Operational Problems in Water Flooding

By JIM B. THOMAS
SACROC

INTRODUCTION

The recovery of additional oil by pressure maintenance or water flooding presents numerous and diverse operating problems. However, because new problems seem to occur every day, this paper does not include all problems which might be encountered in the operation of a pressure maintenance or water flood project. Also specific solutions to problems discussed are not included since most problems have several solutions. The conditions, circumstances and personnel involved will have a great influence on the solution chosen. The primary purpose of this paper is to point out some of the more common problems which may occur.

It has been assumed that the necessary engineering studies have been made on the reservoir and that a pressure maintenance or water flood project is ready to be started. It is further assumed that all necessary governmental or regulatory approval has been obtained and that the flood pattern (five spot, line drive, etc.) has been selected.

Many problems which now arise will not have clearcut solutions. In fact, there may be several solutions, and selection of which is best may be a matter of judgment and economics. For example, gold plated lines may be a solution to the problem of the handling of corrosive water, but the cost is prohibitive. The life of the project and the length of time during which the equipment will be needed are major factors to be considered in arriving at the most practical solution.

INITIAL INJECTION

The wells to be used for injection service fall into two general classifications: (1) producing wells converted to injection wells, and (2) wells drilled specifically for injection wells. If producing wells are converted to injection service, then different types of completions from open hole to almost completely cased wells may be expected. Thus, the size and condition of the casing may vary and will limit to some extent the type work which can be done down hole. For instance, if an open hole completion is utilized, the injected water may cause the formation to slough and create a fill-up problem to the extent that clean-outs of the injection wells become necessary. Fill-up and plugging may occur from impurities in the injection water or in the products resulting from corrosion by the injection water.

Wells drilled specifically for injection wells will generally be cased through the injection interval and perforated. In this case, if dense or hard streaks are present, blank spaces in the casing string should be left so that future work on the well may be confined to certain sections of the formation.

The source and type of water to be used in the injection program will determine the treatment and facilities necessary for handling the water. If the water is corrosive, treatment or special equipment such as corrosion resistant pumps and valves and lined or special piping may be needed. However, the undissolved solids in the water may require filtration prior to injection. The size and type filters will depend on the quality of water used and required, for water from surface sources is subject to more changes in quality from time to time than is water produced from subsurface reservoirs, and surface water is more likely to contain free oxygen. Such changes in quality are caused by changing weather conditions; for example, wind causes the water in a reservoir to circulate and rainfall runoff will materially change the reservoir water.

Furthermore, the water produced from subsurface strata is more likely to contain hydrogen sulfide and/or carbon dioxide than is water from a surface source. The surface water is aerated and aeration is one method for removing hydrogen sulfide and carbon dioxide but in turn adding free oxygen to the water. All these three gases will attack bare metal. However, these are not the only causes of corrosion but are mentioned because of the common occurrance of these gases. Also bacteria, particularly sulfate reducing bacteria, can create havoc with a water system, and, if all of the free oxygen is removed from the water, an ideal anaerobic condition for the growth of sulfate reducing bacteria is created.

In some cases it seems that the cure may be as bad as the problem, so cures must be based on the individual cases and conditions. Checks for corrosion and its control should always be made to determine if and to what extent it is occurring. As in all cases, judgment and prevailing conditions should determine what if anything should be done. For instance, one problem is neglecting salvage: it would not be practical to design or protect equipment for a thirty-year use if the expected life of the project is only ten years.

The initial injection rate to be used, of course, depends on the type of project, pattern selected, reservoir characteristics, and conditions. If the production is not prorated, maximum oil production consistent with recovery efficiency and economics will determine the rate. Also, the condition and character of the rock at the injection wells and the formation as a whole will affect the rate at which water can be injected into the formation. And, depth will help determine the maximum pressure which can be exerted on the reservoir before fracturing occurs. Furthermore, the distribution of fluids in the formation, gas, oil and water saturations, and the rate at which it is desired to improve conditions in the reservoir will also affect the rate of injection. These are some of the factors which should be considered when selecting a starting rate. It will, in all probability, be necessary to adjust the rate after injection is started, and performance and experience will be the guide in these adjustments.

