40
7/26/79

Hq. 2910

LBL-9089
GREMP-5
UC-66a

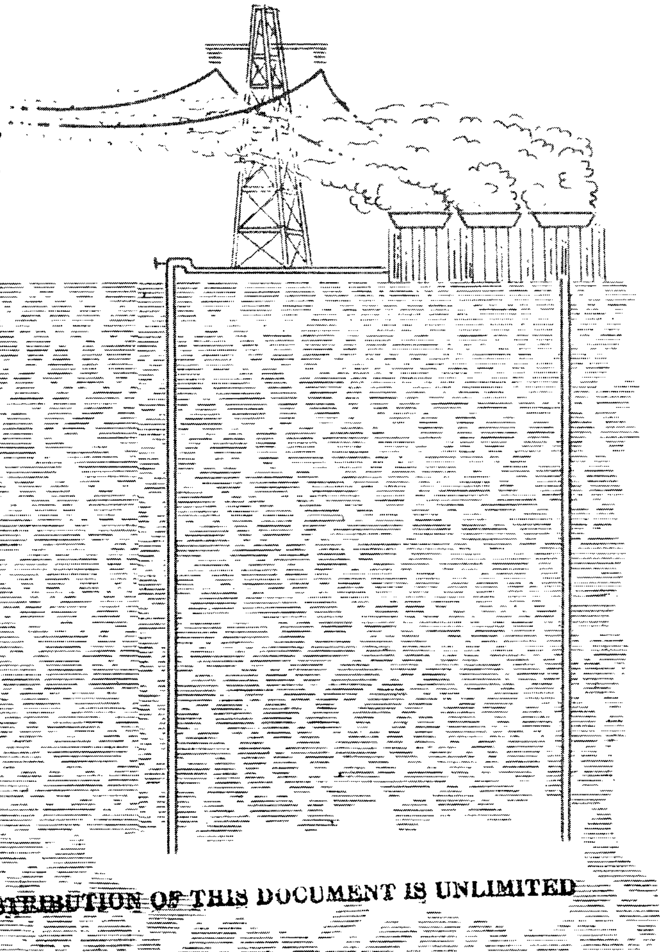
Scale Inhibition in Geothermal Operations — Experiments with Dequest® 2060 Phosphonate in Republic's East Mesa Field

O. J. Vetter
Vetter Research
and
D. A. Campbell
Republic Geothermal, Inc.

MASTER

JUNE 1979

Geothermal Reservoir Engineering Management Program



EARTH SCIENCES DIVISION
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA, BERKELEY

Prepared for U.S. Department of Energy under Contract W-7405-ENG-48

DISCLAIMER

Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161
Price Code: A04

REPORT

SCALE INHIBITION IN GEOTHERMAL OPERATIONS - EXPERIMENTS WITH DEQUEST* 2060 PHOSPHONATE IN REPUBLIC'S EAST MESA FIELD

PREPARED BY

O. J. VETTER, VETTER RESEARCH
AND
D. A. CAMPBELL, REPUBLIC GEOTHERMAL, INC.

SUBMITTED TO

LAWRENCE BERKELEY LABORATORY
BERKELEY, CALIFORNIA

*DEQUEST IS A REGISTERED TRADEMARK OF MONSANTO COMPANY

ACKNOWLEDGMENT

The authors wish to express their gratitude to the program technical monitors J. H. Howard, O. Weres and W. J. Schwarz of the Lawrence Berkeley Laboratory (LBL) for their advice, consideration and review of this study. Special thanks is also extended to the Earth Science Division of LBL who supported this effort through P.O. # 5138802, with H. A. Todd of LBL's Purchasing Department as the Contract Administrator. This work was supported by the U. S. Department of Energy.

TABLE OF CONTENTS

1.0 ABSTRACT

Two calcium carbonate ($CaCO_3$) scale inhibition tests have been performed at Republic Geothermal, Inc.'s (RGI's) East Mesa wells #16-29 and #56-30. The first test at well #16-29 could not be finished due to downhole pump problems. However, two inhibitor concentration runs were completed and a third run started before the pump failed. A follow-up test at well #56-30 was completed according to the original plan. Typical power plant conditions (i.e., pressure and temperature drops, flow conditions) were simulated by using test loops (pipe diameters of eight inches at well #16-29 and twelve inches at well #56-30) and field separators.

Untreated East Mesa brine exhibits a calcium carbonate scale tendency as soon as the pressure is dropped below 75 psig. The uninhibited brine from well #16-29 formed a maximum scale thickness of 0.5 inch in an eight inch ID pipe after a 92.75 hour test run at an average production rate of 375,000 lb/hr. The brine from well #56-30 formed a maximum scale thickness of 1.25 inches in a twelve inch ID pipe after a 104 hour test run at an average production rate of 722,000 lb/hr.

The principal conclusions of this test work are:

1) The formation of $CaCO_3$ scale in RGI's wells and facilities at East Mesa can be prevented by addition of Monsanto's Dequest* 2060 inhibitor at concentrations of less than 1.0 μl per liter.

2) The estimated inhibition cost is on the order of 0.3 mills ($0.0003) per KWhr for full-scale electrical power generation operations at East Mesa.

3) Any scale inhibitor must be carefully applied. Too much inhibitor (i.e., greater than 7.5 μl Dequest* 2060 per liter at East Mesa) will result in the formation of pseudo-scale and, possibly, injection well plugging; too little inhibitor (i.e., less than 1.0 μl Dequest* 2060 per liter at East Mesa) will not give efficient scale inhibition.

4) Even though RGI's East Mesa scale problems have been solved with respect to future power plant operations, additional test work may be required to solve $CaCO_3$ scale problems in other areas and fields having different brines and conditions. This is particularly true if downhole scale is encountered in the absence of downhole pumping capability. The described study is a significant technical advance, but must be considered only a first step toward solving all carbonate scale problems in geothermal operations.

2.0 RESULTS

1) Scale deposition was prevented throughout the RGI East Mesa test system by injection of 1.0 μl Dequest* 2060 per liter of total flow. This is an important milestone in the area of scale handling in geothermal operations, and the data obtained during this test program are very encouraging. It is now proven that chemical inhibition of $CaCO_3$ scale formation can be achieved at temperatures up to at least 320°F.

2) Pseudo-scale (calcium phosphonate) formed at concentrations of greater than 7.5 μl Dequest* 2060 per liter of brine. Thus, the application of the Dequest* 2060 compound must be carefully tailored to the water:

    a) Too much chemical will cause formation of a pseudo-scale (calcium phosphonate); and

    b) Too little chemical will most likely not result in efficient scale inhibition.

3) New instrumentation used during this test at well #56-30 showed that while the scale at East Mesa is predominantly calcium carbonates, there are significant components of strontium, barium, iron and magnesium carbonates.

4) The pseudo-scale occurred in a totally unexpected location, i.e., at temperatures between 270°F and 320°F, and not at lower temperatures. This suggests that the calcium salt of the phosphonate has a "reversed" solubility like, e.g., anhydrite. This information must be carefully considered in future applications of Dequest* 2060, especially for downhole applications and for waters having a high calcium content.

5) Even though the solubility product of the calcium phosphonate in East Mesa water at 320°F is very low and is exceeded at an injection of 7.5 μl Dequest* 2060 per liter of brine, it is still high enough to ensure proper scale inhibition in the presence of pseudo-scale. This is encouraging information for possible formation squeezes with Dequest* 2060 despite the formation of a calcium salt of the inhibitor. The precipitated calcium phosphonate will be redissolved by the reservoir fluid and will still act as a usable inhibitor. Thus, the formation of a calcium salt of the inhibitor in the reservoir may not be as detrimental as normally assumed.

6) The deposition rate of calcium phosphonate salts was low compared to that of the $CaCO_3$. Therefore, a highly efficient protection from scaling using these inhibitors at lower inhibitor concentrations can be expected. No undesired interference with the water constituents should occur at these low inhibitor concentrations.

7) The test data show that scale inhibition using a chemical like Dequest* 2060 can probably be more economical than any procedure using acids. Scale control at East Mesa using this method will most likely add less than 0.3 mill/KWhr to the cost of electricity.

8) Significant plugging of the injection well was experienced during the inhibitor test work at well #16-29 even though the carbonate scale was eliminated in the test loop. Premature termination of this test and analytical problems in the lab prevented identification of the plugging material. Little or no demonstrable plugging of the injector was experienced during the inhibitor injection tests at well #56-30. Filter analyses in the latter test showed that very little phosphonate containing particles penetrated the filter elements. The majority of the particles in the filter elements contained carbonates. It is therefore assumed that carbonate particles caused the injector plugging during thes test at well #16-29.

9) Any application of scale inhibitors can cause the formation of pseudo-scale and/or injector plugging by scale particles. The inhibitor used should be preferably a "threshold" type inhibitor such as Dequest* 2060 and not an inhibitor which prevents the adherence of the precipitated material without preventing the precipitation per se.

10) Laboratory tests with radioactive C-14 labeled Dequest* 2060 showed an extremely complicated precipitation behavior of this compound. The critical precipitations of calcium phosphonate depend upon the: (a) temperature; (b) brine composition, particularly the calcium content; (c) pH; and (d) Dequest* 2060 concentration.

11) The amount of calcium phosphonate precipitation in artificial brines created in the laboratory could be measured only at high calcium and Dequest* 2060 concentrations. Using the actual field brine showed precipitations at fairly low calcium concentrations. It is not quite clear why calcium phosphonate precipitates from the field brine at low calcium concentrations, while the artificial brines show precipitations only at much higher calcium concentrations. However, it was found that NaCl in the aqueous fluid enhances the precipitations of calcium phosphonate.

3.0 RECOMMENDATIONS

1) Field tests similar to those described in this report are recommended for solving calcium carbonate scale problems elsewhere in surface installations. The maximum and minimum amounts of an inhibitor must be determined for the specific conditions existing at other locations.

2) Additional methods for scale inhibitor implacement should be evaluated in the field if carbonate scale is formed downhole. The successful tests at RGI's East Mesa field must be considered only the first step towards solving the downhole carbonate scale problem in geothermal operations.

3) Laboratory tests with radioactively labeled Dequest* 2060 or other scale inhibitors should be expanded to evaluate the precipitation of pseudo-scale forming inhibitors salts over a wide range of geothermal conditions. By evaluating the precipitation range in the laboratory before applying the inhibitor in the field, major damage due to pseudo-scale formation in the downhole equipment can be avoided in the field.

4.0 INTRODUCTION

Lawrence Berkeley Laboratories (LBL) manages a comprehensive program concerned with the development of geothermal resources for the United States Department of Energy, Division of Geothermal Energy (DOE/DGE). They are therefore interested in research and field methods leading to an effective control of scale in geothermal operations. Republic Geothermal, Inc. (RGI), a geothermal operator in East Mesa, California, was confronted with $CaCO_3$ scale problems. Monsanto Chemical Company (MCC) is a major manufacturer of chemical scale inhibitors and wanted to evaluate the effectiveness of its products in a geothermal field. In 1978, a contract was awarded to Vetter Research (VR), Costa Mesa, California, to study the feasibility of effective scale control in RGI's East Mesa field with inhibitors. This work was funded by LBL (DOE), RGI and MCC.

Two series of inhibitor tests were performed. Both tests had the same basic objective: to prevent the $CaCO_3$ scale formation in the field at a reasonable cost without generating problems due to undesired side effects caused by the addition of the inhibitor. The inhibitor used was Dequest* 2060, a Monsanto chemical.

The first field test at well #16-29 was conducted between March 25, 1978 and April 7, 1978. This test was prematurely terminated because of a downhole pump failure. To finish the project, a new scale inhibition field test at well #56-30 was conducted between February 8, 1979 and March 6, 1979. This latter test completed RGI's program on scale inhibitor evaluation because the carbonate scale problem at East Mesa were solved in a technically and economically feasible way.

The balance of the report which follows contains: (a) a general discussion of the background and motivation for the work; (b) detailed descriptions of the two inhibitor experiments and their results, and (c) a summary of the pre-requisite laboratory work on Dequest* 2060 behavior.

5.0 BACKGROUND ON SCALE IN GEOTHERMAL OPERATIONS

Scale is a major problem in geothermal operations. Different types of scale are found in the various geothermal areas and, sometimes, even within the various wells of a given field. A wide variety of types of scale (composition and morphology) and scale deposition rates can be expected because of differences between brine compositions, reservoir conditions and operational procedures in geothermal fields. In addition, almost every field exhibits different types of scale depending upon the location within the field system. For example, carbonates, heavy metal sulfides and silicates commonly form scales of changing composition and thickness within production wells. Both composition and thickness can change drastically with depth. As the produced brine flows through the surface system, additional scaling may occur. Further cooling of the brine may ultimately lead to the formation of silica scales of varying morphology.

This variety of different scales leads to considerable confusion among operating personnel. What is not understood is that the reactions (precipitations) leading to scale build-ups are complicated functions of the thermodynamics (brine composition, pressure, temperature), the kinetics (time required to start and complete a reaction) and the hydrodynamics which may control the diffusion of the ions and the transport of precipitated particles to the walls of the system. All these basic parameters can change within a very short time or distance in the system which contains the flowing geothermal brine.

5.1 PREVENTING SCALE CAN BE A COMPLEX PROBLEM

To prevent or minimize scale in a technically and economically feasible way requires a thorough knowledge of many of the reactions leading to its formation. Whatever the approach, it will probably be specific to only one of the individual scales formed in a given geothermal operation. For example, a chosen method may prevent the formation of $CaCO_3$ scale, but may have no effect on the silica and heavy metal sulfides scales.

Also, the method chosen to fight the individual scale must be compatible with the remaining fluids and operations within the field. This is a major requirement and cannot be overlooked. Chemical brine alterations, e.g., adjusting the pH to low levels (prevention of carbonate scales) or to high levels (prevention of silica scale), may cause more operating problems than they solve. The same holds true when other methods including the application of "threshold" inhibitors, are used to prevent sulfate or carbonate scales.

5.2 $CaCO_3$ INHIBITION IN GEOTHERMAL OPERATIONS

The study described in this report is concerned only with $CaCO_3$ scale formation and its prevention under a specific set of conditions; i.e., those at RGI's East Mesa field. In general, however, $CaCO_3$ scale can be formed in various locations within a field: e.g., (a) the reservoir in the vicinity of the producers; (b) the producer wellbores; (c) the surface facilities; (d) the injector wellbores; and (e) the reservoir in the vicinity of the injectors.

Of particular concern to many operators is heavy $CaCO_3$ scale formation downhole in the production wellbore and reservoir. Sometimes, wells flow only for a limited number of days or even hours before the production ceases because of an extraordinarily rapid formation of $CaCO_3$ scale. Some operations, e.g., the fields in Turkey, have come to a standstill because of this problem. Various operators are presently attempting to inhibit $CaCO_3$ scaling downhole. No data regarding these attempts have been disseminated into the public domain.

Future $CaCO_3$ test programs should include attempts to inhibit scale in wellbores by: (a) continuous injection of inhibitors through a maccaroni string at the bottom of the well; and (b) squeezing of the inhibitor into the formation around the production well. Conventional types of scale inhibitors, used successfully in oil and gas fields, seem to have a better chance than chemical brine alteration, e.g., continuous or batchwise acidification, to successfully solve scale problems in this manner. However, there are major problems in downhole experimentation with these inhibitors:

1) Downhole applications of the chemicals in a flowing well are costly and not without risk to the well itself.

2) Compatibility problems between the inhibitors and various components of the brine can lead to serious operating problems and costly subsequent work-overs.

3) The hardware required to apply the inhibitors downhole is not yet developed or proven for the special flow conditions in a geothermal well.

4) The necessary information to apply the squeeze inhibition technique is not yet available.

5) The required hydrothermal stability of the inhibitors has not yet been proven or even measured in lab experiments.

6) The efficiencies of the large number of commercially available inhibitors under the high bottomhole temperatures has never been measured. It is not feasible economically and time-wise to measure the efficiency of a large number of inhibitors in actual well tests.

5.3 $CaCO_3$ PREVENTION IN SURFACE OPERATIONS AT EAST MESA

RGI, MCC and VR were well aware of the foregoing problems with downhole inhibition and developed a plan of attack. Instead of attempting to solve the more difficult downhole problems first, a less severe set of temperature and inhibitor application conditions was thought to be more appropriate. RGI had an "ideal" candidate for the planned field tests. Its wells in East Mesa have a fairly low temperature (320-340°F) and are produced by downhole pumping. This production method prevents the dissolved CO_2 from breaking out of solution within the wellbore. This, in turn, prevents the $CaCO_3$ scale from forming within the wellbore and shifts the location of the entire $CaCO_3$ scale problem into the surface equipment where it is more accessible. In a way, the surface equipment becomes an accessible extension of the wellbore. This set-up is ideally suited for experiments of this nature. The shift of the CO_2 flash zones due to the installed downhole pumps allow inhibiitor and other experiments in inexpensive and conveniently operatable test loops on the surface. Then, a comprehensive study of single phase and two phase systems can be easily conducted.

