Water Analyses—A Basis for the Detection and Prevention of Injection Water Problems

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ABSTRACT

In any water flood project the operator may take one of two routes regarding water analyses. One route is to have few or no water analyses made at the start of the project and during its life. The other, a more desirable route, is to have pertinent analyses made at the beginning and periodically during the life of the project.

This paper outlines some of the problems that can occur as the result of changes in an injection water. Corrosion of equipment and piping, plugging of the producing sand, scale formations, and the role of bacteria are discussed.

Various water analyses are related to the early detection of typical water problems. Intelligent interpretation of mineral, dissolved gas, deposit, corrosion, bacterial, and membrane filter analysis results is shown to reveal the presence of these potential problems.

Detection and treatment methods are discussed as a means of preventing potential problems from becoming a reality. The necessity of an early detection of expected problems, the application of effective preventive measures, and the value of periodic water treatment evaluations is stressed.

INTRODUCTION

The injection of water into oil producing horizons is often associated with troublesome and costly problems. Management and plant operating personnel are frequently faced with the prospect of repeated well workovers, replacing or cleaning of filter media, and repairing or replacing metal tanks, lines, and pumps. All of these remedial jobs are the result of a kind of operating disease that might well be called "waterflooditis."

What is "waterflooditis"? This coined term is as its name implies, an inflammation, congestion, or irritation in the system of a water project. It can be the cause of considerable consternation to the management and operating personnel. The disease usually manifests itself in three common forms:

(1) corrosion of internal metal surfaces of tanks, lines, and pump parts;
(2) scale build-up on these same metal surfaces; and
(3) plugging of the pores at the sand face.

Two questions most frequently heard when the symptoms of "waterflooditis" become noticeable are "Can the disease be cured?" and "Could it have been prevented?" Experience shows that both queries may be answered in the affirmative but only if sound operating procedures are practiced.

These operating techniques are determined by applying a full knowledge of the water that is to be used. Mere water analyses are not enough -- they must be interpreted in terms of the behavior of the water under actual working conditions. The effects of an adequate knowledge of a water compared to little or no knowledge of the same water may be outlined as in Fig. 1. In Situation I, adequate representative water analyses may at the beginning or very early in a water flood project give an immediate insight into the potential problems that may be faced throughout the life of the project. Armed with this information, a

