EARLY STAGE CARBONATE SCALING CHARACTERISTICS IN DIXIE VALLEY WELLBORES

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ABSTRACT

Carbonate scale in seven Dixie Valley wellbores has been logged, primarily with Schlumberger's multifinger caliper tool. The scale deposition rate is different for each well and is primarily controlled by the pre-flash calcium content in the fluid, which varies considerably between wells. The deepest scale is found at the deepest flash point. Above this the scale rapidly increases in thickness and then gradually thins over total lengths up to 1700'. The minimum possible scale length at Dixie Valley is on the order of 600 to 800'. By varying wellhead pressure this length can be extended and the maximum thickness minimized. Estimated times between scale cleanouts will depend on how the wells are produced but will probably average 3 to 4 months for wells with 9-5/8" production casing and 6 to 12 months for wells with 13-3/8" production casing.

INTRODUCTION

Fluids from liquid-dominated geothermal reservoirs usually precipitate calcium carbonate scale when boiling of the fluid occurs. In Dixie Valley this flash occurs in the wellbores. As the scale thickens it creates a restriction to flow and gradually reduces the output of the well to a point where the well can not supply an adequate volume of fluid at required pressures. At this point the scale must be removed, either chemically or mechanically. This can be expensive, both in terms of lost production and scale removal costs.

To estimate the annual cost of scale removal at the Dixie Valley geothermal field, Oxbow Geothermal Corporation obtained caliper logs in seven wells that had partially scaled during flow testing operations. These wells had developed scale rinds with a maximum thickness of between 0.27 and 1.14".

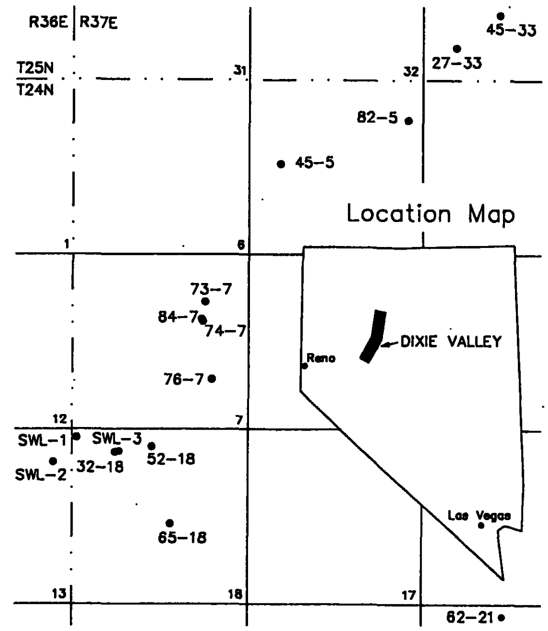


FIGURE 1

The thickest scale reduced the open wellbore cross section by 45 % but had not significantly reduced the flowing wellhead parameters. This study therefore only evaluated the early stage of carbonate scale buildup in wellbores. The later stage would commence once the scale is thick enough to significantly impair the flowing wellhead parameters.

FIELD BACKGROUND

The liquid-dominated Dixie Valley geothermal field is located in west-central Nevada (Figure 1). The producing intervals in the reservoir are both a Miocene basalt and a sequence of Jurassic oceanic floor rocks known as the Humboldt Lopolith (Waibel, 1987). All wells produce from one or the other unit, primarily where they are intersected by the Stillwater Fault. No wells produce from both units. Producing intervals lie between depths

TABLE 1
REPRESENTATIVE PRE-FLASH FLUID COMPOSITIONS IN PARTS PER MILLION

Well	Na	K	Ca	Si	B	Li	Cl	SO4	HCO3	CO3	F	CO2	pH
45-33	312	49.6	0.71	514	4.74	2.05	251	96.6	277	22.3	13.1	1685	8.9
27-33	319	50.0	0.70	520	4.64	2.10	246	95.7	231	43.6	12.0	1807	9.4
73-7	351	53.5	0.61	509	5.67	2.20	299	110.7	261	30.6	9.7	1982	8.8
84-7	328	50.2	0.71	482	5.37	2.03	278	107.4	228	36.7	9.2	2100	9.2
74-7	336	51.3	0.68	495	5.45	2.12	300	107.4	264	21.6	9.3	1990	8.9
76-7	343	45.4	1.01	486	5.58	2.11	306	110.5	240	22.8	8.7	1605	8.9
65-18	396	36.8	0.86	388	5.90	1.76	337	132.0	338	6.8	6.8	1545	8.6

of 7200 and 10266'. Fluid entry temperatures vary by 50°F, increasing with depth.