In addition to the foregoing advantages, the brines produced at East Mesa have four extremely important favorable properties for these types of experiments:

1) The formation of carbonate scales is significant. For example, a flow rate of 50,000 barrels per day can deposit as much as 1.5 inches of carbonate scale at the flash point in less than 100 hours of flow. Thus, scale inhibitor efficiencies can be studied in fairly short experiment times.

2) The calcium, magnesium and iron content of the brines is very low; thus, no serious interference between the inhibitor molecules and divalent ions (pseudo-scale) are expected.

3) The low iron content does not act as an inhibitor poison.

4) The composition of the reservoir brine is easy to determine without the need for lengthy and, possibly, wrong calculations because no interfering scale is formed downhole.

It was felt by the partners (RGI, MCC and VR) in this study that the RGI East Mesa field was an ideal candidate for starting a technically viable research program on the various aspects of $CaCO_3$ scale prevention in geothermal operations. A successful effort at East Mesa, however, represents only a start at preventing $CaCO_3$ scaling elsewhere under conditions which are less favorable for the application of inhibitors.

5.4 PREVIOUS SCALE PREVENTION WORK IN RGI'S EAST MESA OPERATIONS

Work prior to that reported herein at East Mesa with continuous and batch acid treatment showed that it is technically feasible to remove $CaCO_3$ on a continuous or batch basis. DOE reports on this subject are being printed for dissemination into the public domain. Continuous acid treatment proved to be very expensive. Batch acid treatment is economically feasible, but may require special precautions in designing and operating a future power plant. Mechanical removal is another economically feasible scale control method, but also complicates plant design and maintenance. An experiment with scale inhibitors to evaluate the technical and economic feasibility of preventing $CaCO_3$ scale on a continuous basis was required to complete the examination of alternatives.

6.0 INHIBITOR TEST AT WELL NO. 16-29

This test work was not covered under the LBL contract to VR. It was funded by RGI and MCC. The field and lab work was performed by VR. RGI's and MCC's management allowed the inclusion of the description of the field experiments, lab work and test results in the present report for completeness.

The field equipment used during these tests was described in previous DOE reports.** These reports are presently being printed and will be distributed through the NTIS system. The basic field test equipment is shown in Figure 1.

6.1 BASE LINE TEST WITHOUT INJECTION OF SCALE INHIBITOR

Flow through the test loop (Figure 1) after acid cleaning was started on March 28, 1978 at 10:15 a.m. During this first test period, no inhibitor was injected. This was done in order to determine the base line data, namely, the deposition rates of the $CaCO_3$ scale in the absence of an inhibitor. The loop was operated for 92 hours and 45 minutes and then shut down for visual inspection and collection of samples on April 1, 1978 at 7:00 a.m.

The loop incorporated orifice plates of predetermined sizes to control the pressure and temperature within the four test spools. The orifice sizes were 2.5, 3.5, 5.0, and 7.0 inches. The average flow rate was 375,000 lb/hr. Average temperatures and pressures observed throughout the test facility are listed in Table I. An effort was made to maintain constant conditions during the test.

**Vetter, O.J., Campbell, D.A., Kandarpa, V. and Walker, M., "Geothermal Fluid Investigations at RGI's East Messa Test Site"

Conventional pressure and temperature gauges were used to monitor pressures and temperatures at the well site. These gauges are somewhat inaccurate, partially because the thermometer wells tend to scale downstream of the flash point and, thereby, become insulated. It is also possible that the pressure gauges may be accurately reflecting the thermodynamic plus the hydrodynamic pressure regime and not simply the thermodynamic equilibrium condition reflected by the steam table comparisons shown. The data in Table I are accurate within a few psi or degrees at worst, however, and adequately portray the pressure/temperature drops in the system.

No appreciable steam flash was encountered until downstream of the first spool. On the other hand, CO_2 flashing was definitely experienced at all locations within the test loop. This was confirmed by actual measurements and theoretical calculations. The CO_2 starts to flash from this water at pressures less than 130 psig with a measured wellhead temperature of 320°F.

After shutting down the test loop, it was taken apart and each spool and orifice plate was thoroughly examined visually, the thickness of the scale at various points in the loop was measured, and samples were taken to be analyzed for their composition in the laboratory.

6.1.1 SCALE TYPE

Each scale sample was dried for 24 hours at 120°C and then dissolved in acid. The acid soluble fraction was then analyzed by AA for its composition. The results are given in Table II.

6.1.1.1 CARBONATE SCALE

The majority of the scale is $CaCO_3$. This was expected and is clearly indicated in Table II. However, the scale is not pure $CaCO_3$. A small amount of iron and magnesium carbonates are also present along with a small amount of siliceous material (acid insoluble). The last column in Table II shows the calculated fraction of $CaCO_3$ in the acid soluble portion of the entire scale.

6.1.1.2 SILICEOUS SCALE

The acid insoluble portion of the scale has not been analyzed in detail, but appears to be a complex mixture of silicates, clays and silica. Present theory does not predict silica precipitation at these high temperatures and, therefore, such material may consist of produced formation fines and silicate scale. The presence of siliceous materials in the $CaCO_3$ matrix, even though minor, cannot be ignored because it can effect long-term injectivity; i.e., injector plugging cannot be completely restored by a simple HCl acid job with this "insoluble" residue present.

6.1.2 SCALE DEPOSITION RATE

The rate of scale formation in the test loop was significant. The thickness of the scale varied from spool to spool as indicated in Table III. An average of 0.22 inches (0.56 cm) was found throughout the length of the test loop and most likely extended all the way into the separator. The total length of the eight inch diameter pipe (OD) of the scaled portion of the loop is approximately 54 feet (16.5 meters) with an additional 25 feet (7.6 meters) from the loop to the separator. A rough calculation shows that the total volume of deposited scale was approximately 3,360 cubic inches or 55,000 cubic centimeters in the loop alone. A total volume of 3.48×10^7 pounds or 110,500 barrels of total mass flow was produced during this test. This volume is equivalent to 4.64×10^6 gallons or 1.76×10^7 liters of water. This means each liter of this water (total flow) produced has deposited 3.1×10^{-3} cm^3 or approximately 6.5 mg of $CaCO_3$ scale in the test loop assuming a $CaCO_3$ specific weight of only 2.1***. This is roughly the same value as found previously for well #38-30, even though the Ca^{++} content of #16-29 water is approximately 2.5 times that of the #38-30 water.

The amount of scale deposited per liter of water is fairly small, but illustrates a common problem in most geothermal operations. The detrimental effects of scale formation may be very small per volume unit of produced water (e.g., per liter). However, the overall effects become large due to the extremely large amounts of fluid produced in power generating operations. A 64 Mw power plant at East Mesa requires approximately 1.85×10^6 gallons or 7.0×10^6 liters of total flow per hour. This flow would deposit 4.55×10^4 grams or approximately 100 pounds of $CaCO_3$ per hour.

The heaviest scale formation was encountered in the third spool (downstream of the five inch orifice). The scale thickness here averaged 0.44 inches. Assuming a constant scale deposition rate of 0.44 inches per 92.75 hour period, the entire third spool (eight inch pipe) would have been filled with scale after an operational period of 843 hours or 35 days. Even if extremely large flash chambers and separators are used in a future power plant, this rate of scale formation will still cause problems if ignored.

6.2 THE EXPERIMENTAL SET-UP

The set-up of the inhibitor injection equipment at the wellsite was very similar to that used for previous acid injection experiments.

***The specific weight of $CaCO_3$ (calcite) is 2.71. However, only a very small portion of the deposited calcite has this high bulk density. The majority of the scale is a very porous, fluffy material, with a bulk density of approximately 2.1 as measured in the laboratory.

Two 50-gallon plastic containers were used as the storage for the diluted inhibitor. A dilution of one part inhibitor to three parts produced water was used. A Pulsafeeder pump model 7120 was used for the injection. A stainless steel filter was mounted in the suction line to prevent a failure of the ball check valves in the suction and discharge. A back pressure regulator in the discharge line was installed and set at 500 psig to achieve constant flow conditions. The pump rate was monitored through a three-liter calibrated lucite vessel installed in the suction line of the pump. This lucite vessel was also connected to the 50-gallon drums and could easily be filled through a valve manifold in the suction line. A very constant pump rate of 110 ml/min was necessary to obtain a constant concentration of 10µl**** of inhibitor (as delivered in the drum) per liter of total mass flow. The injection nipple was installed approximately 10 feet downstream of the wellhead.

6.3 THE DEQUEST* 2060 INJECTION

The test loop was cleaned of previously deposited $CaCO_3$ scale by acidizing. Dequest* 2060 injection was started on April 1, 1978 at approximately 8:00 p.m. The rate of injection was adjusted to the predetermined Dequest* 2060 concentration of 10 µl/liter in the water while the total flow was directed through the by-pass line, i.e., not through the test loop. These adjustments were finished by 11:00 p.m., at which time the test loop was opened. The test loop was run under conditions similar to those described for the base run. The loop was shut down on April 7, 1978 at 1:30 p.m. by directing the total mass flow through the by-pass line. The loop was then opened, visually inspected for scale deposits and samples of deposited solids were taken.

During the injection of the Dequest* 2060, a large number of liquid samples was collected throughout the surface installations at wells #16-29 and #18-28 (injection well). These samples were analyzed in an elaborate analytical program to allow conclusions as to the Dequest* 2060 behavior and its effect on the scaling tendency at various locations. The description of the samples and the analytical results are provided in Table IV.

A number of samples were also collected to determine the CO_2 concentrations at various locations, thereby allowing a comparison of the CO_2 flashing with and without an inhibitor. This CO_2 data is provided in Tables V and X.

****The goal was to inject "10 ppm" Dequest* 2060. However, for practical monitoring and injection in the field, it was decided to use the unit "µl/l". The specific weight of the delivered Dequest* 2060 was 1.4 and the activity was 50 percent. This unit is very easy to comprehend and allows very quick conversions from metric to English systems.

A comparison of these CO_2 data illustrates that the injection of Dequest* 2060 has no measurable effect on the CO_2 flashing at injection rates between 2.5 and 10.0 µl Dequest* 2060 per liter wellhead brine.

The CO_2 data in Tables V and X can also be used to determine CO_2 phase distributions and flash behavior in the entire field installation between the wellhead and the settling tanks. Material balance calculations using a steam flash of 10 percent and the CO_2 concentrations in wellhead water (1098 mg/liter), steam (6747 mg/liter), and discharged water (444 mg/liter) show an almost perfect balance. Using the CO_2 concentrations in the steam and the discharged water, one can calculate how much CO_2 should have been in the wellhead water: 1075 mg/liter. The actually measured concentration was 1082-1098 mg/liter.

6.4 "SCALE" DEPOSITION DURING 10 µl/l DEQUEST* 2060 INJECTION

Samples from the deposited solids were taken from the opened test loop and analyzed for their major components. Tables VI and VII show the analyses of the "scale" samples collected during this run. Considerable time and effort was expended on analyzing these solid samples for their components. A major analytical problem occurred during attempts to analyze the organic phosphonates and inorganic phosphonates in these solid samples. Dr. H. Harris, MONSANTO, St. Louis, attempted structural analyses of the samples. Unfortunately, the X-ray diffraction analyses showed that all the samples were X-ray amorphous. The phosphorous NMR data are also useless because no spectrum would be obtained. The iron content in these solid samples caused band widening, thus preventing usable spectra in the NMR.

Fairly rough attempts to shed some preliminary light on the molecular structure of this "scale" ended with the following results:

1) The samples are most likely the calcium salts of the Dequest* 2060.

2) The molecular ratio of calcium ions to the original Dequest* 2060 molecule falls into the range of 4.70 to 4.80, i.e., this ratio is roughly 5.0. In other words, each Dequest* 2060 molecule chelated five calcium ions.

3) There is no appreciable amount of CO_2 contained in these samples. This means, this "scale" is definitely not $CaCO_3$ such as the scale formed under the same thermodynamic conditions, but in the absence of Dequest* 2060 phosphonate.

4) It may be assumed that this "scale" is a pseudo-scale of calcium phosphonate formed by the interaction between the added Dequest* 2060 molecules and the calcium ions contained in the native water.

Table VIII shows the results of the visual loop inspection on April 6, 1978 after injection of Dequest* 2060 (10 µl/l). A comparison between the data listed in Table III and those given in Table VIII allows one quick conclusion: The "scale" deposition formed during Dequest* 2060 injection was less than that formed without Dequest* 2060 by at least a factor of 20. This by itself can be considered a success. In addition, no scale was formed upstream of the inlet valve and downstream of the outlet valve of the test loop.

The "scale" deposited during this period had a totally different appearance than that previously encountered. It formed hardly any bond with the metal surfaces and was easily wiped off with the finger.

A few facts became obvious after evaluating the information presented in Tables I, III, and VIII:

1) The Dequest* 2060 compound completely eliminated the calcium carbonate deposition at all locations in the test loop.

2) Dequest* 2060 will inhibit any $CaCO_3$ scale formation at the East Mesa site at concentrations lower than 10 µl per liter. A quick calculation shows that 10 µl of Dequest* 2060 per liter of total mass flow (single phase water) represents an hourly need of 18.8 gallons for a 64 Mw plant assuming a 10 percent flash, 22 lbs. of steam per KW hr and 315 lb. per barrel of produced water. The cost for this inhibitor would be $220 per hour, assuming a bulk sales price of $11.70 per gallon. This cost would add $0.0034 or approximately 3 mills to the production of each KWhr. This price is not acceptable relative to alternatives.

3) The Dequest* 2060 phosphonate compound reacted with the calcium ions of the water and formed a fairly insoluble calcium salt which -by itself - forms a so-called pseudo-scale. This type of chemical reaction was expected, but it was hoped that the reaction would not occur at the extremely low Dequest* 2060 and calcium concentrations.

4) The solubility of this pseudo-scale increases with decreasing temperatures. This means the formation of this pseudo-scale is not only a function of the water composition and inhibitor concentration as expected, but it is also a function of the temperature.

5) The solubility product of the calcium phosphonate in this water was approximately 2.4×10^{-24} at 320°F, assuming a ratio of five calcium ions per mole Dequest* 2060 in the solid phase and the data presented in Table IV (approximately 7 mg/liter $Ca^{++} = 1.75 \times 10^{-4}$ mole Ca^{++}/liter) and 7 mg/liter Dequest* 2060 molecules (= 10 µl/liter = 1.46×10^{-5} mole/liter). This solubility product is lower than expected.

6) Even at this extremely low solubility product, the Dequest* 2060 was still an extremely effective scale inhibitor.

The results of this phase of experiment were considered to be an extremely successful milestone in the effort to prevent scale formation in geothermal operations through chemicals similar to Dequest* 2060. Further work was definitely warranted.

6.5 INJECTION PROBLEMS DURING 10 µl/l DEQUEST* 2060 INJECTION

Some injection problems were experienced during the 10 µl/l Dequest* 2060 injection. The injectivity of the injector declined faster than usual despite the presence of an elaborate filter system upstream of the injector wellhead. Conversely, the filters were plugging at a much lower rate than usual during the Dequest* 2060 injection. Both phenomena (increased well plugging and decreased filter plugging) must be related to the presence of Dequest* 2060 in the water. It is felt that either one or both of the following conditions prevailed:

1) The inhibition by the Dequest* 2060 is time dependent, i.e., the efficiency of this and most other scale inhibitors decreases with elasped time. This may have resulted in a delayed precipitation of $CaCO_3$ in extremely fine and non-adhering particles which easily passed through the filters, but still plugged the formation.

2) The solubility of calcium phosphonate shows a totally unexpected behavior. There is a distinct possibility that the slope of the curve showing the relation "solubility product vs. temperature" changes again at lower temperatures. Very fine calcium phosphonate precipitates could have caused the plugging if they occur at the lower temperatures as well as at the higher temperatures in the loop. Also, a delayed calcium phosphonate precipitation may occur. This delayed precipitation may have the same effect on the filters and injection well as the delayed precipitation of $CaCO_3$ (see above).

An attempt was made to extract some concrete information from the water analyses listed in Tables IV and IX to clarify this injection problem. Unfortunately, the analytical reproducibility is only on the order of a few percent. This is sufficient for most purposes, but not for solving this type of problem.

6.6 ATTEMPT TO INJECT 2.5 µl/l DEQUEST* 2060

The test loop was started up again on April 6, 1978 at 5:00 p.m. The Dequest* 2060 injection rate was adjusted to 2.5 µl/liter. The loop was shut down on April 7, 1978 at 5:00 p.m. because of a downhole pump failure. Inspection of the loop after this 24-hour period showed no scale anywhere in the loop, neither real scale nor pseudo-scale. However, the time period may have been too short to allow unquestionable conclusions. Still, this preliminary result was very encouraging. The cost of chemicals consumed in a 64 Mw power plant using this concentration of Dequest* 2060 would be on the order of 0.725 mills per KWhr.

Samples of the water were taken at various locations and analyzed for their constituents (see Table IX). Liquid and gas samples were also collected to determine the CO_2 concentrations in the various process streams (see Table X).