FIG. 1

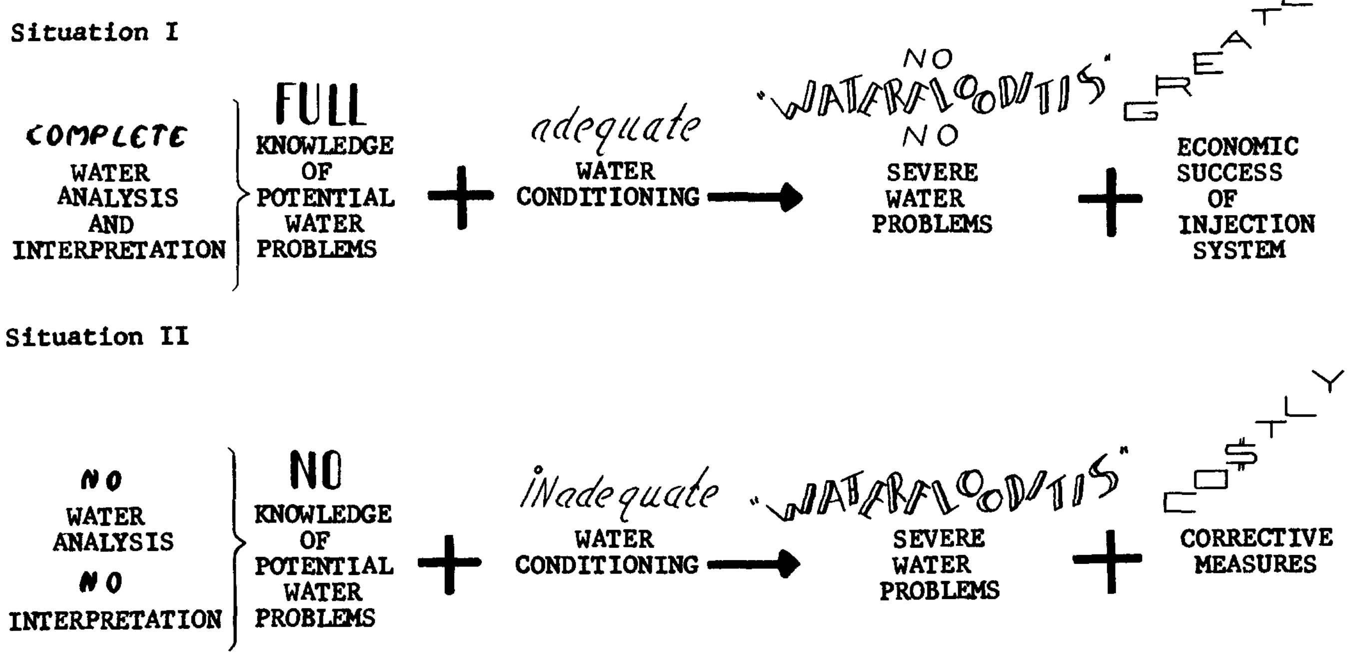

FIG. 2

trained and experienced water specialist working with the project engineer can recommend and apply preventive measures that will assure a smooth functioning project with few or no severe water problems. This is contrasted in Situation II with a project where no or few representative water analyses are made. In this case, the project may operate for a period of time with no outward indication of any water problems. In time, however, severe and troublesome problems appear. To correct them often entails costly and extensive remedial work that soon cuts a big swath through the expected profits of the project.

It will be worthwhile to keep Fig. 1 in mind as the role of water analysis interpretation is discussed and then later as the three most often encountered forms of "waterflooditis" are considered. Water analyses will be related to each situation.

PLANNING A WATER FLOOD PROJECT

Assume that you have a horizon that will yield sufficient oil on water flooding, that you have decided where to put the water, and that you have a sufficient quantity of water; the next step would be to actually put the water where you want it -- the producing sand. Too often plants have been designed, engineered, priced, and constructed before any water has been pumped from the supply source and subjected to analysis and interpretation. Frequently this type of plant presents its operators with severe problems.

For example, a plant in West Texas following such a pattern of operation began injecting a water that had a very high content of dissolved carbon dioxide, carbonates, and hardness. When the water was pumped from the supply well, the pressure that kept the carbon dioxide in solution deep in the water bearing formation was released. Most of this gas escaped from the water in the raw water tank and out through the thief hatch. The loss of carbon dioxide and the accompanying increase in the pH value of the water resulted in a lowering of the solubility of calcium carbonate. Thus, calcium carbonate was deposited in the filter bed, on the pressure lines, and on the sand face.

After only nine months of operation, it was necessary to use six hundred gallons of 15% acid to loosen the cemented filter media (Fig.2) so that it could be removed and replaced. Acid treatment of most of the lines and wells was necessary in order to inject the desired volumes of water. These workover and remedial procedures cost the operator a large sum of money and an unestimated additional amount of lost profits through lost production.

If adequate and representative water analyses had been obtained as soon as water was available, the tendency toward precipitation of calcium carbonate could have been detected by intelligent interpretation of the test results. Plant design could have been modified to allow the insoluble calcium carbonate to drop out of solution at a point in the system where the reaction could be controlled. Proper mechanical handling of the water coupled with the right chemical treatment could have saved this operator a considerable amount of money.

This example serves to illustrate the value -- the necessity in most cases -- of basing plant design on water treating and conditioning requirements that will obtain and maintain the desired quality of injection water. These requirements can only be determined by a study of representative water analyses.