Representative chemical analyses from the seven logged wells are shown on Table 1. The samples were collected from two phase flow lines with a mini-separator and have been corrected to pre-flash conditions. During collection the samples were filtered through 0.45 micron filter paper. The calcium values in Table 1 do not reflect the amount of calcite precipitated in the wellbore as carbonate scale or any scale particles removed during filtering. All produced waters are of the sodium - mixed anion type. The noncondensible gas content varies from 0.17 to 0.22 weight percent of the pre-flash fluid and is at least 96 % carbon dioxide by weight.

FLOW TESTING AND CALIPER LOGGING

The logged wells were flowed during three separate tests. Well 27-33 was flowed and logged twice, in 1983 and 1984, and early in 1986. The scale created during the first test has been subtracted from the total to give the results presented on Table 2. Well 84-7 was flowed in early 1986. Wells 45-33, 73-7, 74-7, 76-7, and 65-18 were flowed simultaneously in mid 1986.

Prior to this multiwell test, wells 73-7 and 76-7 had clean wellbores as they had not been flowed for more than a few hours. Well 74-7 had been flowed for two weeks earlier in 1986. The volume of fluid produced during this earlier test has been added to the more extensive test to give the total volume shown on Table 2. Wells 65-18, 84-7, and 45-33 were worked over prior to testing. It is assumed these wellbores were clean when testing began.

During testing, the wells were flowed in a wide-open condition. Wellhead parameters were allowed to decline naturally. The only time the wells were throttled back was to run productivity tests, generally lasting less than half a day. Only two or three of these were run on each well. A six day productivity test was run on well 45-33.

In all wells except 27-33, the amount of scale was determined with Schlumberger's multifinger caliper, a state- of-the-art caliper tool which has a horizontal resolution of 0.01". Three different sizes of multifinger caliper tools are available. Different sized tools had to be used in the 9-5/8 and 13-3/8" wells due to the large radius differences. Scale thicknesses were small enough so that the entire scaled interval in each well was logged with a single tool. In well 27-33 the scale was logged with a 3-arm bowspring type, single trace tool. A 0.25" (diameter) correction had to be made to this survey because the tool did not record the clean casing diameter correctly. The multifinger caliper tool produced excellent quality data.

DISCUSSION

The multifinger caliper log contains 11 radius traces. The average radius trace was used to determine scale thickness, length, and volume (Table 2). To determine the scale thickness, the clean casing radius was drawn on the original caliper log and the difference was read every 50'. These replotted scale profiles are shown on Figure 2 with the