6.7 CO_2 CONCENTRATION DURING 2.5 µl/1 DEQUEST* 2060 INJECTION

Table X shows the measured CO_2 data during this test period. The main reason for collecting and analyzing these samples was to determine the mass balance of the CO_2 in the various process streams. It was also necessary to determine whether this mass balance changes due to the injection of 2.5 µl/1 Dequest* 2060. A comparison of the data listed in Table V with those shown in Table X shows that there is no difference in the entire mass balance when the Dequest* 2060 is present at 10 µl/1 or at 2.5 µl/1. In addition, Table X shows again an almost perfect mass balance of the CO_2 in all the process streams. For example, using the numbers of 6752 mg/liter CO_2 in the steam, 426 mg/liter CO_2 in the water leaving the separator, and assuming 10 percent flash yields a calculated value of 1058 mg/liter at the wellhead. The measured concentrations at the wellhead were between 1026 and 1044 mg/liter CO_2.

It is also interesting to note that there is hardly any difference between the CO_2 concentration in the water entering the tank and that leaving the tank. This owuld be expected from calculations regarding CO_2 behavior using Henry's Law. This general behavior is indicated by Henry's Law, but not the absolute magnitude of the CO_2 concentration in this water. The actually measured CO_2 concentrations of this water are much higher than calculated by using Henry's Law. Latest considerations and calculations show that the water entering the tank has a total CO_2 content consisting of three different "types" of CO_2:

1) Henry's Law CO_2

2) Chemically reacted CO_2

3) "Entrained" CO_2

These CO_2 "types" are discussed in a separate DOE report on the CO_2 behavior of the East Mesa geothermal fluids.

6.8 ANALYTICAL PROBLEMS ENCOUNTERED DURING TEST WORK

Tables IV and IX list the water analyses for samples taken during the two Dequest* 2060 injection periods. All the cations were determined by using a Perkin-Elmer 603 AA spectrometer. Chloride and sulfate were determined by wet analyses. The inorganic and organic phosphate components were determined by the standard method of digesting the organic phosphate with ammonium persulfate and analyzing the samples before and after digestion by UV spectroscopy (Perkin-Elmer Model 575) of the complexes generated with vanado-molybdates. These methods are sufficient for most projects requiring this type of analytical data. However, the analytical errors at these low concentrations, even though they are relatively small - on the order of a few percent - are too large to permit the precise calculations required to shed some light on the injection problems encountered during the test.

One way of attacking the injector plugging problem is to collect and analyze water samples. One set of the samples is acidified ("RA" in Tables IV and IX) and the other samples are left untreated ("RU" in Tables IV and IX). The filtered acidified water should show a different composition than the filtered untreated water because (a) some of the particles contained in the original water are redissolved by the addition of the acid, and (b) more particles may come out of the untreated water during storage and shipment. Thus, if $CaCO_3$ precipitated from the water (Table IV), the Ca^{++} concentration of the RU and RA samples should be different, whereas, the remainder of the analyses should not change. On the other hand, if calcium phosphonate precipitated, the Ca^{++} and PO_4 (total) concentrations should be different in the RU and RA samples. This method was used successfully in solving this type of problem in previous test work at well #38-30. However, attempts to find obvious trends in the data from the current test have failed.

There are two possible reasons for this failure:

1) The analytical data, particularly the PO_4 analyses, are not accurate enough. This is not caused by "sloppy" analytical work, but by a lack of extremely accurate analytical methods. The BATTELLE report on "Analysis of Geothermal Brines" documents this problem.

2) Even if the analytical data were very precise, the variations of the PO_4 analyses in Table IV and IX are outside of analytical error limits. This indicates that the particle distribution of the suspended material in the waters changes rapidly with time.

These results indicate that chemical analyses of waters collected during field work are inadequate for determining the nature of the plugging materials. Therefore, it was recommended that laboratory tests be conducted to investigate the problem. The proposed solubility product determination work would not yield any information as to the particle geometry; but it would allow the determination of the chemical nature of the particles by a process of elimination. This data could then be used to design preventive measures for the next field test.

7.0 INHIBITOR TEST AT WELL NO. 56-30

A second scale inhibitor injection test was performed at well #56-30 between February 8 (2300 hours) and March 6 (1045 hours). The chemical used in this new series of tests was again Monsanto's Dequest* 2060. However, the test facility differed somewhat from that used during the previously conducted test (well #16-29). Figure 2 shows the set-up at well #56-30. The heavy lines in Figure 2 show the brine and steam lines, whereas the thin lines indicate the piping used for injection of the chemical (Dequest* 2060 inhibitor) and the acid (15% HCl).

Acid addition was required during the flow periods when no inhibitor was injected (base line tests, see below). The lowering of the flashed brine pH was intended to prevent the formation of $CaCO_3$ particles suspended in the injection brine. If these particles (without the addition of acid or the inhibitor) are allowed to form, the filters installed at the injection wellhead need frequent and costly replacement. In addition, the acid was also to be used to prevent the formation of pseudo-scale in case of an overtreatment with the inhibitor. Thus, no plugging of the injection well would occur as was experienced in the well #16-29 tests.

Two separators (see Figure 2), each capable of handling about 400,000 lbs/hr, were required because of the large flow rate (averaging 722,000 lbs/hr) employed during this test. Table XI shows the pertinent wellhead and test loop pressures and temperatures measured during the inhibitor tests at well #56-30. The relevant dates and times are also given in Table XI.

The analytical methods used to analyze the liquid and solid samples were different from those previously used. Instead of using only AA methods (see paragraph 6.8), an ARL ICAP spectrometer (inductively coupled argon plasma) having 36 channels was used for the analyses of the liquids and solids. This instrument allowed the simultaneous determination of 36 elements in each sample. Thus, major and minor components of a sample cannot easily escape detection and previously unknown components will be automatically determined. For example, it was found that the scale was not only $CaCO_3$ and SiO_2 as previously indicated by AA and X-ray diffraction analyses, but consisted of a mixture of calcium, strontium, barium and iron carbonates and SiO_2 with $CaCO_3$ being the major component.

7.1 BASE LINE TESTS WITHOUT INJECTION OF SCALE INHIBITOR

The total flow of the produced brine was first switched into the test loop on February 8, 1979 (see Table XI). It was noted that the pressure in the fourth spool was constantly increasing (from 65 to 75 psig) during this first base line run. The apparent reason was that the scale deposited downstream of the fourth orifice plate caused a constantly rising backpressure in the fourth spool. Thus, the scale deposition in the fourth and fifth spool could not be kept constant. Under these conditions, it would have been nearly impossible to relate the scale deposition as a function of pressure, temperature and flow rate during the base line test to the scale formation rates during the injection of inhibitor. In addition, the conditions in the fourth spool approached more and more the conditions in the third spool (see Table XI). Therefore, one of the test objectives, namely, to study the brine and scale behavior over a wide range of conditions, could not have been accomplished. A large pressure and temperature gap in these conditions would have resulted. This suspicion became certainty during the inspection of the test loop and examination of the scale deposition in the 4th spool (see Plate No. 1). The scale obviously acted like an effective choke for the flowing brine, thus constantly increasing the pressure and temperature in the 4th spool.

Therefore, it was decided to repeat the base line test with larger orifices in the plates to accomplish a more stable condition in the fourth and fifth spools. This was considered critical because the heaviest scale formation would result at the lower pressures and temperatures. On February 16, 1979 (1900 hours, see Table XI), a second base line test was started and finished on February 21, 1979. The temperature and pressure conditions during this second base line test were rather stable (Table XI) and could be duplicated during the subsequent inhibitor injection tests.

The scale deposition rates in the various spools during the second baseline run are shown in Table XII. These scale deposition rates are similar to those encountered during the base line test of the previous scale inhibition test work at well #16-29. Even though the thickness of the scale deposits was larger than that found in the previous test, the scaling rates per volume unit of flowing brine was approximately the same in both base line tests (at wells #16-29 and #56-30).

7.2 INHIBITOR INJECTION AT 7.5, 2.0 AND 1.0 μl DEQUEST* 2060 PER LITER

The injection of 7.5 μl Dequest* 2060 per liter of brine (total fluid flow) resulted in the total inhibition of carbonate scale. However, the phosphonate pseudo-scale was formed again. The inhibitor injection rate of 2.0 μl Dequest* 2060 per liter of brine showed neither carbonate scale nor pseudo-scale. Thus, the maximum allowable inhibitor concentration lies between 2.0 and 7.5 µl Dequest* 2060 per liter of brine. A final run was made with 1.0 µl Dequest* 2060 per liter of brine. The result was also an absolutely scale free system at all pressures and temperatures. This latter rate is the equivalent of 0.33 mills per KWhr. Inhibitor injection must be considered an economical solution to the scale problems encountered in RGI's East Mesa field.

7.3 SCALE TYPE

Table XIII shows the analyses of the scale samples collected during the various runs. A mixture of calcium, strontium, barium, magnesium and iron carbonates formed the majority of the scale during the base line tests (see Table XIII, VR Code 0001-03-671 to 0001-03-673 and 0001-03-677 to 0001-03-684). Sample No. VR 0001-03-670 (see Table XIII) shows the composition of a black scale formed during the first base line test (see Plate No. 3). It is a mixture of $CaCO_3$, FeS and silicate and forms only at the higher temperatures (higher than the carbonates). The only scale found during the inhibitor injection periods (7.5 µl Dequest* 2060 per liter brine) was pseudo-scale (see Table XIII, VR No. 0001-03-674 to 0001-03-676).

As previously noted, the test loop remained perfectly clean (see metal color in Plate No. 10) during the injection of 2.0 and 1.0 µl Dequest* 2060 per liter of brine. The 4th spool showed the heaviest scale during the base line tests. A comparison between Plates No. 1, 5 and 10 shows the efficiency of the Dequest* 2060 scale inhibitor in maintaining a scale-free environment.

7.4 WELLHEAD BRINE COMPOSITIONS

Table XIV shows the chemical composition of the wellhead brine. Two sets of samples were collected:

1) Unflashed, untreated brine carefully cooled to atmospheric conditions to avoid or minimize flashing of steam and gases.

2) The same brines, but acidified with 5 ml of nitric acid per liter of cooled brine to avoid precipitation of carbonates.

Conclusions as to the maximum amount of $CaCO_3$ and $SrCO_3$ precipitating from the untreated brine must be avoided. The carefully cooled but untreated brine releases only a small amount of CO_2 during collecting and storing. This careful cooling causes a quench effect regarding the release of CO_2 and the accompanying rise in the pH. If this brine is allowed to flash gases during the sample collection, (i.e., without careful cooling) the pH would be on the order of 9.2 instead of 7.9 and 7.2 (see Table XIV). Due to this quench effect, the pH of the sample stays low and none (or almost none) of the eventually precipitating carbonates will come out of solution as indicated in Table XIV.

These precipitations could be determined by taking the liquid samples in two different ways:

1) Careful cooling to avoid flashing of gases as described above and

2) Without careful cooling, i.e., taking the samples at fairly high temperatures (approximately 90°C) or boiling the cooled but untreated samples (i.e., without adding of acid) under reflux.

A comparison of the composition of these two sample types would allow conclusions as to the potential carbonate precipitations in the field. Unfortunately, the second type of sample was not collected.

7.5 INJECTION BRINE COMPOSITIONS

Samples were taken downstream of the Baker tanks and upstream of the acid injection port (see Figure 2) to determine the chemical composition of the injected brine. Each sample was taken in duplicate. One set of samples was acidified with 5 ml of 31% HCl per liter of sample to prevent precipitations before analyzing the samples. The analytical results are shown in Table XV. The other set of samples was untreated and analyzed as collected. These analytical results are given in Table XVI.

A comparison between the calcium and strontium values listed in both Tables XV and XVI shows that care must be taken to prevent the carbonate precipitation after collecting the samples and before analyzing them.

As opposed to the samples of cooled and unflashed wellhead brine (see previous paragraph and Table XIV), the samples of injection brine have been flashed under high temperature (212°F) in the Baker Tank (see Figure 2). Therefore, the unacidified samples (see Table XVI) have a generally lower calcium and strontium content than those of the unflashed wellhead brine (see Table XIV). This is true despite the fact that an approximately 10% flash occurred between the wellhead and the Baker tanks.

The difference between the calcium and strontium contents of the wellhead brine samples and those of the injection brine samples (acidified, see Table XV) is due to the carbonate scale formation in the test facility. The difference between the calcium and strontium contents of the acidified and those of the unacidified injection brine is due to the precipitation of carbonates in the samples of the unacidified samples during shipment and storage. Thus, the composition of the water samples allows an estimation of the scale tendency within the entire test facility. A comparison between the calcium and strontium contents of the acidified and those of the modified Baker tank brine

(Tables XV and XVI) indicates that the injection brine leaving the Baker tanks (see Figure 2) still has a considerable scale-forming tendency.

The average calcium content of the unacidified brine (see Table XV) is 4.34 mg/l and that of the acidified brine (see Table XVI) is 3.03 mg/l. This means, a maximum of 4.34 - 3.03 = 1.31 mg/l calcium can precipitate in the form of $CaCO_3$ from the Baker tank brine. A comparison of the strontium values given in Tables XV and XVI indicates that a maximum of 0.13 mg/l strontium can precipitate in the form of $SrCO_3$ from this brine.

7.6 ACID INJECTION AND MONITORING

As noted above, hydrochloric acid injection was intended to keep the injection lines between Baker tanks and injection wells (see Figure 2) clean during the base line tests. In addition, should severe pseudo-scale formation begin to impair the injectivity of the injection well, the acid was supposed to alleviate this problem during the field test work.

A pH monitor (see Figure 3) was installed downstream of the Baker tanks The pH was maintained automatically at a pH value of 6.2 during the base line tests. Carbonate scale could still form upstream of this point during the base line tests, thus causing scale deposits throughout the test facility. These deposits must be removed to ensure proper operating of the separators, valves, lines, etc. Small lines (0.5 inch OD tubing) were installed between the acid injection pumps and the brine lines upstream of the separators. This allowed the cleaning of the facilities during and after the base line tests (lines are not shown in Figure 2).

Table XVII shows an analysis of the solids accumulated in the filter elements at the injector wellhead during the base line test prior to beginning acid injection. After acid injection was begun in the base line test and during subsequent inhibitor injection periods, the same types of solids continued to accumulate in the filters, but the total volume of solids was greatly reduced and the acid insoluble portion increased to 30-50% of the total. No significant amount of phosphonate material was detected in the filter solids.

8.0 LABORATORY TESTS WITH RADIOACTIVELY LABELED DEQUEST* 2060

Calcium ions and phosphonate inhibitors may form fairly insoluble calcium salts. These precipitating calcium salts of the inhibitors act precisely like scale in the field. As previously noted, these artificial scale deposites are termed "pseudo-scale".

Subsequent to the well #16-29 tests, a series of laboratory experiments were carried out prior to and during the additional inhibitor field tests funded by DOE (DGE) at well #56-30. The objective of these laboratory experiments was to determine the solubility of Dequest* 2060 in the presence of calcium under conditions simulating some of the pressures, brine compositions and pH values expected to be encountered during the field work.

The critical part of these laboratory tests was the utilization of Dequest* 2060 labeled with C-14. This radioactively labeled compound allowed the performance of solubility measurements at extremely low concentration levels. This was necessary because conventional analytical methods for determining the solubility products of the calcium phosphonates with the required accuracy at the extremely low concentration levels (e.g., 1-10 μl Dequest* 2060 per liter brine) always failed in the past. Most of these analytical problem can be overcome by using C-14 labeled inhibitors and a very sensitive liquid scintillation spectrometer (Beckman LS 9000).

8.1 SOLUBILITIES OF CALCIUM - DEQUEST* 2060 SALTS IN ARTIFICIAL BRINES

It should be understood that not all conditions encountered in a field can be simulated in the laboratory. This also holds true for the solubility determinations of the calcium phosphonates. It was expected that the solubility of these salts would depend on pH, temperature and brine composition, particularly the calcium content. A limited number of conditions were simulated in the laboratory. These conditions were temperature, 200°F-300°F (95°C-150°C), sodium chloride (0 and 0.5 molar), Dequest* 2060 concentration (4 to 25 ppm) and calcium concentration (0-2000 ppm).

The pseudo-scale in the field was found at high temperatures (270°F and higher). This means that the pH of the brine at the pseudo-scale formation under field conditions was between 6.3 and 6.7 with the temperature at 270°F. On the other hand, the brine pH increased and the temperature decreased as the fluids went from the test loop (pseudo-scale formation) to the Baker tanks (pH: 9.2; temperature: 212°F). Therefore, the potential for pseudo-scale formation was determined in the laboratory for these two pH values and temperatures.

Artificial brines were used to simulate the pH of 6.3. The range of the calcium and Dequest* 2060 concentrations was extended far beyond the concentrations found in the field. The reasons were (a) to obtain some additional information on the behavior of Dequest* 2060 in geothermal brine and (b) to establish the methodology suitable for these experiments.

$CaCl_2$ solutions of various Ca^{++} and Dequest* 2060 (using radioactively labeled inhibitor) concentrations were made up. These solutions were combined and the remaining Dequest* 2060 was measured by scintillation counting. These solubility tests were carried out at 300°F. Figure 4 shows the results of these experiments. The tests were repeated at 200°C without NaCl (see Figure 5, solid lines) and with NaCl (see Figure 5, broken lines).