You cannot effectively attempt to treat that which you do not understand. A man going to the north pole usually does not get a malaria shot before departing. Neither should a water plant design be made before it has been determined what problems must be faced and prevented.

OPERATING PROJECTS

Three common forms of "waterflooditis" and an example of each will be presented with the request that you consider how they might have been detected early by judicious study of the water to be used. Some corrective and preventive measures will also be presented for your consideration.

"WATERFLOODITIS I" - CORROSION

Corrosion in a water injection system may be found in many forms. A number of events occurring either singularly or in combination are known to contribute to this type of "waterflooditis". Let us consider, as an example, a water flood in Texas.

This project had been operating for almost a year with no apparent problems. Rather suddenly a few leaks developed in one high pressure line. In less than two months the leaks became so numerous the line had to be replaced. Leaks also began to appear in other lines and in another three months a second complete line was replaced. The operator had the benefit of only meager partial water analyses, performed primarily to identify the source water. The water was a strong brine, high in hardness, alkalinity, and dissolved carbon dioxide and hydrogen sulfide.

Shortly after injection was started, it was necessary to use the produced water. The make-up water and produced water were mixed after the make-up water had passed through an aeration tower to remove hydrogen sulfide. Aeration in the tower was successful to the extent that an initial hydrogen sulfide content of about 400 ppm was reduced to about 40 ppm. A further reduction in hydrogen sulfide content to 2 ppm was attained as the water passed through the open pits. At times, however, there was as much as 8 ppm of hydrogen sulfide at all points in the system. Until the time the severe corrosion became evident, a few hydrogen sulfide determinations plus the initial partial analyses made up the water analysis

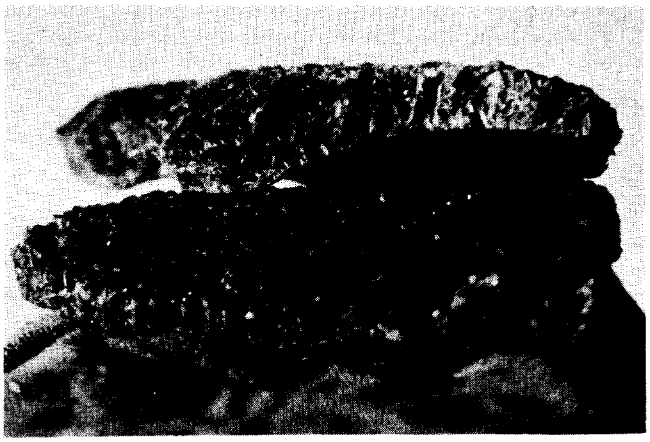

FIG. 3

program.

An investigation of the severe corrosion problem was accomplished by a complete set of water analyses, an inspection of the plant operating equipment, and an X-ray and metallographic study of a section of pipe that had failed.

The X-ray and metallographic investigations pointed to the presence of hydrogen sulfide, concentrated at localized points, as the cause of the pin-point type corrosion.

Over pits in the internal pipe surface tubercles were found. A deposit analysis proved them to be largely iron sulfide with a small amount of calcium carbonate. Chemical analysis of a number of water samples revealed an increase in hydrogen sulfide content had occurred along the line to the injection well.

Bacterial Analysis

A bacterial analysis of the water taken at pertinent points throughout the system indicated sulfate reducing bacteria were entering with the supply water. The numbers of these bacteria increased as the water passed through the system to the injection wells. A careful bacteriological study of typical tubercles showed that sulfate reducing bacteria were concentrated at these points in large numbers.

A thorough examination of all the analytical data led to the conclusion that hydrogen sulfide, concentrating at localized points in the system, was the cause of the pin-point type corrosion. The hydrogen sulfide was present due to poor aerator operation and the action of sulfate reducing bacteria.