FIGURE 2

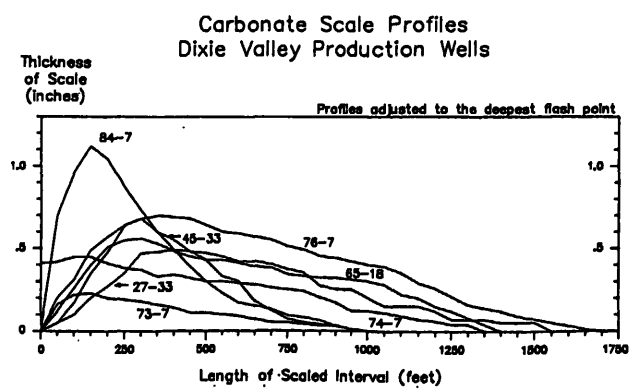


TABLE 2

CALIPER AND FLOWING DATA

WELL	TOTAL FLUID PRODUCED (1000 lbs)	INTERNAL DIAMETER OF CASING (Inches)	VOLUME OF SCALE (Inches3)	MAXIMUM SCALE THICKNESS (Inches)	DEPTH TO BOTTOM OF SCALE (Feet)	DEPTH TO TOP OF SCALE (Feet)	LENGTH OF SCALE (Feet)	WELLHEAD PRESSURE (Psia)	INITIAL FLASH POINT DEPTH (Feet)	FINAL FLASH POINT DEPTH (Feet)	SCALE DEPOSITION RATE (lbs Fluid/In.3)	PERCENT RESTRICTION
27-33	726,000	8.755	102,640	0.50	4290	2756	1534	96-92	3700	3930	7,073	22
84-7	1,170,000	8.835	119,796	1.14	2366	1416	950	161-153	2457	2457	9,767	45
65-18	737,019	8.835	140,319	0.58	2155	760	1395	115-79	1243	1998	5,252	25
45-33	1,260,453	8.681	104,355	0.68	1882	900	982	153-128	1393	1725	12,079	29
73-7	901,278	10.05	46,104	0.27	2631	1658	973	135-127	2408	2878	19,550	10
76-7	1,997,549	12.515	274,323	0.70	2840	1200	1640	161-111	1748	2758	7,282	21
74-7	1,969,136	12.415	151,924	0.46	3251	1920	1331	175-133	2597	3470	12,961	14

deepest scale defining a common zero point. This allows an easy visual comparison between wells with respect to length, thickness, and distribution of scale. There is considerable variation in scale profiles.

The relative visual scale volume estimates can be misleading due to the different diameters of wellbores involved. For instance, well 74-7, with 13-3/8" (O.D.) casing (Table 2), contains about 11,000 cubic inches of scale more than well 65-18 with 9-5/8" (O.D.) casing. Yet cursory inspection of Figure 2 suggests well 65-18 contains the larger volume of scale. Larger circumference casing requires a greater scale volume to reach the same thickness as a smaller casing. Depending on the casing weight, the internal circumference of 13-3/8" casing is about 39.16" and the circumference of 9-5/8" casing is about 27.27". To have the same scale thickness, all other factors being equal, the 13-3/8" casing will require about 1.44 times the volume of scale as 9-5/8" casing.

The scale, except in well 74-7, has the classic shape of a flame above a candle. Presumably this is the same as the ventury-type restriction reported by Gudmundsson et al. (1983). Scale begins at the deepest flash point and rapidly thickens upward to a maximum within 100 to 400'. Above this maximum the scale progressively thins over a length of up to 1300'. The bottom of the scale in well 74-7 coincides with a change in casing diameter from 13-3/8 to 9-5/8". The scale in this well is abnormally thick near the bottom. Apparently the large change in casing cross section was close enough to the flash point that it controlled the flash point depth and associated scale deposition.

Well 73-7 has the least volume of scale. While flowing, the casing collapsed and during the subsequent swedging operations some scale must have been scrapped off the casing by the swedge. During kick off, 2600' of coiled tubing was lost in 73-7. This tubing, removed prior to swedging, had up to 0.1" of scale which otherwise would have adhered to the casing. The volume and thickness of the scale and the scale deposition rate in well 73-7 are therefore minimum numbers.

The simplest correlation expected in scale formation should be between the volume of fluid produced and the quantity of scale (Figure 3). However, the wells, as a group, do not define a narrow linear trend. There is considerable scatter between the 9-5/8" wellbores and the two 13-3/8" wellbores show no trend away from the origin. Additional factors must also control the quantity of scale formation.

The chemistry of the reservoir fluid, particularly the pH, and amounts of bicarbonate, carbonate, calcium, and carbon dioxide have a major influence on scale formation. Calcium is by far the