The results show three different effects of importance:

1) No precipitation was measured at low Dequest* 2060 concentrations (4 and 8 ppm) at either temperature (200° or 300°F).

2) No precipitation was found at calcium concentrations below 50 ppm at either temperature (200° or 300°F).

3) Adding NaCl to the solutions (see Figure 5, broken lines) has a pronounced effect on the solubility of the calcium phosphonate: it enhances the precipitation. The precipitation started at approximately 5 ppm calcium, which confirms the observations made in the field.

8.2 CALCIUM-DEQUEST* 2060 SOLUBILITIES IN BRINE FROM EAST MESA #56-30

The calcium phosphonate solubility investigations using labeled Dequest* 2060 were repeated with brine from well #56-30 collected from the injection line. The pH was not adjusted, but left at 9.3 during the solubility determinations of the calcium phosphonate.

Adding Dequest* 2060 to the field brine resulted in no measurable precipitation of the calcium salt at 150°C. In order to determine the solubility product of the calcium phosphonate salt, various amounts of $CaCl_2$ were added to the brine containing varying concentrations of Dequest* 2060.

Figure 6 shows the results of these experiments. The "amazing" fact is that these brine-$CaCl_2$ mixtures behaved totally different than the artificial brines (see Figures 4 and 5). Starting with high Dequest* 2060 concentrations (25 and 50 ppm), the amount of precipitation increases with increasing Ca^{++} content at higher Ca^{++} concentrations. On the other hand, at low Dequest* 2060 concentrations (4, 8 and 15 ppm), the precipitation first increases sharply with the Ca^{++} content at lower Ca^{++} concentrations and then slows down at the higher Ca^{++} concentrations. This behavior is believed to reflect the strong tendency of the Dequest* 2060 to form coordination compounds (chemical complexes) with the calcium ions.

The data shown in Figure 6 indicate that the solubility product of a calcium phosphonate salt is almost reached at concentrations of 4 to 15 ppm Dequest* 2060 in the brine without additional Ca^{++} ions in the solution. This fact follows from extrapolating the data at high Ca^{++} content back to 0, i.e., no Ca^{++} ions added to the solutions (see Figure 6). The curves are rising until they reach the ordinate (no Ca^{++} ions added).

This behavior is not so pronounced at the high Dequest* 2060 concentrations (25 and 50 ppm) even though a similar extrapolation indicates that the concentrations have also reached the solubility product of the calcium phosphonate. However, adding of Ca^{++} ions to the solution containing these high concentrations of Dequest* 2060 does not result in significant precipitations unless the large amounts of calcium are added (see Figure 6).

These experiments showed a very complex solubility behavior of the calcium phosphonate as a function of temperature, calcium content, Dequest* 2060 content, NaCl content, and pH.

8.3 SIGNIFICANCE OF LABORATORY TESTS FOR FIELD OPERATIONS

These experiments represent an attempt to determine the solubility product of the calcium phosphonate in laboratory tests by simulating some field conditions. It was hoped to design a laboratory test to measure the solubility of the pseudo-scale forming salts before field experiments are conducted. Thus, the conditions under which pseudo-scale forms could be predetermined, i.e., field experiments could be designed so that no actual pseudo-scale is formed by avoiding the concentration ranges at which these deposits start to form. The experiments indicate four facts significant for field applications:

1) Pseudo-scale would form at high pH values (9.3) assuming a temperature of 150°C and a Dequest* 2060 concentration as low as 4 ppm.

2) Pseudo-scale formation in the RGI East Mesa brine can be expected at Dequest* 2060 concentrations as low as 4 ppm at a pH of 6.5 and a temperature of 95°C.

3) This type of test can be used to predict the pseudo-scale formation prior to field experiments. The experiments indicate a complicated and as yet unpredictable solubility behavior of the calcium phosphonate (and with that, the pseudo-scale formation) may be expected if this compound is used in brines or temperatures different from those encountered in RGI's East Mesa field.

4) These preliminary results warrant a thorough investigation of the Dequest* 2060 behavior if this compound is to be used for scale inhibition in other fields to avoid major damage by possible pseudo-scale formation.

TABLE I
AVERAGE PRESSURES AND TEMPERATURES AT RGI'S WELL NO. 16-29 DURING SCALE INHIBITION TEST WORK
(MARCH-APRIL, 1978)

Location	Measured		Steamtables	
	Pressure (psig)	Temp (°F)	Pressure[a.] (psig)	Temp [b.] (°F)
Wellhead	220	320	c.	c.
Trunk Line Upstream of 1. Spool	95	304	c.	c.
1. Spool	64	304	57	311
2. Spool	32	290	43	277
3. Spool	23	250	15	264
4. Spool	14	245	13	248
Separator Brine Line (in)	14	245	13	248
Separator Brine Line (out)	8	230	4	234
Steam Line (out)	8	225	6	234

a. Steamtable pressure assuming temperature is measured correctly.

b. Steamtable temperature assuming pressure is measured correctly.

c. Prior to flash. Steamtable equilibrium assumption does not apply.

TABLE II
BASE LINE TEST: SCALE ANALYSES (ACID SOLUBLE FRACTION)
DEQUEST*2060 INJECTION, EAST MESA NO. 16-29/APRIL 1978

VR CODE	IDENTIFICATION[a.]	DATE SAMPLED	WEIGHT SCALE[b.]	WEIGHT RESIDUE[c.]	WEIGHT % RESIDUE OF TOTAL SCALE	Ca[d.]	Mg[d.]	Fe[d.]	WEIGHT $\%CaCO_3$ IN SCALE[e.]
011-041	1st Spool Downstream	4/1/78	543.2	43.0	7.9	200.0	2.08	8.20	91.9
011-042	1st Orifice Downstream	4/1/78	557.7	21.6	3.9	213.0	2.24	7.20	95.4
011-043	2nd Spool Downstream	4/1/78	566.7	30.8	5.4	210.0	3.28	3.80	92.5
011-044	3rd Orifice Upstream	4/1/78	588.4	9.1	1.5	228.0	3.16	3.20	96.8
011-045	3rd Orifice Downstream	4/1/78	566.6	20.2	3.6	216.8	3.03	3.25	95.5
011-046	3rd Spool Upstream	4/1/78	603.1	20.5	3.4	231.5	2.95	3.25	95.8
011-047	3rd Spool Downstream	4/1/78	593.0	22.3	3.8	227.8	3.50	2.75	95.9
011-048	4th Spool Upstream	4/1/78	583.3	30.3	5.2	220.5	3.30	3.00	94.4
011-049	4th Spool Downstream	4/1/78	580.0	22.0	3.8	221.5	3.25	3.50	95.4

a. Date analyzed 4/15/78.

b. Weight scale is the initial weight of scale in mg taken for analysis after drying 24 hours at 120^{o} C. All samples dissolved with extensive gas evolution.

c. Weight residue is measured after digesting the scale in concentrated HCl, filtering, washing, and drying (expressed as mg).

d. The weight of constituent in the acid soluble fraction (expressed as mg).

e. Weight percent of $CaCO_3$ in total scale deposit calculated from Ca^{++} content in acid soluble part. The weight percent of $CaCO_3$ plus the weight percent of residue is less than 100% due to the Mg^{++} and Fe^{++} components of the scale as well as analytical uncertainties in the acid soluble residue weights.

TABLE III
APPEARANCE AND THICKNESS OF SCALE IN TEST LOOP AFTER 92.75 HOUR BASE LINE FLOW PERIOD
(WELL NO. 16-29, RGI, EAST MESA)

SPOOL NO. (STARTING UPSTREAM)	SPOOL LENGTH IN FEET	SCALE THICKNESS IN INCH		AVERAGE SCALE THICKNESS IN INCH	OPTICAL SCALE APPEARANCE
		TOP;	BOTTOM		
1	10	1/64;	1/64	0.0625	Dense and Very Crystalline
2	12	1/16;	3/8	0.22	Dense and Crystalline
"Horn"	10	1/16;	3/8	0.22	Dense and Crystalline
3	12	3/8;	1/2	0.44	Fluffy Material
4	10	1/8;	3/16	0.156	Fluffy Material
AVERAGE	54	-		0.22	-

TABLE IV
WATER ANALYSES
10µl/l DEQUEST* 2060 INJECTION, EAST MESA NO. 16-29/APRIL 1978

VR CODE	IDENTIFICATION[a]	DATE SAMPLED	TIME	Cl	Li	Na	Mg	Ca	SO_4	PO_4[b]	TOTAL PO_4[b]
011-001	16-29 Wellhead RU	4/6/78	12:20	508	1.3	619	0.18	6.3	161	1.6	9.0
011-002	16-29 Wellhead RA	4/6/78	12:20	-	1.2	649	0.18	6.5	153	1.5	8.6
011-007	16-29 Downstream Baker Tank RU	4/6/78	12:45	627	1.5	701	0.18	6.9	187	0.69	8.4
011-008	16-29 Downstream Baker Tank RA	4/6/78	12:50	-	1.4	722	0.25	8.0	198	0.86	9.0
011-003	16-29 Downstream of Separator RU	4/6/78	12:46	547	1.4	678	0.18	6.5	175	0.73	8.8
011-004	16-29 Downstream of Separator RA	4/6/78	12:46	-	1.3	700	0.41	8.4	178	0.73	8.4
011-005	16-29 Condensate Steamline RU	4/6/78	13:05	≤0.2	<0.04	0.1	0.04	0.34	<1	0.04	0.7
011-006	16-29 Condensate Steamline RA	4/6/78	13:05	-	<0.04	0.5	0.12	1.1	2	0.08	0.2
011-009	18-28 Upstream Filter RU	4/6/78	13:40	568	1.5	711	0.16	6.7	187	0.89	6.8
011-010	18-28 Upstream Filter RA	4/6/78	13:40	-	1.4	745	0.22	7.3	181	1.0	8.8
011-011	18-28 Downstream Filter RU	4/6/78	13:40	553	1.5	682	0.22	6.9	192	0.83	7.2
011-012	18-28 Downstream Filter RA	4/6/78	13:40	-	1.3	705	0.25	7.1	187	1.0	8.6

a. Date analyzed 4/15-4/18/78. Results expressed as mg/l.

b. The value given for PO_4 is that determined before oxidative degradation of the sample. Total PO_4 has been determined after oxidative degradation of the sample. This converts all phosphonate to PO_4.

TABLE V
CARBON DIOXIDE ANALYSES
10μl/l DEQUEST* 2060 INJECTION, EAST MESA NO. 16-29/APRIL 1978

IDENTIFICATION[a]	DATE SAMPLED	TIME	MG CO_2[c] PER LITER OF SAMPLE	MG CO_2[d] PER LITER OF COOLED LIQUID
16-29 Blank	4/6/78	12:20	110[b]	--
16-29 Wellhead 750-1500 (1:1)	4/6/78	12:30	604	1098
16-29 Wellhead 750-1500 (1:1)	4/6/78	12:40	596	1082
16-29 Downstream of Separator 750-1500 (1:1)	4/6/78	12:45	277	444
16-29 Downstream of Separator 750-1500 (1:1)	4/6/78	12:50	262	414
16-29 Steamline 1250-1500 (5:1)	4/6/78	13:35	1270	7070
16-29 Steamline 1250-1500 (5:1)	4/6/78	13:50	1216	6746

a. Date analyzed 4/11/78.

b. Analyzed in triplicate. Care was taken to avoid CO_2 contamination during analysis.

c. CO_2 in all species, ionic and nonionic forms.

d. CO_2 contamination of fluid in line before sample dilution and corrected for CO_2 content of blank and dilution with blank. CO_2 in all species, ionic and nonionic forms.

TABLE VI
CATION ANALYSES OF PSEUDO-SCALE
DEQUEST* 2060 INJECTION, EAST MESA NO. 16-29/APRIL 1978

VR CODE	IDENTIFICATION[a]	DATE SAMPLED	TIME	WEIGHT SCALE[b]	WEIGHT RESIDUE[c]	Ca[d]	Mg[d]	Fe[d]
011-050	1st Orifice Downstream[e]	4/6/78	14:55	543.0	20.9	127.5	2.3	0.55
011-051	1st Spool Downstream-Upstream of 2nd Orifice[e]	4/6/78	14:30	549.2	18.8	130.0	2.3	0.40
011-052	2nd Orifice Upstream[e]	4/6/78	14:15	549.5	0	130.0	2.0	0.48
011-053	2nd Spool Downstream Wet Portion[e]	4/6/78	14:10	542.3	0	126.6	1.96	0.50
011-054	2nd Spool Downstream[e]	4/6/78	14:00	540.7	16.0	126.6	1.92	0.44
011-055	2nd Orifice Downstream[e]	4/6/78	14:50	545.4	16.4	124.4	2.36	0.50
011-056	3rd Spool Top Scale[f] (from previous run)	4/6/78	16:00	546.9	2.2	214.0	2.68	3.12

a. Date analyzed 4/15/78.

b. Weight scale is the initial weight of scale in mg. taken for analysis after drying 24 hours at 120° C.

c. Weight residue is after digesting the scale in concentrated HCl, filtering, washing, and drying (expressed as mg).

d. The weight of constituent in the acid soluble fraction (expressed as mg).

e. Little, if any, gas evolution observed upon digestion in concentrated HCl.

f. Moderate to extensive gas evolution observed upon digestion in concentrated HCl.

TABLE VII
SCALE ANALYSES
DEQUEST*2060 INJECTION, EAST MESA NO. 16-29/APRIL 1978

VR CODE	IDENTIFICATION[a]	DATE SAMPLED	TIME	WEIGHT SCALE[b]	WEIGHT RESIDUE[c]	TOTAL PO_4[d]
011-049	4th Spool Downstream[e]	4/1/78**		580.0	25.0	4.25
011-050	1st Orifice Downstream[f]	4/6/78	14:55	543.0	20.9	332.5
011-051	1st Spool Downstream-Upstream of 2nd Orifice[f]	4/6/78	14:30	549.2	18.8	312.5
011-052	2nd Spool Upstream[f]	4/6/78	14:15	549.5	0	337.5
011-053	2nd Spool Downstream-Wet Portion[f]	4/6/78	14:10	542.3	0	324.0
011-054	2nd Spool Downstream[f]	4/6/78	14:00	540.7	1.6	316.0
011-055	2nd Orifice Downstream[f]	4/6/78	14:50	545.4	16.4	310.0
011-056	3rd Spool Top Scale (from previous run)[e]	4/6/78	16:00	546.9	2.2	4.8

a. Date analyzed 4/15-4/18/78.

b. Weight scale is the initial weight of scale in mg taken for analysis after drying 24 hours at 120° C.

c. Weight residue is after digesting the scale in concentrated HCl, filtering, washing, and drying (expressed as mg).

d. Total PO_4 is the weight of PO_4 after oxidative degradation of the acid soluble fraction of the sample (expressed as mg).

e. Moderate to extensive gas evolution observed upon digestion in concentrated HCl.

f. Little, if any, gas evolution observed upon digestion in concentrated HCl.

** Scale sample from previous run (see Table II). This sample was analyzed for PO_4 to establish analytical reliability and behavior of PO_4 native in brine.

TABLE VIII
APPEARANCE AND THICKNESS OF SCALE IN TEST LOOP AFTER 110.5 HOUR FLOW PERIOD USING 10μl/l DEQUEST* 2060
(WELL NO. 16-29, RGI, EAST MESA)

SPOOL NO. (STARTING UPSTREAM)	SPOOL LENGTH IN FEET	MAXIMUM SCALE THICKNESS IN INCH		AVERAGE SCALE THICKNESS IN INCH	OPTICAL SCALE APPEARANCE
		TOP	BOTTOM		
1	10	1/16 **	1/16 **	approx. 1/64	white amorphous
2	12	1/16-1/32	1/16-1/32	1/16-1/32	gray-green crystalline
"Horn"	10	1/16-1/32	1/16-1/32	1/16-1/32	gray-green crystalline
3	12	NONE	NONE	NONE	Mill marks on steel visible
4	10	NONE	NONE	NONE	Mill marks on steel visible
AVERAGE	54	-		approx. 0.01	-

** Scale extended only 2 feet from each end into spool. Center of spool was clean.

TABLE IX
WATER ANALYSES
2.5μl/l DEQUEST* 2060 INJECTION, EAST MESA NO. 16-29/APRIL 1978

VR CODE	IDENTIFICATION[a.]	DATE SAMPLED	TIME	Cl	Li	Na	Mg	Ca	SO_4	PO_4[b.]	TOTAL PO_4[b.]
011-013	16-29 Wellhead RU	4/7/78	9:10	394	1.2	571	0.15	5.8	161	0.30	2.0
011-014	16-29 Wellhead RA	4/7/78	9:05	-	1.2	607	0.19	6.2	158	0.28	3.5
011-019	16-29 Downstream Baker Tank RU	4/7/78	8:50	553	1.4	652	0.18	6.8	181	0.25	2.1
011-020	16-29 Downstream Baker Tank RA	4/7/78	8:45	-	1.3	670	0.18	6.8	192	0.48	1.8
011-017	16-29 Downstream of Separator RU	4/7/78	8:25	634	1.4	634	0.13	6.6	187	0.11	0.6
011-018	16-29 Downstream of Separator RA	4/7/78	8:30	-	1.3	679	0.18	6.8	181	0.24	1.0
011-015	16-29 Condensate Steamline RU	4/7/78	8:05	0.4	<0.04	0.05	0.01	0.08	<1	.05	0.6
011-016	16-29 Condensate Steamline RA	4/7/78	8:10	-	<0.04	0.03	0.01	0.37	<1	.03	0.2
011-021	18-28 Upstream Filter RU	4/7/78	10:30	562	1.4	652	0.14	6.4	190	0.48	1.7
011-022	18-28 Upstream Filter RA	4/7/78	10:30	-	1.4	688	0.24	6.5	184	0.39	2.5
011-023	18-28 Downstream Filter RU	4/7/78	10:35	558	1.4	634	0.18	6.6	195	0.29	2.2
011-024	18-28 Downstream Filter RA	4/7/78	10:35	-	1.3	670	0.20	6.8	187	0.36	2.6

a. Date analyzed 4/15-4/18/78. Results expressed as mg/l.

b. The value given for PO_4 is that determined before oxidative degradation of the sample. Total PO_4 has been determined after oxidative degradation of the sample. This converts all phosphonate to PO_4.