Laboratory bactericide screening tests were performed in which six commercial bactericides were evaluated for their effectiveness against the particular strain of organisms growing in the system. The tests were made in an actual sample of flood water. The bactericide that gave the desired percent kill at the lowest cost was recommended for a field trial. Since the bacteria were multiplying under old deposits, it was necessary to thoroughly clean the system. Bacterial counts were made after chemical treatment was initiated and at regular intervals thereafter. Present indications are that the use of an effective bactericide in conjunction with a reliable corrosion inhibitor is preventing any serious additional corrosion in this system.

"WATERFLOODITIS II" - SCALING

Scaling, the buildup of insoluble deposits on injection equipment and lines, is another common form of the "waterflooditis" disease. As already mentioned, scale deposition can plug and cement filter media, it can restrict flow in piping and injection pumps, and it can plug and reduce the efficiency of producing wells and heater treaters. Scale deposition, whether in the injection or production portion of a system, can be the result of the same basic changes in a water. Therefore, I request that you consider as cases of "waterflooditis" some scale problems that actually are not limited to occurrence in water flood projects.

The three most commonly encountered types of scale are calcium carbonate (acid soluble), calcium sulfate (relatively acid insoluble), and barium sulfate (acid insoluble). The latter two have customarily been removed by mechanical means but some of the newer scale removers show considerable promise.

We shall consider briefly a few cases of scale deposition -- a calcium carbonate scale in an injection system, a calcium sulfate deposit in a producing well, a barium sulfate scale in another producing well, and a calcium sulfate depost in a heater treater.

Calcium Carbonate - Injection System

As an example of calcium carbonate deposition, consider a closed system in West Texas. At this project a high hardness brine with a temperature of approximately 150 F was being injected. The water as it came from the supply well contained over 400 ppm dissolved carbon dioxide and a low level of dissolved hydrogen sulfide. The water was pumped to a raw water storage tank, then through a filter to a clear water storage tank, and finally repressured for injection. Since so much carbon dioxide and accompanying hydrogen sulfide were evolved in the raw and clear water tanks, the thief hatches were constantly open to permit these gases to escape. No water quality control was practiced during the first 18 months of operation. When some severe corrosion was experienced in the water tanks, complete water analyses were made to determine the cause of the trouble.

The findings indicated severe plugging of the filter and piping may have occurred since a considerable decrease in carbon dioxide content of the water was detected from the supply well through the plant and along the line to the intake wells. Hardness, sulfate, and carbonate also showed a decrease en route. The equilibrium tests indicated there was a tendency for the water to precipitate carbonates. Membrane filter studies of the water entering and leaving the pressure filter showed it was removing only very small amounts of the suspended solids.

The high pressure lines were opened at a number of points and considerable carbonate scale was found to have been deposited. An examination of the filter media was made. As suspected, this material had been cemented into a solid mass by the deposited calcium carbonate. Considerable quantities of acid were required to loosen the media so that it could be removed and replaced. Some of the injection well tubing was so severely plugged, logging gear could not be run into the hole.

Needless to say, the calcium carbonate deposits

FIG. 4

seriously hampered water flood operations and considerable expenditures were necessary before the system was finally restored to working order.

Mechanical Changes Recommended

After a thorough study of the plant and a complete survey of the water problems had been made, a number of mechanical changes were recommended. These modifications in the system were designed to permit the dissolved gases to escape at points in the system where the precipitation of calcium carbonate could be controlled. The unprecipitated calcium carbonate was to be stabilized in solution by the addition of a complex phosphate. Due to economic and other operating considerations, the operator decided against most of the mechanical changes.

Complex phosphate feed was begun by dissolving the chemical in a small quantity of fresh water and injecting a portion of the feed solution ahead of the filter with the remainder being added after filtration. This compromise did succeed in preventing cementation of the new filter media and further deposition of carbonate scale in the lines.

This illustrates that scaling and corrosion can exist in the same system. It is obvious that while the use of a complex phosphate did prevent scale formation, the original problem of corrosion was still present. Without the benefit of the suggested mechanical changes, the corrosion continued unabated and in a short time it was necessary to replace several metal tanks and lines.