WATER ENTRY

Formation plugging and scale formation in lines may occur, and the type scale and the degree of build-up or plugging will determine if treatment to prevent or control should be started. An acid soluable scale creates fewer problems than does an acid insoluable scale; however, the economics and frequency of acid jobs will influence how much water treating should be done. Primarily, the extent to which acid insoluable scale is occurring will be a guiding factor for determining treatment. Scale formation on the lines can be of some benefit in protection from corrosion because bare metal is not in contact with the injection water; but complete protection is almost impossible.

After injection has commenced, the entry of the water into the formation may or may not become a problem, depending upon where the water is being injected. If injection is into the producing zone, the water should enter as uniformly as practical and displace the oil. The more uniformly the oil is displaced, the greater the initial sweep efficiency, and the more economical the recovery.

There are several tools available for determining the water entry profile of an injection well. None are fool proof or give the exact answer, and all should be used more as a guide to than as a prediction of the actual conditions occurring in the reservoir. Some of the tools are more qualitative than quantative, or vice versa, and it should be emphasized that these instruments, with a limited degree of accuracy, measure the place where the water is leaving the injection well bore and not its movement through the formation. The water may enter a 10 ft zone at the well bore but spread to cover a 50 ft zone some distance away from the well bore. It should not be concluded from a water entry profile that water leaving the well bore in a given zone is contained in that zone beyond the well bore. This conclusion could be true, but additional information from offsetting producing wells is needed to confirm such conditions.

Should it be determined that better distribution of the injected water in a well is desirable, there arise the problems of how this distribution can be accomplished. It is helpful to determine if the poor distribution is because of well bore damage in completion. If this completion damage is the problem, then a simple acid wash may correct the condition and give the desired results. The character of the formation could be such as to require selective acid treatment or selective fracing. Also, there could be a zone taking more than the desired amount of water; and, rather than improving water entry into other sections in the well bore, the reduction of the water entering that one zone may be desired. In this case, water entry may be reduced by partial plugging with some suitable material or by stopping injection by isolating the zone with packers. It all depends on the conditions encountered, and a workover which is successful in one well may not be the solution in some other well.

PRODUCING WELLS

The producing wells in a pressure maintenance or water flood project present their share of the problems, all of which may not be directly the result of water injection but instead may have been inherited from the beginning of a flood project. It is desirable to have the producing wells completed so as to give the greatest sweep efficiency and thereby obtain the greatest ultimate recovery. For example, the producing wells may have been completed without any knowledge that a water flood project would be used later. And it is possible that, if a number of leases are taken over from several former operators, the wells will probably include many different types of completions. Or the project area may be located in an old field in the last stages of primary depletion where well records are not available. It is evident that in a situation of this type many questions can and will arise, and it may be necessary to log and core some of the wells to get additional data. When the field was being drilled, if bottom water was considered to be a problem, many of the wells would probably penetrate only the top of the producing formation. On the other hand, if it was believed that a gas cap formation would become a problem as the formation was depleted, many of the wells would probably have cased off large sections of the producing interval. In either event, it will be necessary to determine the type completion best fitted to the particular conditions and remedial work completed. And as the project progresses and high reservoir pressures are expected, it may be desirable to do remedial work on producing wells before the pressure increases. This remedial work would be very important if the sand face in the wells were susceptable to damage from drilling fluids used for pressure control during workover.

In all pressure maintenance projects or water floods, wome of the wells will produce more efficiently than will others. Inefficient producing conditions are indicated by excessive gas-oil ratios, high water production, excessive pressure draw-down and in some cases low producing capacity. In a water flood, if the project is allowed to produce at capacity, the selection of producing wells to be shut-in will probably not be a problem until the economic limit is reached. However, the situation is quite different in a project where the allowable is prorated and where the project has more producing capacity than allowable. In such a case it become a problem to decide which wells to produce. From a reservoir withdrawal standpoint, wells producing gas in excess of the solution ratio may be shrinking the oil in the reservoir and should be considered for shutting in if another well can more efficiently produce the allowable. By the same token, a well producing large quantities of water and thereby requiring a greater amount of reservoir energy to produce should be shut-in, and the allowable transferred to a more efficient well. The initial guide in selecting wells to be shut-in and wells to be produced will be reservoir conditions and well production histories, while the additional information gained as the project progresses will be the key to future producing practices.