TABLE X
CARBON DIOXIDE ANALYSES
2.5μl/l DEQUEST* 2060 INJECTION, EAST MESA NO. 16-29/APRIL 1978

IDENTIFICATION[a.]		DATE SAMPLED	TIME	MG CO_2[c.] PER LITER OF SAMPLE	MG CO_2[d.] PER LITER OF COOLED LIQUID
16-29	Blank	4/7/78	7:40	110[b.]	--
16-29	Wellhead 750-1500 (1:1)	4/7/78	9:15	568	1026
16-29	Wellhead 750-1500 (1:1)	4/7/78	9:15	577	1044
16-29	Downstream of Separator 750-1500 (1:1)	4/7/78	8:30	276	422
16-29	Downstream of Separator 750-1500 (1:1)	4/7/78	8:35	268	426
16-29	Downstream of Baker Tank 750-1500 (1:1)	4/7/78	8:50	273	436
16-29	Downstream of Baker Tank	4/7/78	8:55	260	410
16-29	Steamline 1250-1500 (5:1)	4/7/78	7:45	1250	6950
16-29	Steamline 1250-1500 (5:1)	4/7/78	7:50	1217	6752

a. Date analyzed 4/11/78.

b. Analyzed in triplicate. Care was taken to avoid CO_2 contamination during analysis.

c. CO_2 in all species, ionic and nonionic forms.

d. CO_2 contamination of fluid in line before sample dilution and corrected for CO_2 content of blank and dilution with blank. CO_2 in all species, ionic and nonionic forms.

TABLE XI

AVERAGE PRESSURES AND TEMPERATURES AT RGI'S WELL NO. 56-30 DURING SCALE INHIBITION TEST WORK (FEBRUARY 8 - MARCH 6, 1979)

TEST AND TEST TIME	WELLHEAD		1. SPOOL		2. SPOOL		3. SPOOL		4. SPOOL		5. SPOOL	
	psig	°F	psig	°F	psig	°F	psig	°F	psig	°F	psig	°F
1. BASE LINE TEST No. 1 2/08/79 (2300 hours) to 2/13/79 (0715 hours)	139	315	107	315	81	310	75	N.A.	65*	304	27	265
2. BASE LINE TEST No. 2 2/16/79 (1900 hours) to 2/21/79 (0715 hours)	145	315	118	316	91	312	74	N.A.	56	300	25	262
7.5 µl/l DEQUEST INJECTION 2/22/79 (1515 hours) to 2/26/79 (1000 hours)	142	315	117	315	90	312	74	N.A.	55	298	26	266
2.0 µl/l DEQUEST INJECTION 2/26/79 (1500 hours) to 3/02/79 (0845 hours)	146	315	117	316	89	312	75	N.A.	55	298	25	266
1.0 µl/l DEQUEST INJECTION 3/02/79 (1045 hours) to 3/06/79 (1045 hours)	147	315	117	316	88	312	75	N.A.	55	298	24	266

* Rising from 65 psig (2/08/79) to 75 psig (2/13/79)

TABLE XII

APPEARANCE AND THICKNESS OF SCALE IN TEST LOOP AFTER 108.25 HOUR BASE LINE FLOW PERIOD

(WELL NO. 56-30, FEBRUARY 16-21, 1979)

SPOOL NO. (STARTING UPSTREAM)	SPOOL LENGTH IN FEET	AVERAGE SCALE THICKNESS IN INCH	OPTICAL SCALE APPEARANCE
1	18	Thin Film	Black
2	18	Thin Film	Black
3 ("Horn")	8.75	0.10	White, Crystaline, Dense
4	18	1.25	Greyish-White, Fluffy
5	18	1.50	Greyish-White, Fluffy, Layered
Average	80.75	0.62	- -

TABLE XIII

SCALE ANALYSES

RGI/EAST MESA WELL #56-30 (FEBRUARY-MARCH, 1979)

VR CODE	SCALE IDENTIFICATION	DATE SAMPLED	RESULTS (% BY WEIGHT OF TOTAL SOLIDS)							
			% ACID SOLUBLE[a]	Ca	Mg	Ba	Sr	Fe	P[b]	CALCULATED[c] RATIO OF Ca TO DEQUEST
0001-03-670	2nd Spool	2/13/79	80.0	21.0	.12	.26	.13	49.0	-	-
0001-03-671	3rd Spool	2/13/79	99.4	33.0	.15	.06	.73	1.6	-	-
0001-03-672	4th Spool	2/13/79	98.1	33.0	.16	.23	3.1	.66	-	-
0001-03-673	Downstr. of Separator	2/13/79	100.0	29.0	.05	.17	3.0	.20	-	-
0001-03-674	3rd Spool	2/26/79	100.0	19.0	.20	.33	1.2	.21	46.0	4.9
0001-03-675	4th Spool	2/26/79	100.0	17.0	.18	.28	1.0	.14	44.0	4.6
0001-03-676	Upstream of Loop	2/26/79	97.0	15.0	.16	.18	.77	.20	36.0	5.0
0001-03-677	Downstream 2nd Spool	2/21/79	95.1	27.0	.14	.03	.48	1.7	-	-
0001-03-678	Orifice between 3rd and 4th Spool	2/21/79	100.0	27.0	.04	.42	3.2	.19	-	-
0001-03-679	Upstream 4th Spool	2/21/79	95.8	35.0	.06	.18	3.5	.12	-	-
0001-03-680	Downstream 3rd Spool	2/21/79	100.0	28.0	.18	.03	.48	2.6	-	-
0001-03-681	4th Spool	2/21/79	100.0	36.0	.05	.37	3.8	.24	-	-
0001-03-682	Upstream 5th Spool	2/21/79	100.0	38.0	.04	.17	3.4	.19	-	-
0001-03-683	Downstream 4th Spool	2/21/79	100.0	34.0	.08	.49	3.9	.25	-	-
0001-03-684	Downstream 5th Spool	2/21/79	97.3	34.0	.07	.69	4.1	.35	-	-

a. The solid samples were dissolved in HNO_3 for analysis.
b. The value for P is expressed as weight percent PO_4.
c. This calculation is from the PO_4 analyses using 5 PO_4/molecule of Dequest 2060

TABLE XIV

WATER ANALYSES OF UNFLASHED WELLHEAD BRINES IN mg/l

(RGI EAST MESA WELL #56-30, FEBRUARY-MARCH, 1979)

COLLECTED	FEBRUARY 7, 1979		MARCH 7, 1979	
SAMPLE TREATMENT	UNTREATED	ACIDIFIED	UNTREATED	ACIDIFIED
Na	604	593	606	599
K	48	47	46	46
Li	0.80	0.79	0.88	0.88
Ca	4.9	4.8	5.0	5.1
Mg	<0.036	<0.036	<0.036	<0.036
Ba	<0.026	<0.026	<0.026	<0.026
Sr	0.45	0.42	0.44	0.47
SiO_2	141	139	143	140
B	0.36	0.40	0.38	0.45
Al	<0.026	<0.026	<0.026	<0.026
Ag	<0.003	<0.003	<0.003	<0.003
As	<0.10	<0.10	<0.10	<0.10
Au	<0.009	<0.009	<0.009	<0.009
Be	<0.001	<0.001	<0.001	<0.001
Cd	<0.007	<0.007	<0.007	<0.007
Ce	<0.13	<0.13	<0.13	<0.13
Co	<0.009	<0.009	<0.009	<0.009
Cr	<0.011	<0.011	<0.011	<0.011
Cu	<0.002	<0.002	<0.002	<0.002
Fe	0.008	0.035	<0.076	<0.15
Ga	<0.065	<0.065	<0.065	<0.065
Ge	<0.075	<0.075	<0.075	<0.075
Hg	<0.030	<0.030	<0.030	<0.030
La	<0.003	<0.003	<0.003	<0.003
Mn	<0.001	<0.001	<0.001	0.005
Mo	<0.075	<0.075	<0.075	<0.075
Ni	<0.035	<0.035	<0.035	<0.035
Pb	<0.050	<0.050	<0.050	<0.050
Sb	<0.40	<0.40	<0.40	<0.40
Se	<0.14	<0.14	<0.14	<0.14
Sn	<0.11	<0.11	<0.11	<0.11
Ti	<0.002	<0.002	<0.002	<0.002
V	<0.003	<0.003	<0.003	<0.003
Zn	<0.007	<0.007	<0.007	<0.007
Zr	<0.005	<0.005	<0.005	<0.005
PO_4	<0.10	<0.10	<0.10	<0.10
Cl	540	520	530	520
SO_4	170	180	170	180
pH	7.9	1.5	7.2	1.5

TABLE XV

BAKER TANK WATER ANALYSES (ACIDIFIED)

RGI/EAST MESA 56-30 TEST, FEBRUARY-MARCH, 1979

VR CODE	DATE SAMPLED	RESULTS (mg/l)														
		Na	K	Li	Ca	Mg	Ba	Sr	B	Al	Zn	Cu	Mn	Fe	PO_4	SiO_2
0001-02-538	2/06/79 (a.m.)	720	26	0.78	2.3	< 0.1	0.15	0.37	0.89	< 0.03	0.01	< 0.002	0.002	0.004	0.1	200
0001-02-543	2/07/79 (a.m.)	680	24	0.87	1.3	0.1	2.1	0.40	1.0	0.30	0.14	< 0.002	0.023	0.10	0.1	190
0001-02-544	2/07/79 (p.m.)	690	24	9.94	5.1	< 0.1	2.5	0.5	0.89	0.26	0.22	0.33	0.022	0.18	0.3	190
0001-02-547	2/08/79 (a.m.)	690	24	0.80	4.6	< 0.1	1.5	0.40	0.94	0.24	0.09	< 0.002	0.017	0.22	0.1	190
0001-02-548	2/08/79 (p.m.)	720	25	1.0	6.1	< 0.1	2.4	0.37	1.1	0.53	3.7	0.042	0.025	0.28	1.8	200
0001-02-551	2/09/79 (a.m.)	720	25	1.0	2.4	< 0.1	1.0	0.28	1.0	0.53	0.07	0.069	0.018	0.33	0.6	200
0001-02-552	2/09/79 (p.m.)	730	25	1.0	2.3	0.1	1.5	0.30	1.3	0.42	0.02	0.063	0.007	0.17	0.1	210
0001-02-555	2/10/79 (a.m.)	730	24	0.95	2.6	< 0.1	1.2	0.40	1.1	0.33	0.02	0.043	0.011	0.33	0.1	200
0001-02-556	2/10/79 (p.m.)	720	24	0.87	2.4	< 0.1	0.51	0.36	1.0	0.19	0.01	< 0.002	0.004	0.17	0.1	200
0001-02-561	2/11/79 (a.m.)	720	25	0.75	3.5	< 0.1	0.50	0.29	0.94	< 0.03	0.01	< 0.002	0.007	0.19	0.1	200
0001-02-562	2/11/79 (p.m.)	680	24	1.0	2.1	0.1	2.0	0.31	1.0	0.33	0.05	0.10	0.016	0.32	0.5	190
0001-02-564	2/12/79 (a.m.)	690	23	1.0	1.6	< 0.1	2.0	0.26	1.3	0.53	0.02	0.057	0.014	0.11	0.7	200
0001-02-599	2/12/79 (p.m.)	710	25	0.88	4.0	< 0.1	1.0	0.32	0.95	0.17	0.01	< 0.002	0.008	0.16	0.1	200
0001-02-600	2/15/79 (p.m.)	680	23	1.1	4.3	0.5	3.0	0.66	0.98	0.66	0.22	0.055	0.064	1.9	1.2	190
0001-02-601	2/16/79 (a.m.)	710	24	0.85	2.3	< 0.1	0.90	0.35	0.95	0.09	0.01	< 0.002	0.007	0.20	0.1	200
0001-02-602	2/16/79 (p.m.)	710	24	0.76	7.5	< 0.1	1.4	0.98	0.86	< 0.03	0.01	< 0.002	0.024	0.45	0.1	200
0001-02-603	2/17/79 (a.m.)	710	25	0.73	3.5	< 0.1	0.60	0.56	0.87	< 0.03	0.01	< 0.002	0.009	0.21	0.1	200
0001-02-604	2/17/79 (p.m.)	710	25	0.74	2.9	< 0.1	0.17	0.35	0.79	< 0.03	0.01	< 0.002	< 0.001	0.04	0.1	200
0001-02-605	2/18/79 (a.m.)	700	24	0.73	6.6	< 0.1	1.3	0.40	0.90	< 0.03	0.01	< 0.002	0.019	0.17	0.1	190
0001-02-606	2/18/79 (p.m.)	700	24	0.72	2.4	< 0.1	0.77	0.92	0.85	< 0.03	0.01	< 0.002	0.006	0.10	0.1	200
0001-02-650	2/21/79 (a.m.)	700	24	0.73	1.3	< 0.1	1.9	1.5	0.88	< 0.03	0.01	< 0.002	0.032	0.21	0.1	190
0001-02-651	2/21/79 (p.m.)	720	25	0.75	2.8	< 0.1	0.03	0.28	0.76	< 0.03	0.01	< 0.002	< 0.001	< 0.003	0.1	200

TABLE XV (CONTINUED)

BAKER TANK WATER ANALYSES (ACIDIFIED)

RGI/EAST MESA 56-30 TEST, FEBRUARY-MARCH, 1979

VR CODE	DATE SAMPLED	RESULTS (mg/l)														
		Na	K	Li	Ca	Mg	Ba	Sr	B	Al	Zn	Cu	Mn	Fe	PO_4	SiO_2
0001-02-652	2/22/79 (a.m.)	680	24	0.69	5.2	< 0.1	0.86	0.65	0.80	< 0.03	< 0.01	< 0.002	0.011	0.065	0.1	190
0001-02-653	2/22/79 (p.m.)	690	24	0.72	9.5	< 0.1	1.5	1.1	0.88	< 0.03	< 0.01	< 0.002	0.027	0.16	5.8	190
0001-02-654	2/23/79 (a.m.)	700	24	0.72	6.0	< 0.1	1.1	0.70	0.80	< 0.03	< 0.01	< 0.002	0.19	0.18	4.6	190
0001-02-655	2/23/79 (p.m.)	690	24	0.71	5.9	< 0.1	1.1	0.76	0.81	< 0.03	< 0.01	< 0.002	0.015	0.082	2.9	190
0001-02-656	2/24/79 (a.m.)	710	25	0.72	5.4	< 0.1	0.91	0.71	0.91	< 0.03	< 0.01	< 0.002	0.011	0.079	0.1	200
0001-02-657	2/26/79 (p.m.)	700	24	0.72	5.5	< 0.1	0.74	0.72	0.86	< 0.03	< 0.01	< 0.002	0.013	0.10	0.62	200
0001-02-658	2/27/79 (a.m.)	690	24	0.73	8.0	< 0.1	1.1	0.86	0.76	< 0.03	< 0.01	< 0.002	0.027	0.40	0.43	190
0001-02-659	2/27/79 (p.m.)	690	24	0.72	5.5	< 0.1	1.0	0.70	0.79	< 0.03	< 0.01	< 0.002	0.014	0.18	0.63	190
0001-02-660	2/28/79 (a.m.)	690	24	0.73	5.6	< 0.1	0.86	0.71	0.77	< 0.03	< 0.01	< 0.002	0.018	0.27	0.49	200
0001-02-661	2/28/79 (p.m.)	700	24	0.73	5.4	< 0.1	0.86	0.70	0.77	< 0.03	< 0.01	< 0.002	0.018	0.27	0.49	200
0001-02-662	3/01/79 (a.m.)	690	23	0.73	5.4	< 0.1	0.93	0.72	0.73	< 0.03	< 0.01	< 0.002	0.014	0.18	1.4	190
0001-02-663	3/01/79 (p.m.)	690	23	0.16	5.2	< 0.1	1.0	0.69	0.94	< 0.03	< 0.01	< 0.002	0.014	0.16	0.49	190
0001-02-664	3/02/79 (a.m.)	670	24	0.71	5.3	< 0.1	0.94	0.70	0.74	< 0.03	< 0.01	< 0.002	0.015	0.19	0.38	190