FIGURE 3

Volume of Fluid Produced versus Volume of Scale Created

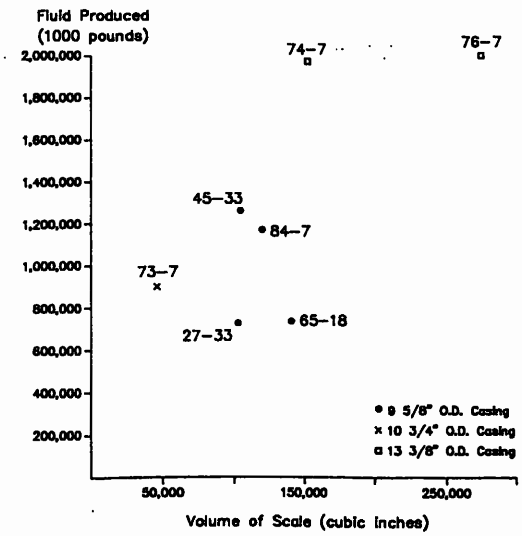


TABLE 3
CALCULATION OF PARTS/MILLION CALCIUM PRECIPITATED AS CARBONATE SCALE

WELL	SCALE VOLUME (in^3)	WT. OF CALCIUM (lbs)	FLUID PRODUCED (lbs x 10^6)	PPM OF CALCIUM
27-33	102,640	2970	726	4.1
84-7	119,796	3466	1170	3.0
65-18	140,319	4060	737	5.5
45-33	104,355	3019	1260	2.4
73-7	46,104	1334	901	1.5
76-7	274,323	7937	1998	4.0
74-7	151,924	4396	1969	2.2

least abundant of these components (Table 1) making it the most affected by scale formation. Assuming that the scale has a density of 2.0 g/cc the amount of calcium precipitated as scale is shown on Table 3.

The amount of precipitated calcium ranges between 2.2 and 5.5 ppm, with the exception of well 73-7. The amount of calcium in the brine at the surface is slightly less than 1 ppm in all wells except 76-7. Most of the available calcium precipitated before geochemical samples could be collected at the surface. This indicates calcium is the limiting factor in scale formation in Dixie Valley. Total calcium varies between 2.9 and 6.4 ppm. While none of the major elements in the Dixie Valley brine show this large percentage variation between wells, some minor elements such as fluoride vary in quantity by a factor of two. As calcium is present in minor amounts in the Dixie Valley fluids it is possible that the large calculated pre-flash variation is real. This indicates that the scaling rate of each well can be unique.

From a production viewpoint, the most important scale parameter is the maximum thickness. This is the dominant factor affecting the flow of the wells. Assuming that a given volume of scale will be created by a given volume of fluid in any single well, the length of the scaled interval will, in large part, control the thickness and visa versa. Increasing scale length will result in thinner scale. However, no distinct multi-well correlation between length and thickness can be shown (Figure 4). In part this absence of correlation is due to the fact the scale thickness is much more dependent on the volume produced than the length of scale and Figure 4 does not take volume into account. The minimum measured scale length in Dixie Valley wells is between 950 and 1000'.

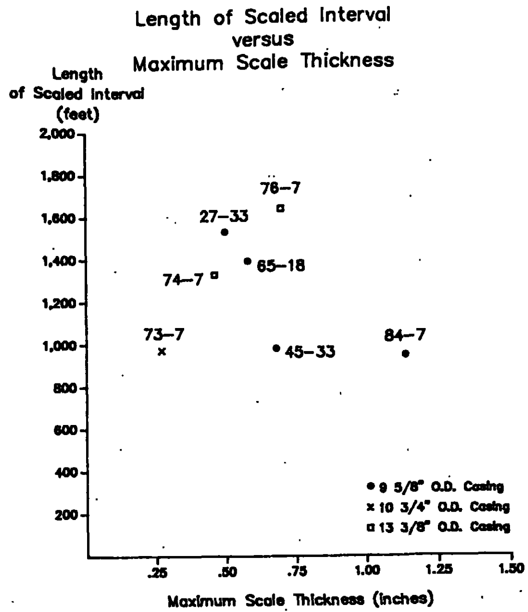


FIGURE 4

The parameter most likely controlling the length of the scaled interval is the change in flash point depth with time. A change in the flash point will be reflected by a change in wellhead pressure. If the flash point moves up or down the wellbore during production, the scale length will increase and the maximum thickness must be less than if the scale built up over a shorter interval. This is especially true during the time when the wellbore is clean. As the wellbore becomes progressively scaled and the wellhead pressure is reduced, the ability to move the flash point by varying the wellhead pressure will diminish. The shortest and thickest scale measured at Dixie Valley is 1.14", in well 84-7 which had no change in the flash point depth during its flow test (Table 2).