Calcium Sulfate - Producing Well

To illustrate calcium sulfate scale as a problem where produced water was reinjected, consider a well in New Mexico. Production from this well progressed for over two years with no more than routine pump problems. The produced water was used to augment the meager make-up supply and, therefore, it was necessary to maintain this source of water in order to operate the flood.

During a routine pulling job, the operator was shocked to find a one-half inch thick layer of scale coating the tubing and pump surfaces (Fig. 3). The scale was removed rather easily since the petroleum products laid down with the scale held the crystals apart and produced a relatively soft deposit. The pump had been placed in operation for only twenty-one days when it was necessary to again pull the well this time due to its complete inability to pump fluids. The operator had the scale analyzed and it was reported to be primarily calcium sulfate.

To correct this situation, a few pounds of controlled solubility phosphate were poured down the annular space. The well completion was ideal for this simple type of treatment as there was ample circulation of fluids to cause proper dissolving of the phosphate. Periodic phosphate determinations on the produced water enabled the supervising engineer to recommend weekly chemical charges. This well and others in the field so treated are still operating. The pumps are now pulled only for routine mechanical workovers and they come out clean with no evidence of any scale formation.

Wells completed in other ways may require different methods of treatment. The controlled solubility phosphate can be administered via

(1) a by-pass feeder in which a portion of the produced fluid is passed through a bed of the phosphate and back down the well annulus,
(2) a porous plastic bag filled with the material and suspended from the pump anchor, or
(3) a dump shot down the annulus after the well has been gravel packed to bring the bottom of the hole up close to the producing formation.

Barium Sulfate - Producing Well

A Central West Texas producing well illustrates another instance of a service engineer using water and deposit analyses as a tool to detect the causes of reduced fluid production. When production declined drastically, the pump was pulled and three or four bushels of small, hard, whitish beads were removed from downhole (Fig. 4). The pump was cleaned and placed in service. After about a week's operation it plugged, and again large quantities of the tiny beads were found.

A subsequent deposit analysis of the beads showed they were composed of barium sulfate with traces of silica and carbonates. The well could not be unplugged with up to 2,000 psi pressure applied at the well head. The produced water analysis showed that the water had a high sulfate content. It was concluded a barium containing water was mixing with the sulfate containing connate water in the well bore, outside casing perforations, and back in the producing formation. The resultant mixture of these waters caused the barium and sulfate ions to unite and form insoluble barium sulfate.

To place the well back on normal production, it was re-perforated and fractured using a special fracturing form of controlled solubility phosphate. This procedure resulted in the well returning to normal fluid production. No plugging has been experienced for over nine months and the produced fluid decline curve is considered normal.

Calcium Sulfate - Heater Treater

A final type of scale problem may be illustrated by a heater treater problem in which the U-tube was periodically coated with a heavy scale (Fig. 5). Deposit analysis demonstrated the scale was mainly calcium sulfate with smaller amounts of calcium carbonate and traces of iron sulfide. To prevent further scale deposition, a portion of the produced fluids entering the treater was by-passed through a bed of controlled solubility phosphate in a by-pass feeder. Scale ceased to be a problem as long as the proper biweekly charges

FIG. 5

were added. Water samples were sent to the laboratory on a regular basis to determine the actual amount and rate of dissolution of the phosphate. Any variation in the desired phosphate residual was compensated for in subsequent additions to the feeder.

"WATERFLOODITIS III" - PLUGGING

It is often impossible to separate entirely the plugging type of water flood disease from the two types already mentioned. In many cases two or all three types may occur simultaneously and as a result of each other. It is something like a bacterial infection that causes pain in a particular part of the human body. Accompanying the pain and inability to use the infected part may be an over-all body fever, nausea, and a general debility of the patient.

To cite all types of well plugging is beyond the scope of this discussion. Therefore, let us examine rather thoroughly one of the most common types of injection well plugging, the deposition of iron compounds on the injection sand face.