TABLE XVI

BAKER TANK WATER ANALYSES (UNACIDIFIED)

RGI/EAST MESA 56-30 TEST, FEBRUARY-MARCH, 1979

VR CODE	DATE SAMPLED	RESULTS (mg/l)						pH
		Ca	Sr	Cl	SO_4	CO_3	HCO_3	
0001-02-538	2/06/79 (a.m.)	2.5	0.4	690	200	-	450	7.3
0001-02-543	2/07/79 (a.m.)	2.6	0.4	590	200	120	310	9.4
0001-02-544	2/07/79 (p.m.)	3.1	0.5	720	200	-	340	7.1
0001-02-547	2/08/79 (a.m.)	2.6	0.4	770	200	-	250	6.5
0001-02-548	2/08/79 (p.m.)	2.3	0.4	800	180	-	210	6.5
0001-02-551	2/09/79 (a.m.)	1.8	0.3	790	210	-	210	6.6
0001-02-552	2/09/79 (p.m.)	0.7	0.3	730	200	-	290	6.9
0001-02-555	2/10/79 (a.m.)	2.0	0.4	760	200	-	250	6.8
0001-02-556	2/10/79 (p.m.)	2.2	0.4	750	200	-	240	6.6
0001-02-561	2/11/79 (a.m.)	1.8	0.3	770	180	-	300	7.1
0001-02-562	2/11/79 (p.m.)	1.8	0.3	770	190	120	330	9.3
0001-02-564	2/12/79 (a.m.)	1.0	0.2	590	190	120	330	9.4
0001-02-599	2/12/79 (p.m.)	1.3	0.5	600	200	120	210	9.3
0001-02-600	2/15/79 (p.m.)	1.0	0.2	600	180	120	190	9.4
0001-02-601	2/16/79 (a.m.)	2.0	0.2	600	180	120	200	9.4
0001-02-602	2/16/79 (p.m.)	1.3	0.2	610	190	120	210	9.3
0001-02-603	2/17-79 (a.m.)	0.9	0.2	590	190	120	200	9.3
0001-02-604	2/17/79 (p.m.)	1.0	0.2	610	180	120	200	9.3
0001-02-605	2/18/79 (a.m.)	1.1	0.2	590	200	120	200	9.3
0001-02-606	2/18/79 (p.m.)	0.8	0.2	590	200	130	180	9.3
0001-02-650	2/21/79 (a.m.)	1.0	0.2	590	180	120	210	9.3
0001-02-651	2/21/79 (p.m.)	1.2	0.2	600	190	110	250	9.2

TABLE XVI (CONTINUED)

BAKER TANK WATER ANALYSES (UNACIDIFIED)

RGI/EAST MESA 56-30 TEST, FEBRUARY-MARCH, 1979

VR CODE	DATE SAMPLED	RESULTS (mg/l)						pH
		Ca	Sr	Cl	SO_4	CO_3	HCO_3	
0001-02-652	2/22/79 (a.m.)	1.7	0.18	610	200	94	270	9.2
0001-02-653	2/22/79 (p.m.)	5.3	0.68	650	190	110	230	9.3
0001-02-654	2/23/79 (a.m.)	5.6	0.74	510	190	120	220	9.2
0001-02-655	2/23/79 (p.m.)	5.4	0.74	670	190	120	230	9.4
0001-02-656	2/24/79 (a.m.)	5.6	0.74	590	180	110	250	9.3
0001-02-657	2/26/79 (p.m.)	5.6	0.74	740	190	130	210	9.3
0001-02-658	2/27/79 (a.m.)	8.1	0.95	610	180	120	230	9.3
0001-02-659	2/27/79 (p.m.)	5.5	0.73	590	190	130	210	9.4
0001-02-660	2/28/79 (a.m.)	5.4	0.75	580	180	120	240	9.3
0001-02-661	2/28/79 (p.m.)	5.5	0.73	580	180	120	220	9.3
0001-02-662	3/01/79 (a.m.)	5.5	0.74	590	190	130	200	9.3
0001-02-663	3/01/79 (p.m.)	5.5	0.74	590	190	130	200	9.3
0001-02-664	3/02/79 (a.m.)	5.4	0.74	590	180	130	220	9.4

TABLE XVII

ANALYSIS OF SOLIDS RETAINED BY FILTER

SAMPLED:	East Mesa/56-30
DATE SAMPLED:	February 6, 1979
VR CODE:	0001-03-540
PRETREATMENT:	Dry at 105° for 12 hours
INITIAL WEIGHT AFTER DRYING:	20.0g

HCl SOLUBLE	HCl INSOLUBLE
WEIGHT SOLUBLE: 18.3g[a]	WEIGHT INSOLUBLE: 1.7g[b]
$MgCO_3$: less than 0.2mg	SiO_2: 1.2g.
$CaCO_3$: 16.0g.	Mg : 0.009g.
$SrCO_3$: 1.5g.	Ca : 0.002g.
$BaCO_3$: none detected	Sr : 0.001g.
	Ba : 0.026g.
	Al : 0.1g.
	Fe : 0.1g.

a. Based on the Ca and Sr analysis assuming only carbonate as the counter ion.

b. The acid insoluble portion was dissolved in a K_2CO_3/Na_2CO_3 flux for analysis.

WELL TEST FACILITY
(E. MESA 16-29)

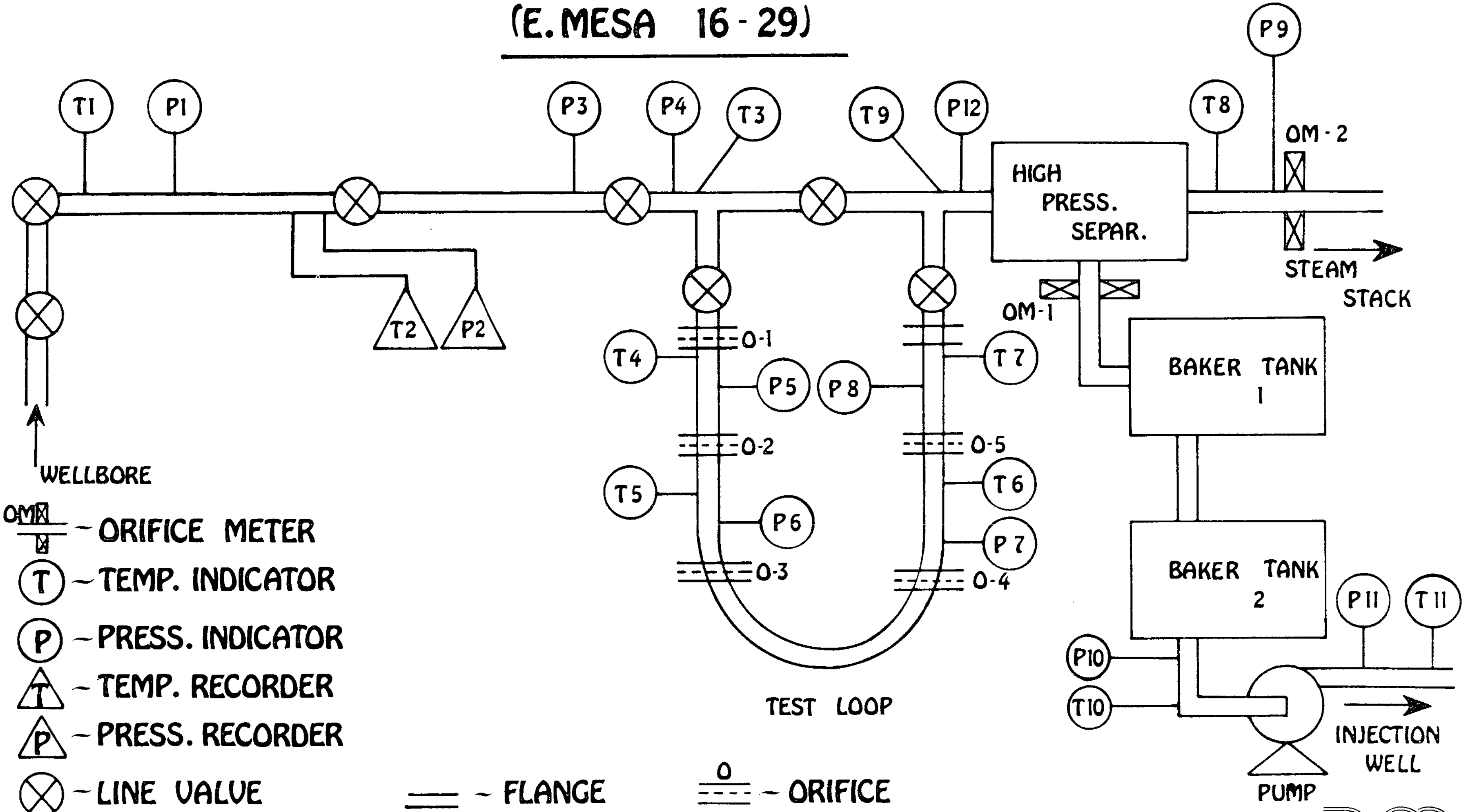
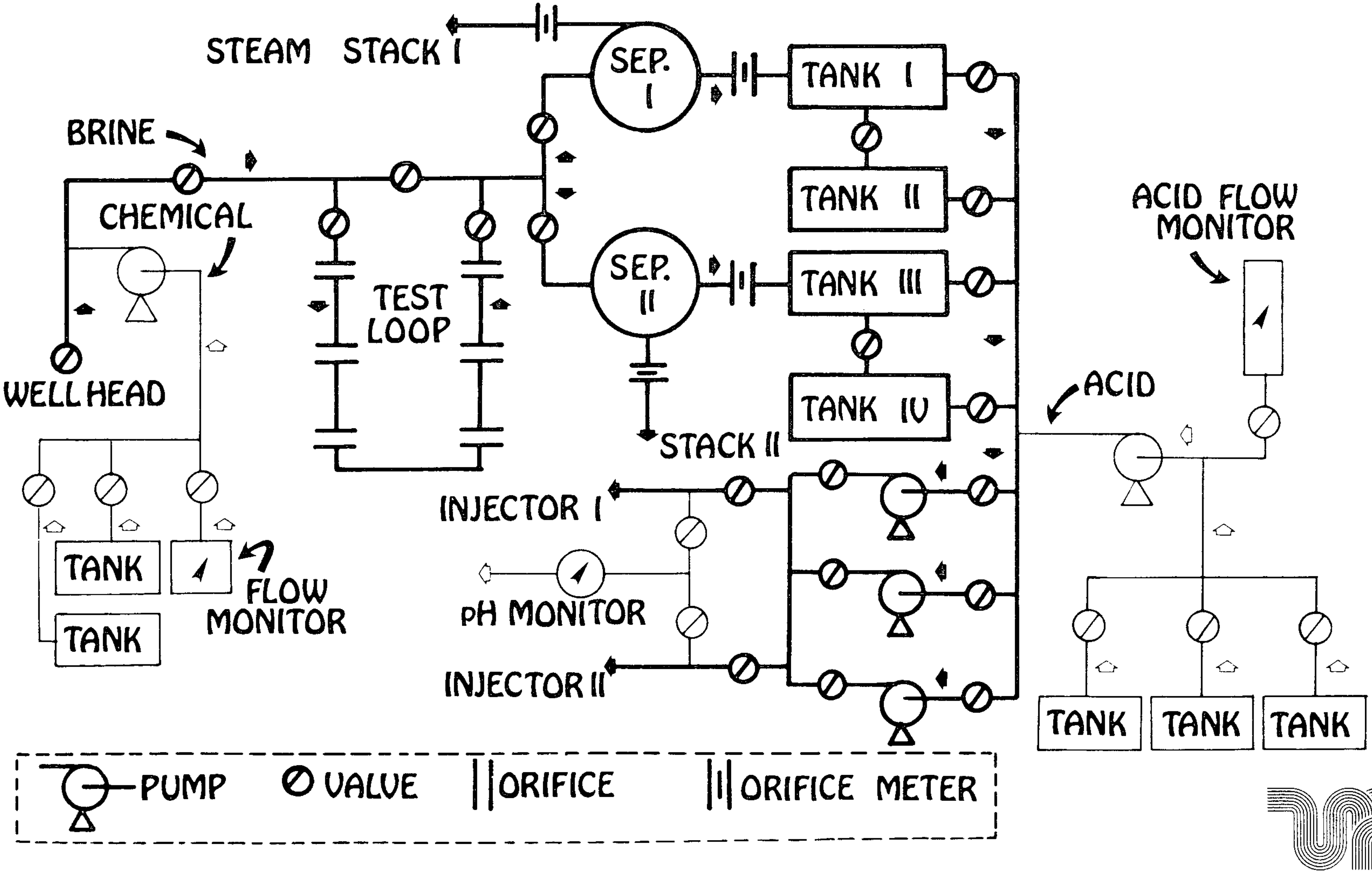


FIGURE 1

FIGURE 2

EAST MESA 56-30
SCHEMATIC DIAGRAM OF TEST FACILITY



IN-LINE PH MEASUREMENT

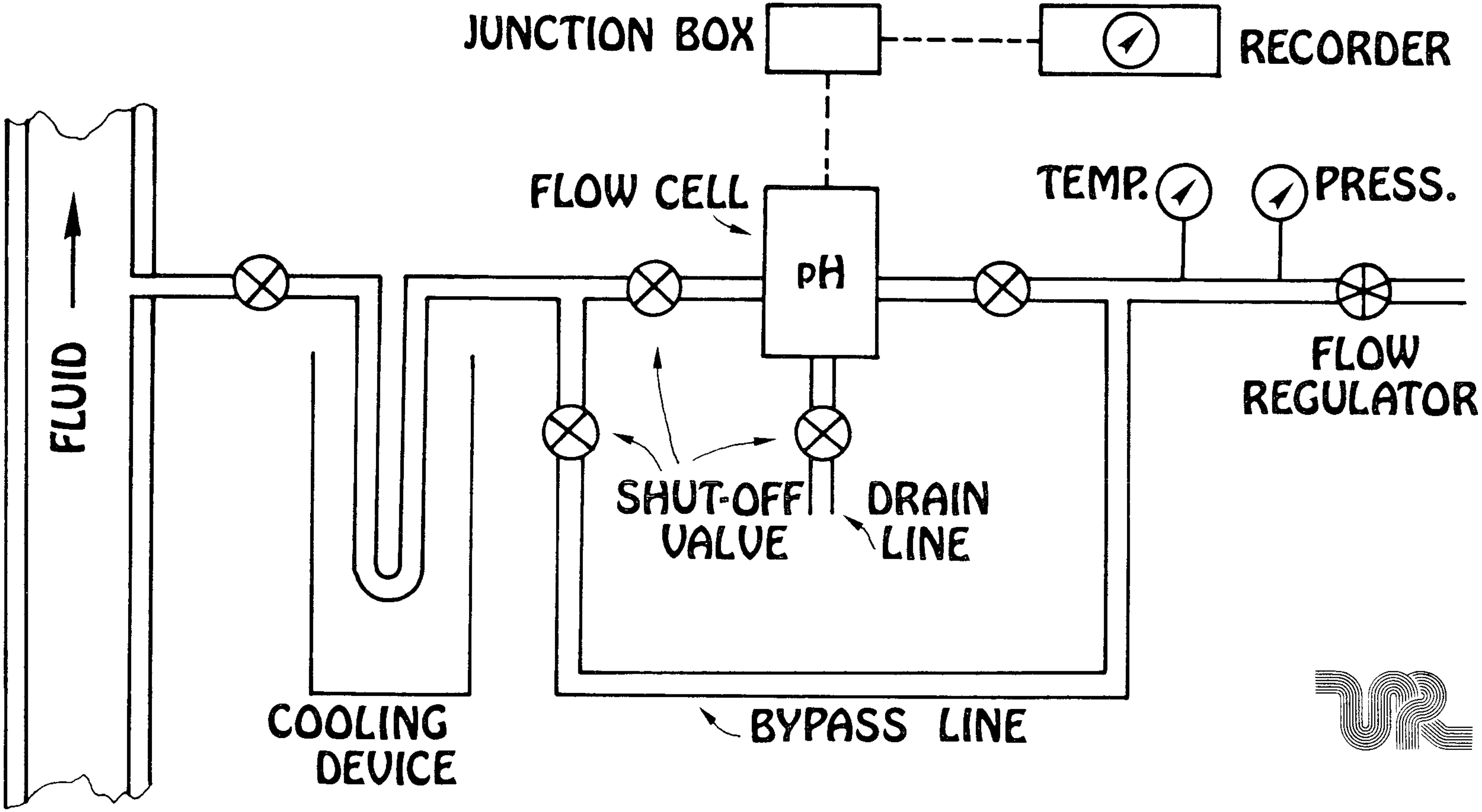


FIGURE 3

CALCIUM–DEQUEST 2060 SOLUBILITY
(pH 6.3; DIST. WATER; 150° C; 24 HOURS)