Flash point depths were calculated using downhole flowing pressure and temperature data and include the effect of dissolved CO_2 on the boiling point pressure. The relationship between calculated flash point depth changes and the associated wellhead pressure changes is shown on Figure 5. A ten pound change in wellhead pressure moves the flash point on average about 200' given the flowing conditions of these wells. The change in wellhead pressure can now be used to interpret the scale length interval. The wellhead pressure is used because it is a directly and easily measured parameter. The flash point depths will later be correlated with actual scale depths.

All wells except 27-33 create a relatively well-defined trend of

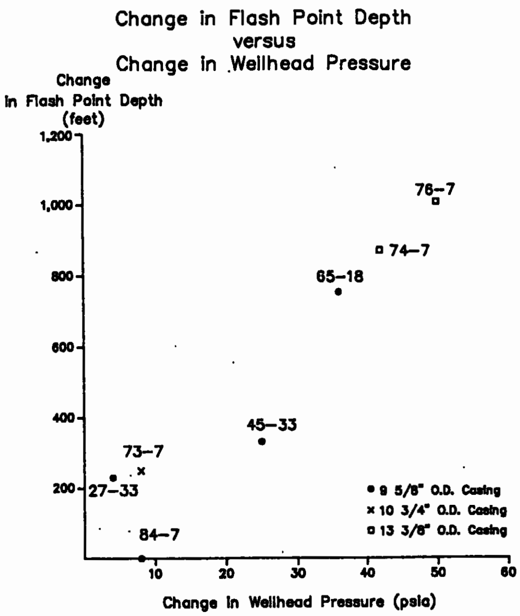
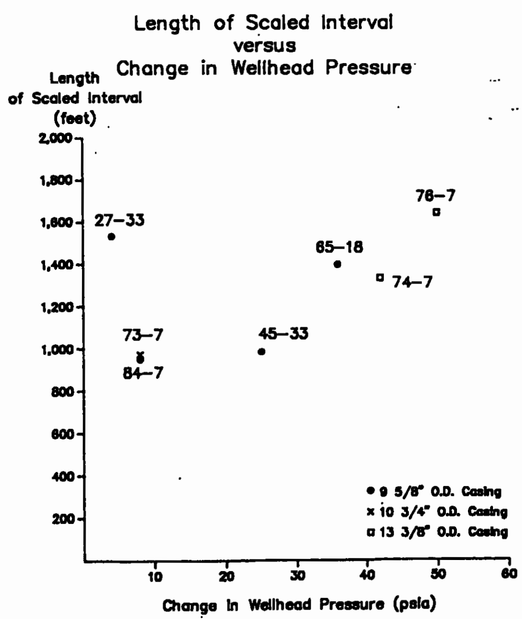


FIGURE 5

increasing scale length with increasing change in wellhead pressure (Figure 6). The scale length should be largely independent of the volume of fluid produced during the early stage of scale formation. Extrapolating the trend to zero change in wellhead pressure indicates that the minimum expected scale length in these wells will be about 600 to 800'.

This reflects two factors. The first is the length over which carbon dioxide gas exsolves from the brine during flashing to create scale particles. The second

FIGURE 6



is the distance that scale particles, precipitated in the interior of the wellbore, travel up the wellbore before they are able to adhere to the casing or existing scale. If these particles never make contact with a solid base they will presumably be ejected from the wellbore or tend to redissolve as temperatures decline higher in the wellbore. As wellbore diameter increases there is less surface area of casing per volume of fluid. Therefore scale particles are less likely to make contact with a solid base in larger diameter wells. This in part explains why the larger diameter wells need scale cleanouts much less frequently than smaller diameter wells.

Most of the wellhead pressure change occurred early in the flow testing, before significant scale could have deposited. This indicates the wellhead pressure declines were primarily due to pressure changes in the reservoir and not as a result of scaling. Had wellhead pressure changes been most pronounced late in the test and the maximum scale thicknesses greater, scaling would be interpreted as the likely cause of the wellhead parameter declines (Gudmundsson et al. 1983).