One of the main objectives of an open system is to oxidize the iron in solution so that it will be in a form that can be removed by coagulation and/or filtration. A closed system on the other hand, attempts to hold the iron in solution. In high iron content waters this is frequently impossible. As an example of iron compounds plugging an injection well, review the case of an operator maintaining a closed system in West Texas. The water being injected was a mixture of a produced brine and a supply brine.

When injection wells began to plug, an organic sequestering agent was added to the water but the high cost of this material soon forced discontinuance of its use. The wells continued to plug and the injection pressures were increased accordingly. This method of operation continued until injection pressures reached such high levels the formation was either fractured, pressure parted, or the overburden lifted. Many wells "channeled out" to the nearest producing well. A study of the entire system was made by a competent engineer and the following information was obtained:

(1) Water analyses showed the produced brine had a very high iron content.
(2) The source or supply brine contained a small amount of dissolved hydrogen sulfide.
(3) Sulfate reducing bacteria were found in the produced brine in very low numbers.
(4) A sample bailed from a plugged well showed the presence of extremely large numbers of sulfate reducing bacteria.
(5) Iron sulfide was also present in large amounts.

The engineer concluded that bacterial cadavers and large amounts of insoluble iron sulfide were plugging the sand face. It was necessary to acidize most water lines and injection wells. Laboratory bactericide screenings indicated that the water could be treated with a suitable bactericide.

Bactericide Treatment

Could all or part of these problems have been prevented? Bacterial analyses would have permitted an early detection of the presence of sulfate reducing bacteria in the produced water. If begun early, bactericide treatment of this portion of the water would have insured against the spread of the "infection" throughout the entire system. Bactericide treating of only the smaller volumes of produced water would have been less costly than treating the entire volume of water injected. Once the presence of these troublesome bacteria had been detected, extreme care and close supervision would have been in force while the organic sequesterant was in use. It is an established fact that many organic acids used to sequester iron can, and actually do, serve as a food for most bacteria.

In the case cited it is my opinion that the use of the organic did in fact contribute to a stimulation of growth of the bacteria throughout the system and downhole on the sand face. Once established in the lines and downhole, the sulfate reducing bacteria produced enough hydrogen sulfide, as a result of their growth, to react with the dissolved iron in the produced water.

The result of the reaction between the hydrogen sulfide and the iron was the formation of insoluble iron sulfide. This insoluble material was filtered from the water at the sand face and contributed to the plugging of the injection wells. Properly interpreted water analyses could have prevented the occurrence of the severe and costly problems experienced at this water flood project.

The disease I have termed "waterflooditis" is found in many forms other than those mentioned above. As already stated, it is beyond the scope of this paper to duscuss all types of this malady.

SUMMARY AND CONCLUSION

Water analyses can be the basis of water injection plant design if representative samples are taken early and the analyses properly interpreted. It is extremely important to remember that no water analysis is more informative or representative than the water sample on which it was made or the comprehension of the person who interprets it.

A careful study of adequate representative water analyses by experienced and trained personnel can detect potential water problems before they are a reality. The application of suitable preventive and corrective measures in the early stages of a water injection project can save a considerable amount of money during the life of the project.

If you think all the problems and troubles you experience due to corrosion, scaling, and well plugging are to be *accepted* as an inherent evil in water flooding you are mistaken. Many of these troublesome situations can be prevented, corrected, or lessened in severity through the application of sound water conditioning principles. Before the principles of good water quality control can be applied, it is imperative that you have as thorough and complete a knowledge of your water as possible. Water analyses are the basis -- the means -- whereby you can obtain this knowledge.

If you are armed with sufficient information, the sequence of events in Situation I, Figure 1, will be possible on your injection project rather than those in Situation II.

You will then be in a much better position to realize maximum oil production over the longest period of time. In short, you will realize a greater financial gain from your water injection project.

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