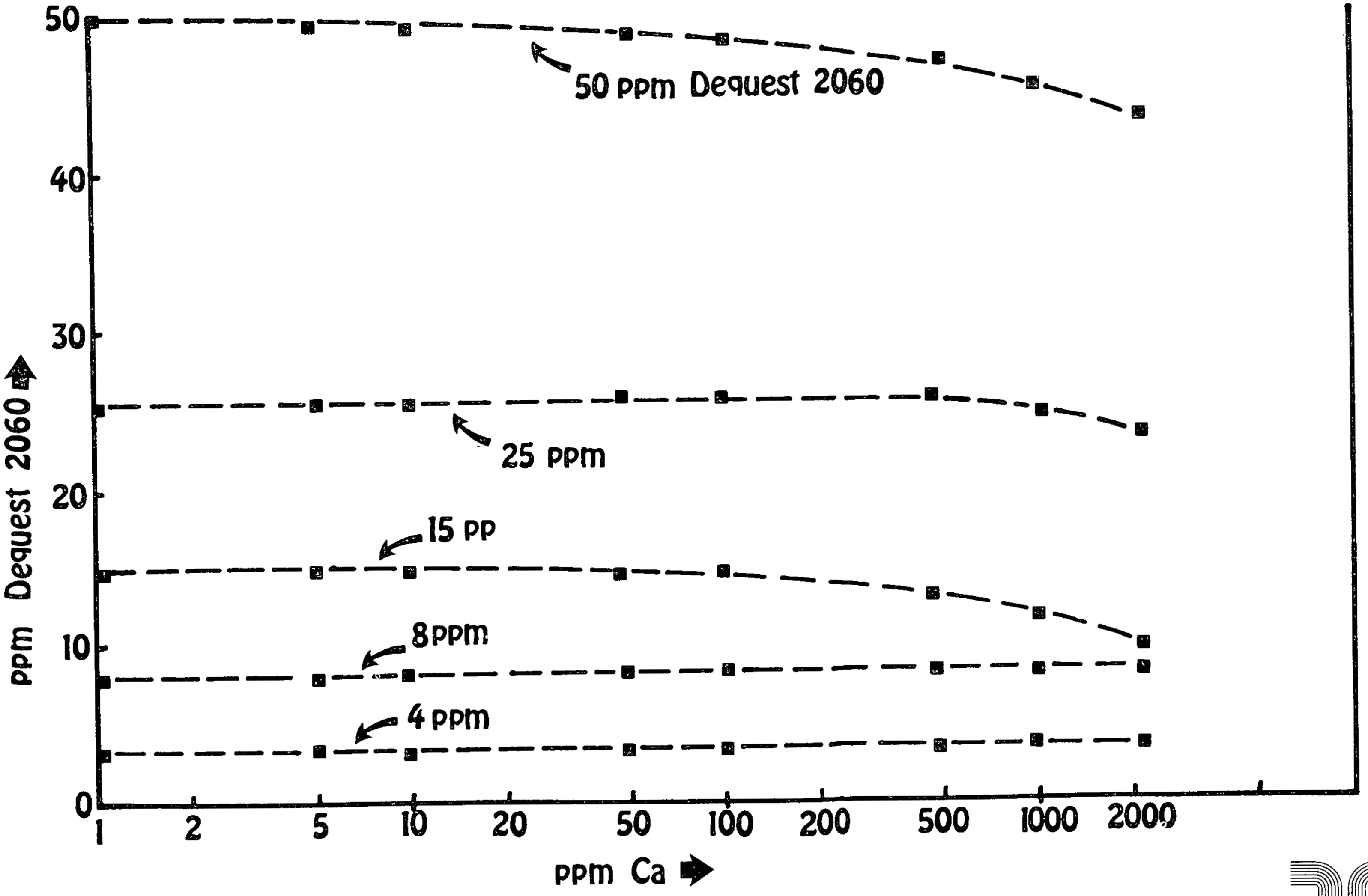


FIGURE 4

CALCIUM-DEQUEST 2060 SOLUBILITY
(pH 6.5; 95°; 24 HOURS)

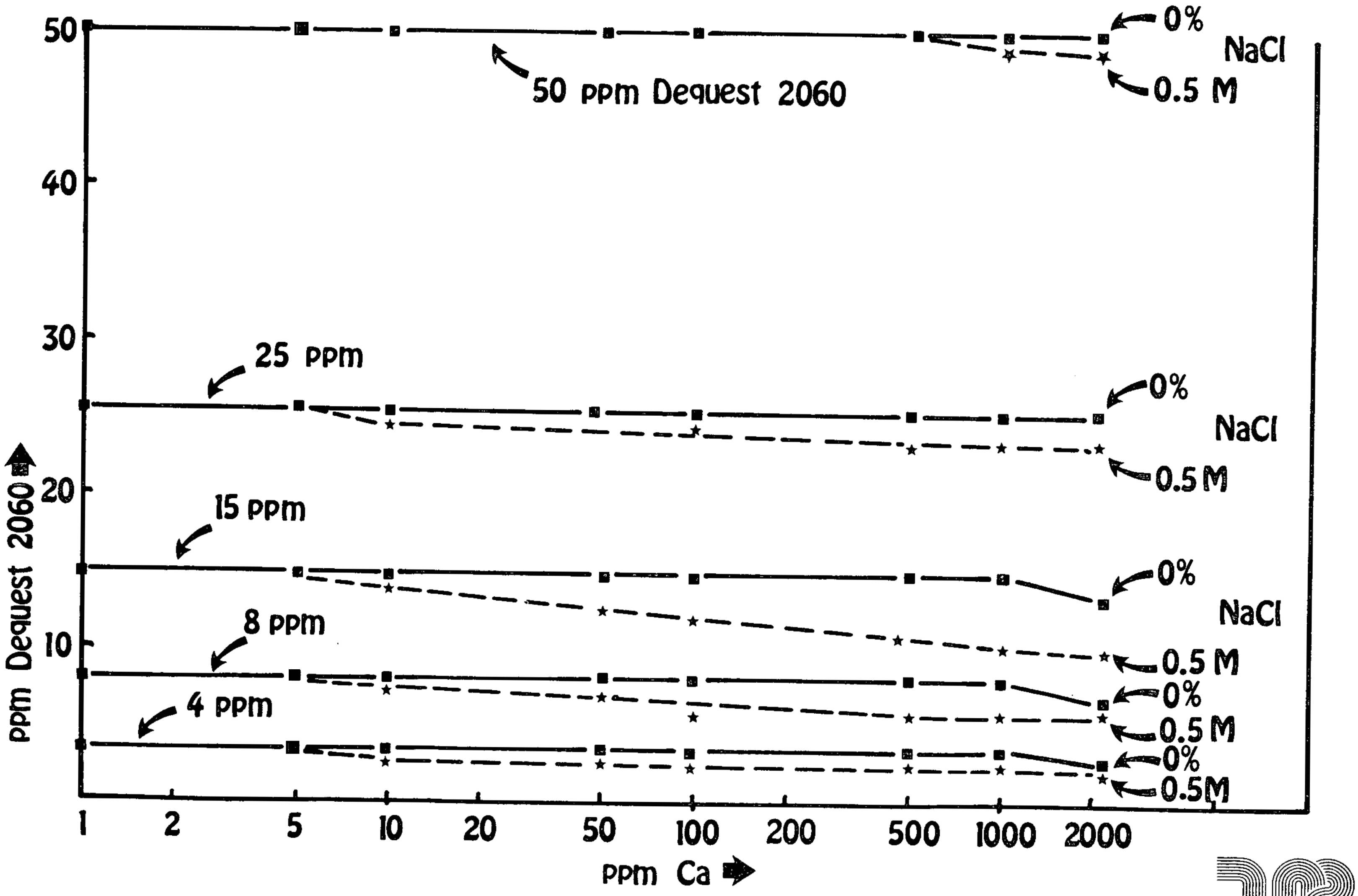
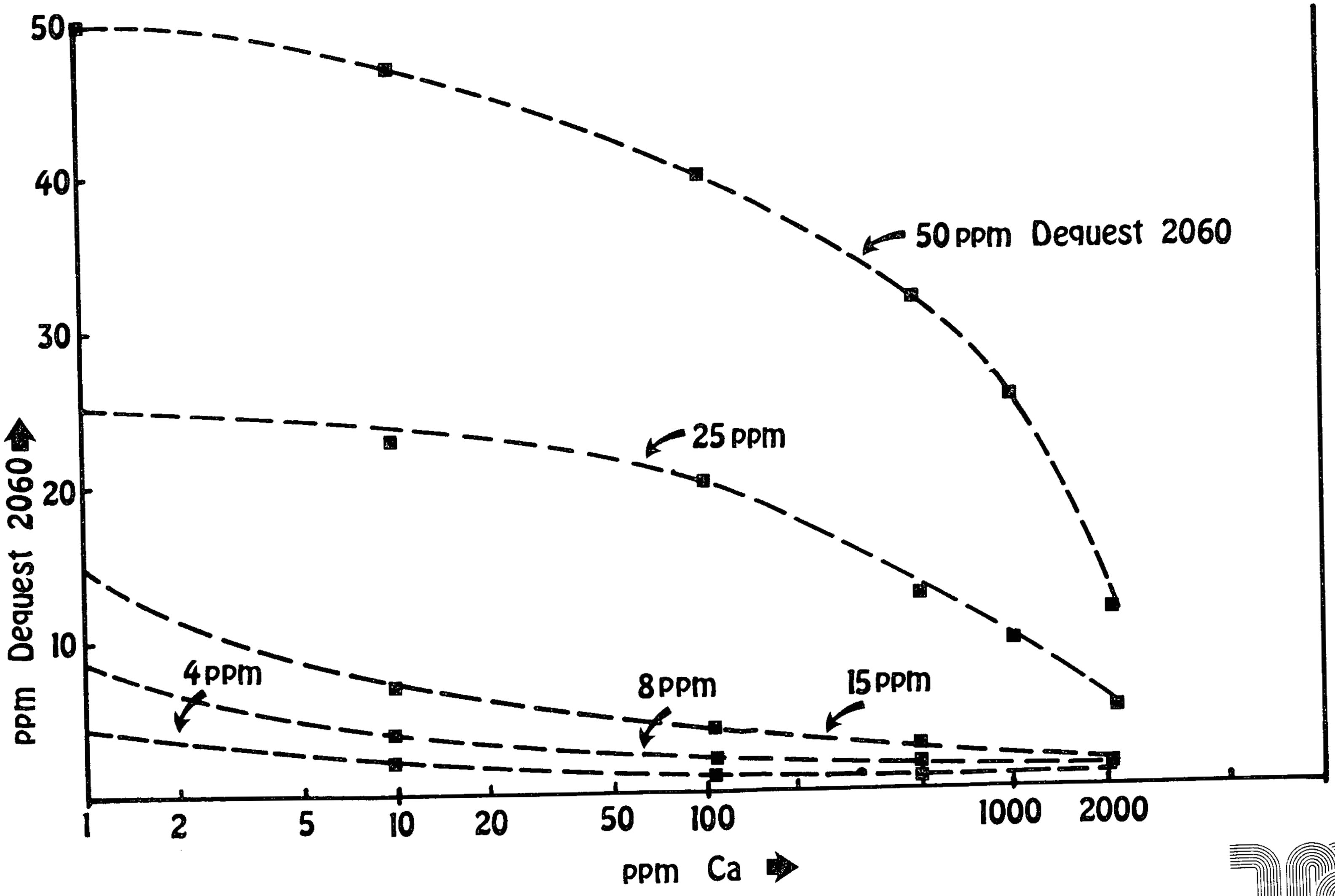


FIGURE 5

FIGURE 6

CALCIUM-DEQUEST 2060 SOLUBILITY
(pH 9.3; RGI WELL NO. 56-30 WATER; 150° C; 24 HOURS)

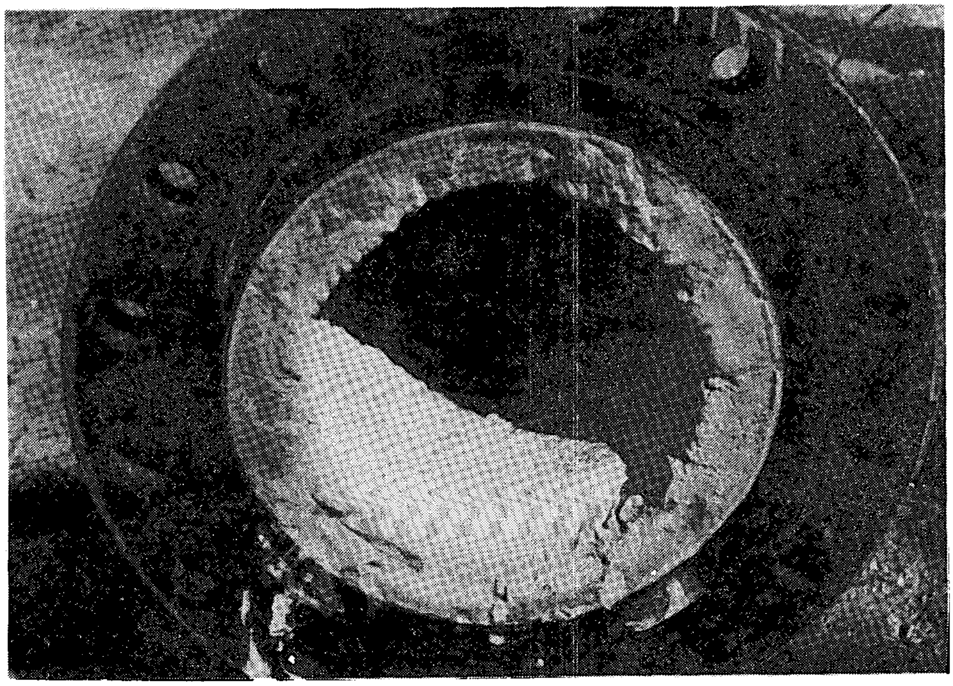


EAST MESA WELL 56-30

SCALE DEPOSITION DURING 1st. BASE LINE TEST

PLATE NO. 1

SCALE IN 4th. SPOOL



CBB 796-7839

EAST MESA WELL 56-30

SCALE DEPOSITION DURING 2nd. BASE LINE TEST

PLATE NO. 2

SCALE IN 1st. SPOOL

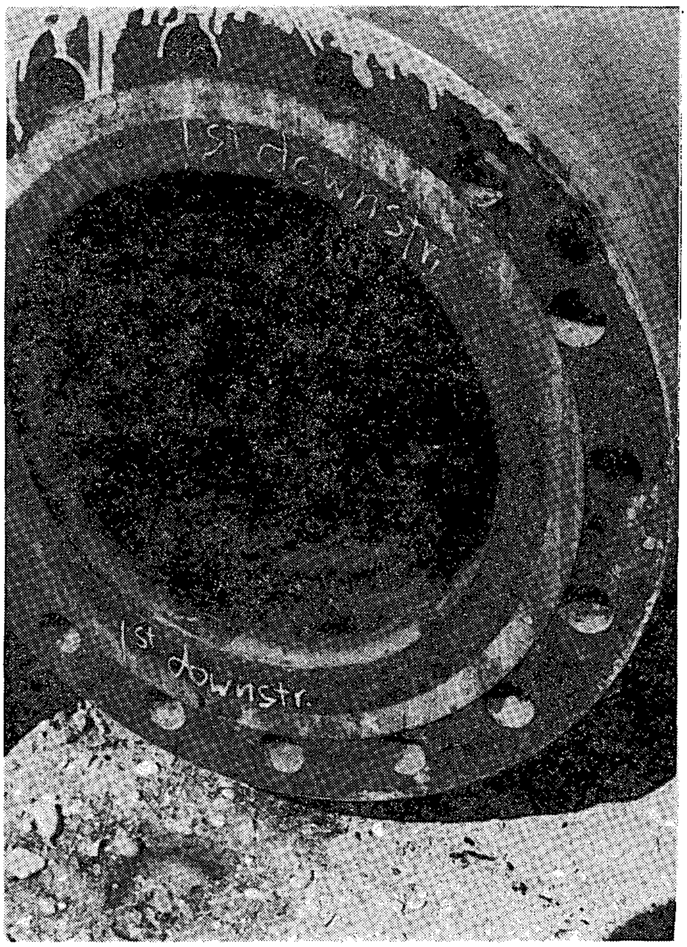
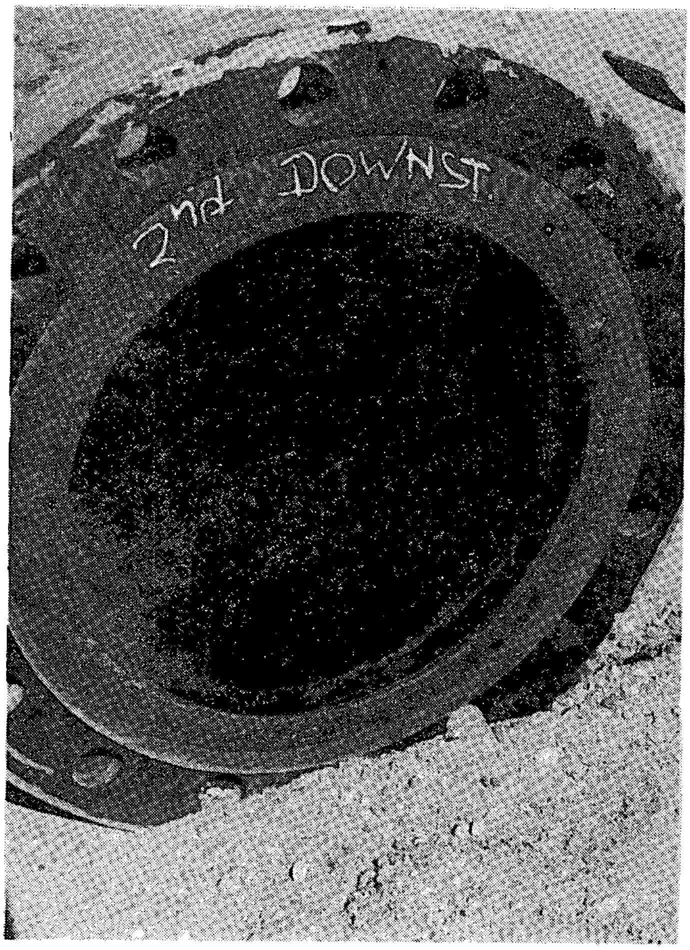