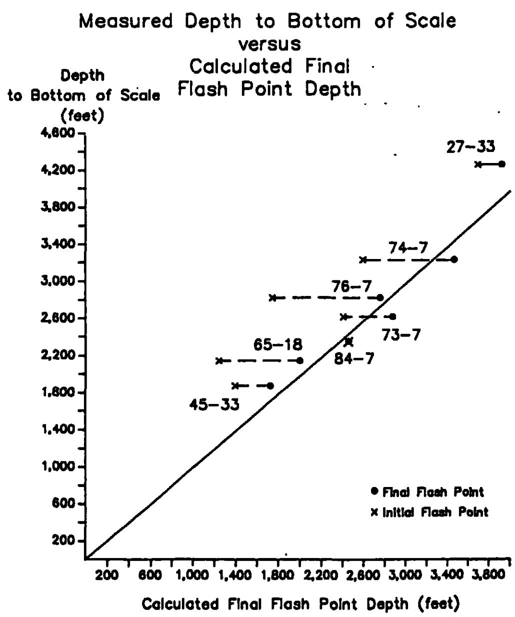
The depths at which the scale forms is also a production concern. There is only 9-5/8" casing in wells 27-33, 45-33, 84-7, and 65-18 so it makes little difference (aside from wellhead pressure) if the scaled interval moves up or down these wellbores. The scaling characteristics should remain the same with the maximum scale thickness being the limiting factor in controlling the times and volumes between scale cleanouts. In wells 73-7, 76-7, and 74-7 the 10-3/4" or 13-3/8" casing is reduced to a 9-5/8" liner between depths of 3256' and 3776'. If the scaled interval moves down into this smaller casing the scaling characteristics will change and the times and volumes between cleanouts will be reduced.

The present bottom of the scaled interval in wells 73-7 and 76-7 are 825'and 764' respectively, above the reduction in casing size. As the wellhead pressure decreases, the flash point moves to a greater depth at an average rate of about 200' for each 10 pound decline in wellhead pressure. A 40 pound wellhead pressure drop in wells 73-7 and 76-7 would lower the flash point into the 9-5/8" liner. It is unlikely that the scaled interval will move, or be allowed to move, down this far. However, the scale in well 74-7 starts at the top of the 9-5/8" liner hanger. Any further downward movement of the scaled interval will move the scale down into the smaller liner. The cure for this is simple, flow the well at a higher wellhead pressure.

In working with actual depths to the bottom and top of scaled intervals the calculated flash point depths, rather than the wellhead pressure changes, must be used. Figures 7 and 8 show the calculated final and initial flash point depths for the wells versus the measured depth to the bottom and top of the scaled intervals. There is good correlation between the final flash point depth (lowest wellhead pressure) and the bottom of the scaled interval. The correlation between the initial flash point depth and the top of the scaled interval (Figure 8) is not very close. The calculated initial flash points are from 483 to 1041' deeper than the measured top of the scale. This provides another estimate of the extra time and distance it takes for the scale to be created and make its way to the casing. This estimated minimum scale length is in general agreement with the 600 to 800' length previously indicated from Figure 6.

The scale profiles and knowledge of the flowing history of the well demonstrate how the scale grows and how its distribution changes with time. Scale initially forms over a 600 to 800' interval in all wells. If the flash point is stationary, scale profiles like that in wells 84-7 and 73-7 develop where the most rapid deposition of scale is about 150' above the flash point. As the flash point progressively declines in the well the scaling profile follows.

FIGURE 7



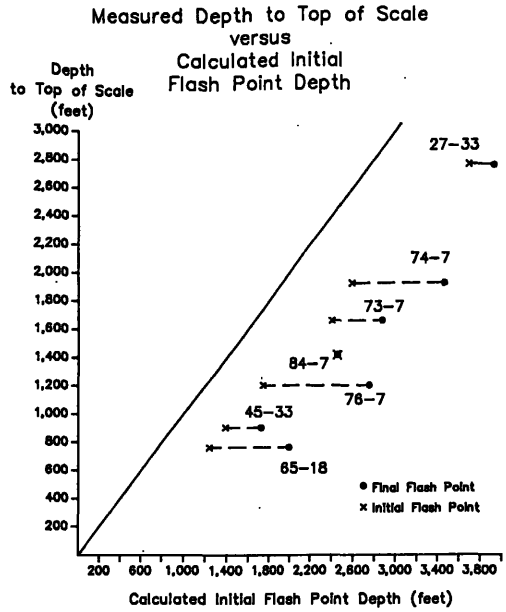


FIGURE 8

The interval of maximum scale deposition is probably always defined by the thickest scale because it is built on an existing base of relatively thick scale that formed a short distance above the flash point. Thus the scale profile initially has a flame or ventury shape and continues to maintain it.

