Width at midpoint = 3-1/4" Depth at midpoint = 1"

Length, overall = 12-1/2"

CAVITY WASHING TEST: No. 7
SOURCE OF SALT: Potash Ore, Good Grade, New Mexico
CONDITION OF TEST: 7" x 12" fracture, 11" between wells
MANNER OF TEST: Inlet and Outlet at bottom of fracture
RECAPITULATION OF DATA

Time Interval Min.	Vol. of Water cc per time interval	Vol. of Water cc cumulative	Flow Rate cc/min	Specific Gravity Outlet Brine	Calculated Vol. Salt Removed cc/stage	Cumulative Volume of Cavity cc	Vol. Water / Vol. Cavity formed
15	770	770	51.4	1.152	84.5	84.5	9.1
15	800	1,570	53.3	1.148	85.8	170.3	9.3
15	765	72,335	51.0	1.147	81.6	251.9	9.3
15	755	3,090	50.3	1.145	79.0	330.9	9.5
15	770	3,860	51.4	1.132	73.9	404.8	10.4
15	760	4,620	50.7	1.117	64.5	469.3	11.7
*15	980	5,600	-	1.098	69.6	538.9	14.1
15	700	6,300	46.7	1.102	51.6	590.5	13.5
**30	1,100	7,400	-	1.122	97.5	688.0	11.3
15	655	8,055	43.7	1.139	65.9	753.9	10.0
***15	630	8,685	42.0	1.129	58.7	812.6	10.7
15	720	9,405	48.0	1.132	68.8	881.4	10.5
15	780	10,185	52.0	1.158	89.4	970.8	8.7
15	765	10,950	51.0	1.158	87.5	1,058.3	8.7
15	750	11,700	50.0	1.157	85.3	1,143.6	8.8
****15	775	12,475	51.7	1.158	89.0	1,232.6	8.7
15	775	13,250	51.7	1.158	89.0	1,321.6	8.7
15	765	14,015	51.0	1.157	86.8	1,408.4	8.8
15	770	14,785	51.3	1.156	87.2	1,495.6	8.8
15	795	15,580	53.0	1.155	89.3	1,584.9	8.9
*****15	610	16,190	40.7	1.139	61.4	1,646.3	1.0
†11	900	17,090	-	1.153	99.7	1,746.0	9.0
Drained	2,160	19,250	-	1.134	209.0	1,955.0	10.3

Total volume of cavity from amount drained = 2,160 cc

No mold made, see pictures

Width at inlet = 9-1/2 inches

Width at outlet = 8-1/4"

Width at midpoint = 8-1/2"

Depth at inlet = 1-1/16"

Depth at outlet = 7/8"

Depth at midpoint = 1"

Length overall = 14-1/2"

*Found air in cavity and flushed out with water.
**Found air to still be in cavity. Turned specimen over to purge of air and found small air leak to one side of inlet end of block. Plugged air leak and purged of air and continued.
***Checked for and found same place as in ** leaking slightly. Repaired and purged of air.
****Took sample for analysis.
*****Found air leaking in again at the same place. Attempted to seal fracture and purged of air and continued.
†Found air still leaking in and filled cavity with water and shut down.