PLATE NO. 3

SCALE IN 2nd. SPOOL



CBB 796-7841

EAST MESA WELL 56-30

SCALE DEPOSITION DURING 2nd. BASE LINE TEST

PLATE NO. 4

SCALE IN 3rd. SPOOL

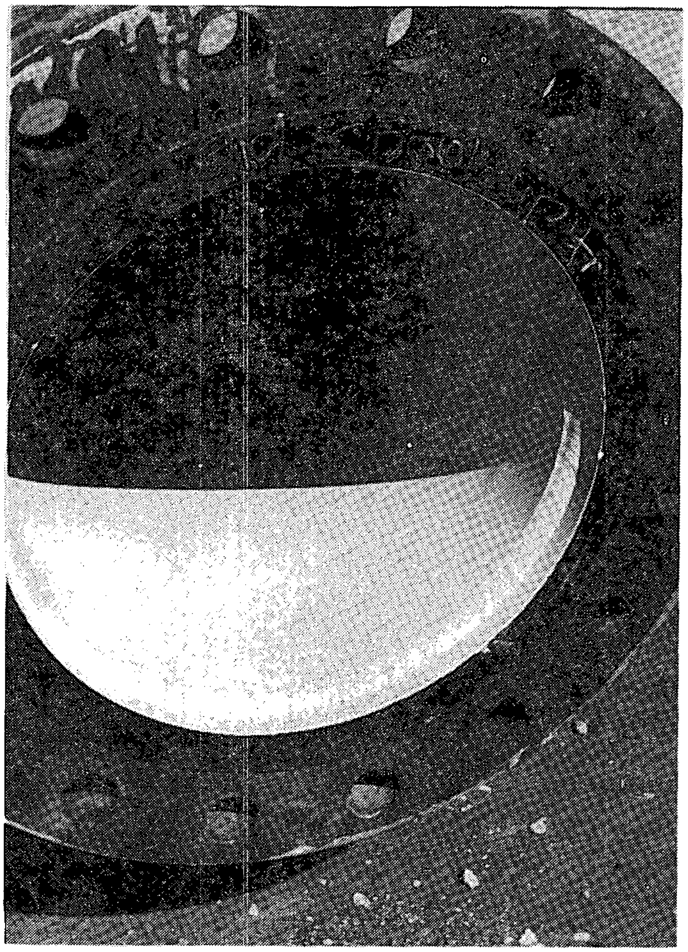
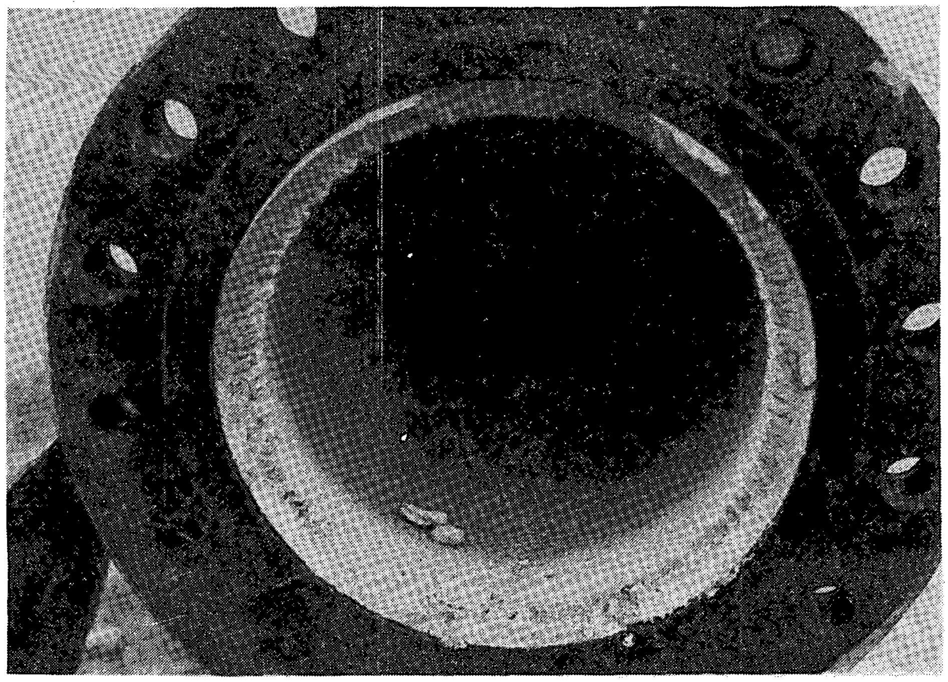


PLATE NO. 5

SCALE IN 4th. SPOOL



CBB 796-7843

EAST MESA WELL 56-30

SCALE DEPOSITION DURING 2nd. BASE LINE TEST

PLATE NO. 6

SCALE IN 4th. SPOOL

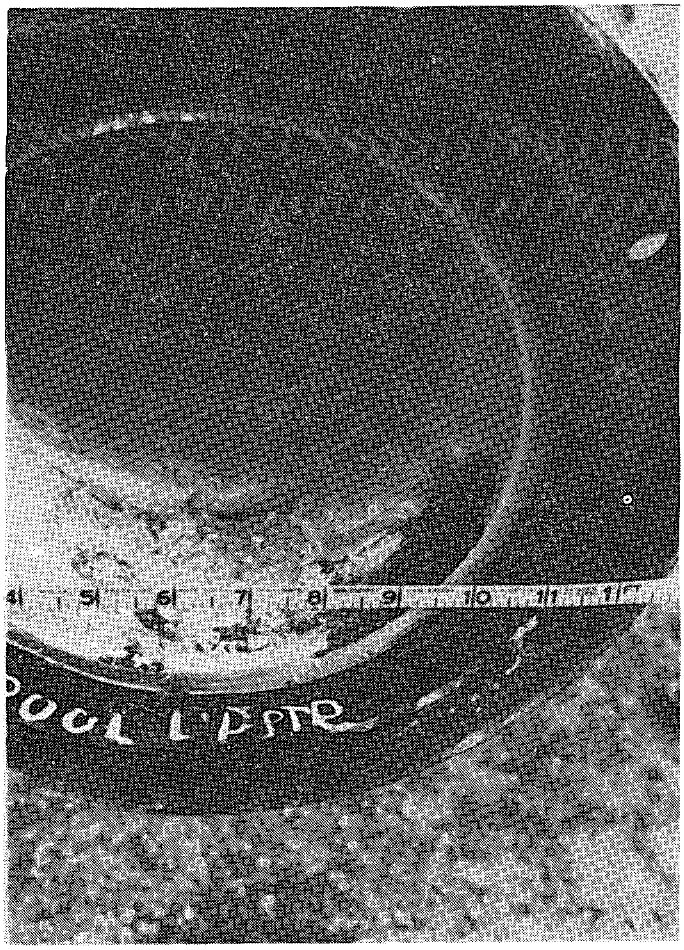
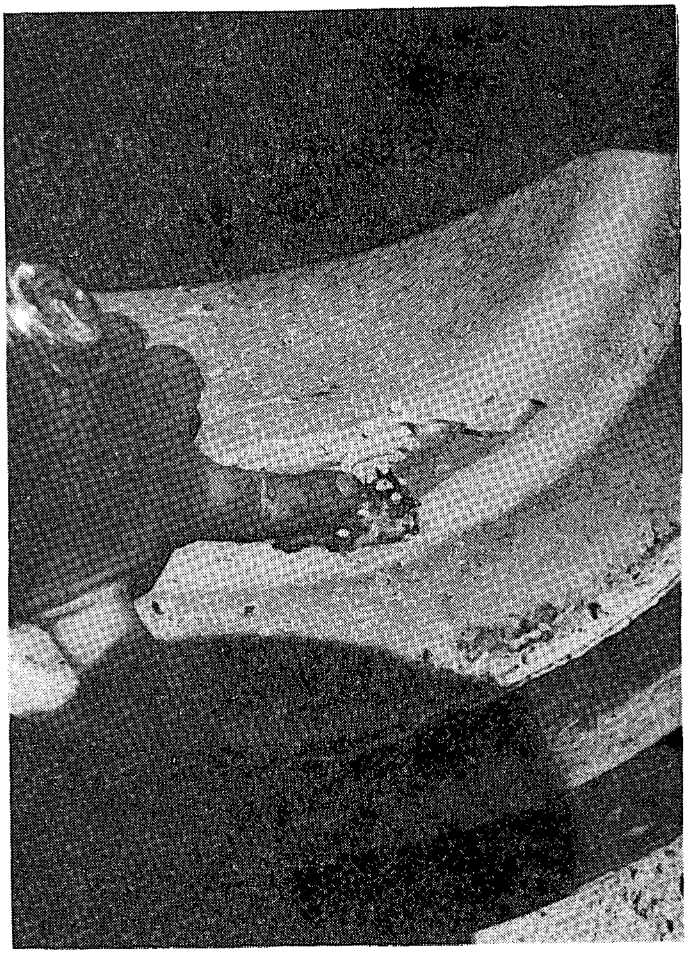


PLATE NO. 7

SCALE IN 5th. SPOOL



CBB 796-7845

EAST MESA WELL 56-30

PSEUDO-SCALE DEPOSITION DURING INJECTION OF 7.5 μl DEQUEST PER LITER BRINE

PLATE NO. 8

PSEUDO-SCALE
IN 3rd SPOOL

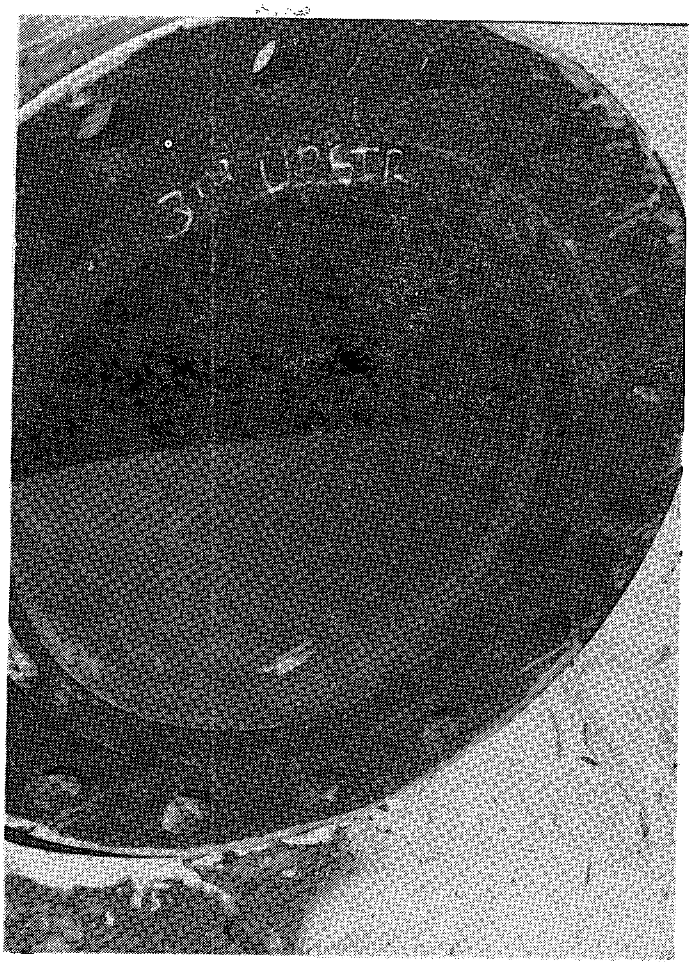
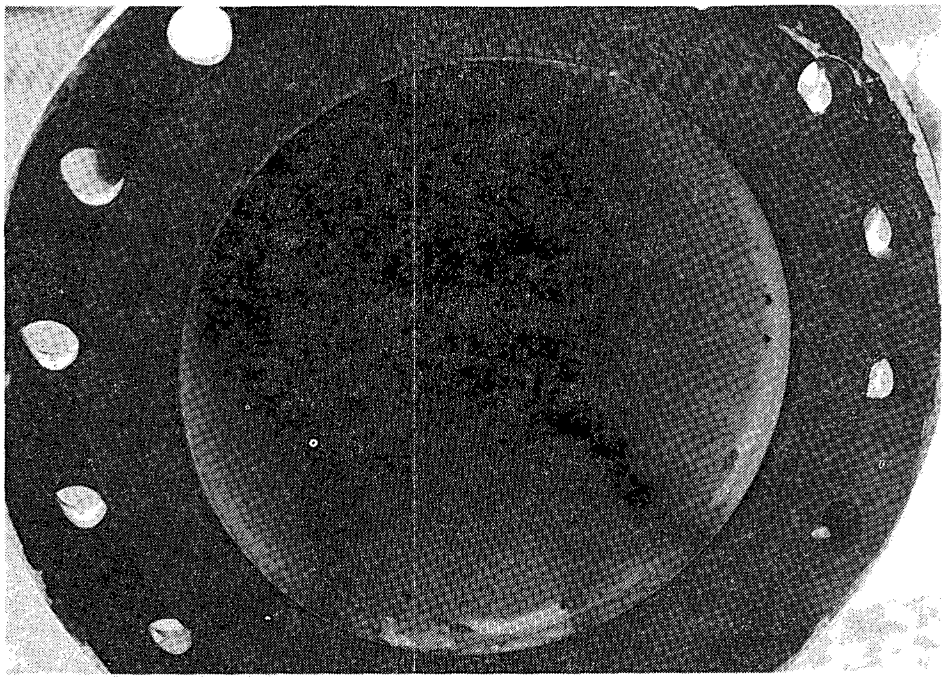


PLATE NO. 9

PSEUDO-SCALE
IN 4th SPOOL



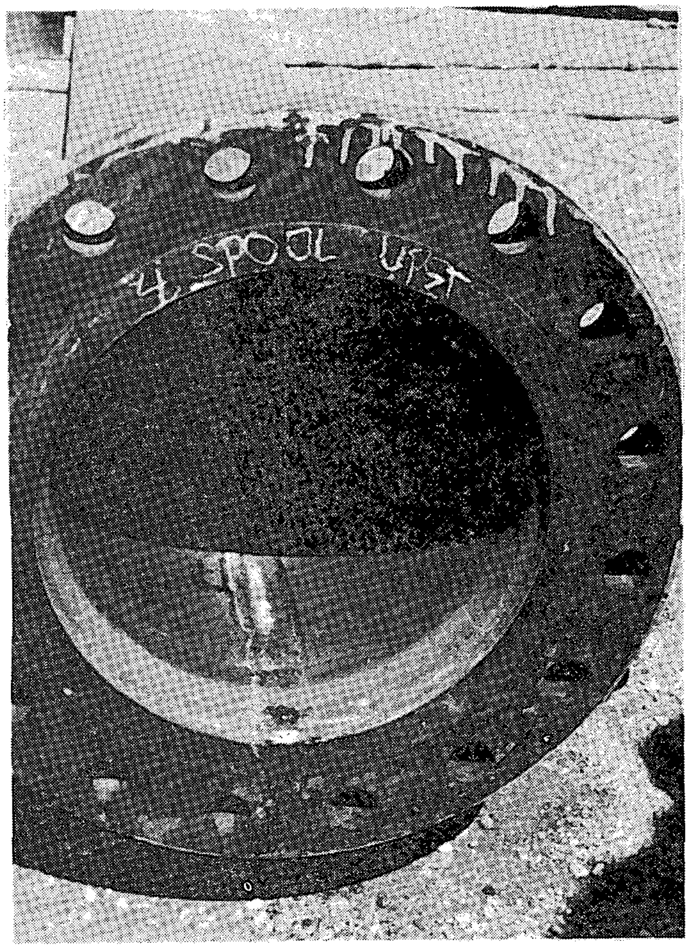
CBB 796-7847

EAST MESA WELL 56-30

SCALE-FREE LINE DURING INJECTION

OF 2.0 μl AND 1.0 μl DEQUEST PER LITER BRINE

PLATE NO. 10



CBB 796-7849

TECHNICAL INFORMATION DIVISION
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720