The bottom of the scale in well 27-33 is over 1000' deeper than any other well (Figure 7). Due to a near wellbore restriction (skin), well 27-33 had a flowing downhole pressure about 1000 psi lower than the other wells. It has since been reworked into a much more efficient well and the scale interval is expected to move much higher.

The average scale deposition rates for the wells range from 5252 to 19,550 pounds of fluid produced per one cubic inch of scale (Table 2). These rates may or may not be constant as the well becomes progressively scaled and do not take into account any scale which was created but did not adhere to the wellbore. If well 73-7 is not considered, the minimum rate drops to 12,961 pounds of fluid per cubic inch of scale in well 74-7. The maximum rate occurs in well 65-18, one of the lower enthalpy wells in the field.

Wells with three different diameters of production casing are present at Dixie Valley. The average scale deposition rates appear to be similar for the 9-5/8 and 13-3/8" casings (Figure 9) but this does not take into account ejected scale. If scale particles are preferentially ejected from the larger

Average Scaling Rate
versus
Internal Casing Diameter

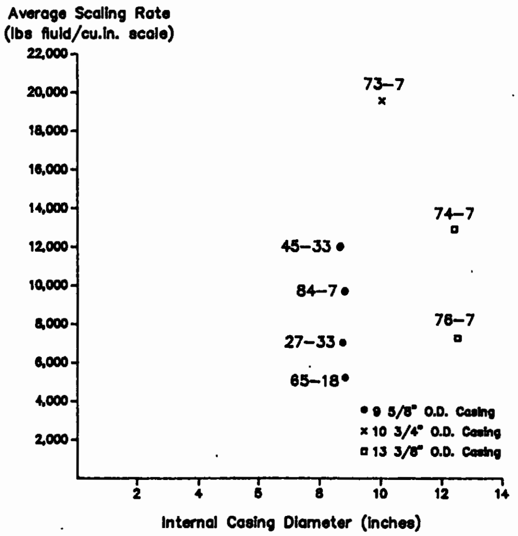


FIGURE 9

Average Scaling Rate
versus
Volume of Scale Created

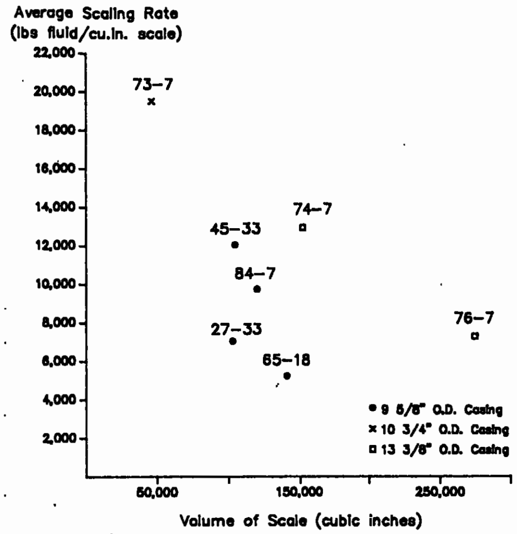


FIGURE 10

wellbores it has not been documented at Dixie Valley due to the use of the filter paper in the sampling process. It is probable that well 73-7 actually has a similar scaling rate because the volume of scale created in this well is known to be greater than actually measured.

Repeated chemical sampling during testing permits the scale deposition rates to have remained constant. With the post-flash calcium contents in the 1 ppm range any significant change in scale deposition rate should be easily discerned if the amount of ejected scale remains constant. The low calcium content also means scale deposition rates in the Dixie Valley wells can increase only 15 to 30 %, assuming the reservoir chemistry and scale ejection rate remain constant.

Both the 9-5/8 and 13-3/8" wells appear to have an increasing scale deposition rate with increasing volume of scale (Figure 10). The most scaled wells with different casing sizes, 65-18 and 76-7 produce from the lower enthalpy basalt aquifer. While the other wells have very similar chemistry, wells 65-18 and 76-7 are different and have the highest post-flash calcium contents (Table 1). If wells 65-18 and 76-7 are ignored, there is no apparent trend on Figure 10.

Predicting the times and volumes that can pass between scale cleanouts is a subjective process. The wells slowly decline in productivity and there is seldom a set point at which the cleanout has to be performed. If the wellhead pressure can be varied then the scale will be spread over a greater length and the time between cleanouts increased. This leads to questions beyond the scope of this paper such as excess well capacity in the field so the wells can be flowed in a throttled back condition when wellbores are clean.

Well 84-7 can be used as a worst case for estimating times between cleanouts. It has 9-5/8" casing and has the greatest scale thickness. Well 84-7 produced 1.17 billion pounds of fluid in 75 days at an average flow rate of 650,000 lbs/hr. During this interval the open cross sectional area of the wellbore decreased by 45 % with no discernible decline in flowing wellhead parameters. It is assumed that the well will need to be cleaned out when the cross sectional area is reduced 65 to 70 % by analogy with a gate valve. When wellhead valves are closed, the flowing parameters generally show little change until the valve is 2/3 to 3/4 closed. Therefore it is unlikely that well 84-7 could flow another 75 days before needing a cleanout. Scale should begin to significantly reduce the 84-7 flowing wellhead parameters within another couple of weeks of flow. The 9-5/8" wells at Dixie Valley could therefore need 3 to 4 scale cleanouts per year. If the wellhead pressure can be varied it may be possible to reduce this by one to two cleanouts per year.

The 13-3/8" wells will need fewer cleanouts per year. Wells 74-7 and 76-7 flowed for 82 and 65 days reducing the cross sectional area by 21 and 14 %

respectively. These wells should flow between six months and a year between cleanouts.

These time intervals are consistent with other geothermal fields in the Basin and Range province. At Desert Peak a 9-5/8" well became severely scaled within two months. Two 13-3/8" wells have supplied the power plant at higher flow rates for a full year between cleanouts. At Roosevelt Hot Springs the 9-5/8" wells require cleanouts from every 1 to 4 months but the 13-3/8" wells will produce for a year.

Why the 13-3/8" wells are capable of flowing from 6 to 10 times longer than the 9-5/8" wells and at substantially higher flow rates (Gudmundsson et al. 1983) is a topic which has received little study. The cross sectional area is only double that of a 9-5/8" well so this doesn't explain all the difference. Other possible factors include differences in scale length to thickness ratios, changes in scale deposition rates both between the different sized wells and between the early and later stages of scaling, and preferential ejection or redissolution of free floating scale particles from larger diameter wells.

At Dixie Valley, there are two 13 3/8" wells, 76-7 and 74-7. Table 1 shows 76-7 to have the highest post-flash calcium content of all the wells which would agree with preferential ejection (assuming they passed through the filter paper) or redissolution of floating scale particles . Well 74-7 has the same post-flash calcium content as the 9 5/8" wells. Unfortunately, the chemical sampling at Dixie Valley was not designed to address the scale particle issue.

The next step in quantifying the scaling process would be to repeatedly log different sized wells with similar flowing conditions as the scaling progresses. Detailed sampling to determine if the 13 3/8" wells are ejecting more scale particles than 9 5/8" wells may also prove interesting.

CONCLUSIONS

During the early stages of scaling, the scale deposition rate for each well at Dixie Valley may be unique and is apparently controlled by the calcium content in the fluid produced. Wells with the highest calcium contents and higher scale deposition rates have lower fluid entry temperatures.

By varying wellhead pressure the scale can be spread out over a longer interval of the wellbore. This has the advantage of reducing the maximum thickness of the scale which, in turn will extend the time between scale cleanouts. By knowing the relationship between flash point depth and wellhead pressure it is possible to design a production program so that the flash point stays in the larger diameter casing.

Perhaps the largest controllable factor over times between scale cleanouts is the choice of production casing size. This logging analysis and operating experience at other geothermal fields indicates that wells completed with 13-3/8" casing will pass several times the volume of fluid between scale cleanouts as 9-5/8" casing. If possible, 13-3/8" casing should be set deep enough to remain below the flash point as reservoir pressures decline over time.

None of the wells at Dixie Valley have been flowed to the point where they entered the later stages of carbonate scaling. It is expected that the later stage scaling characteristics will be different from the early stages.

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