Pressure conditions and changes in producing characteristics are the best indications of performance of a project. The change in reservoir pressures indicate the area in which reservoir fluid has been affected. The presence of gas saturation in the vicinity of the injection wells may be reflected by high pressure gradients which are caused by reduced permeability to water and oil. Furthermore, plugging conditions may also be reflected in the same manner. An isobaric map will give a good indication of where injection rates should be changed.

In a pressure maintenance project there is the question what is the optimum pressure. In most instances low pressure is more harmful than is high pressure. The viscosity of a reservoir fluid of oil and gas is least at the saturation pressure, and the formation volume factor is greatest. The amount of change in both characteristics is greater for a given reduction in pressure below the saturation pressure than it is for the same increase in pressure above the saturation pressure. There may be concern that oil will be pushed out of the field into the formation surrounding the reservoir; but, until the pressure at the edge of the field exceeds the initial reservoir pressure, migration from the field will probably not occur.

In a project which is prorated, the maximum efficient rate (MER) will be requested. Much has been written on the MER's of specific reservoirs but very little has been written on how to determine a MER for a field. In case of pressure maintenance and water flooding, it is a function of how the reservoir takes water, how well the water displaces the oil, and how great is the rate at which the oil can enter the producing well bores. It is evident that the MER of a project can vary considerably from project to project depending upon the above conditions.

WATER PRODUCTION

When water breakthrough first occurs everyone becomes concerned. Is it premature? Has oil been by-passed? Has oil been trapped? If a water injection project is successful, water breakthrough is inevitable. This is a normal occurance if the oil is displaced to the producing wells, but in some instances breakthrough is premature and must be corrected. The method of correction can become quite complicated depending upon the conditions causing the breakthrough. A liner, zone plugging, or isolation by packers may be the solution required.

The water cut to which a well should be produced is simple, if there is no limit on production and/or if the oil cannot be captured and produced at another well. The critical water cut is where it is no longer economical to produce the well. On the other hand, in cases where the oil can be captured and produced at another well or where excess producing capacity is available, a different view is usually taken. In determining an economic limit under such conditions, one should consider the following: the value of the oil produced, the cost of disposing of the produced water, the cost of lifting the total fluid, the cost of replacing the water produced, and the effect on the sweep efficiency. All these factors should be considered and, different answers for different reservoirs will result. But, the correct water cut in one field or even one well may be vastly different for some other field or another well.

Almost as soon as such projects are placed in operation, one asks, "What is the sweep efficiency?". That is a good question. However, every field is different and will require different assumptions upon which to base calculations for making an estimate. In most cases it will be necessary to rely upon laboratory test data and assumptions. Then, when the flood is complete and the production known, an accurate sweep efficiency can be calculated providing the estimates of the oil initially in place were correct. By that time, however, very little interest (other than academic) is usually displayed in sweep efficiency.

After breakthrough occurs and water production begins to increase, the operator should be ready to handle the produced water. For disposing of water there are two choices: above ground and subsurface. If the water is salty — and in most cases it will be — the danger of contamination is present. And even if large enough pits are built so that evaporation takes care of the water, a potential hazard in the form of a deposition of salts is left behind. In the case of subsurface disposal, a suitable formation must be found in which to inject the water. A practical solution in many instances is to reinject the produced water into the formation from which it was produced.

In the first place the voidage created by the water production must be made up from some source. The water will likely be produced at many points scattered over the project. The problem now arises as to how to collect the water. Since all water is corrosive to some extent, consideration must be given to the characteristics of the water produced, and a system for collecting and handling this water must be designed. If the water is corrosive, a material must be selected which will resist attack; also, the terrain of the land will influence the type of material which can be used in the system. Energy resulting from differences in elevation, if available, should be utilized to reduce power demand. Too, predictions of future water production must be made to properly size lines and pumps, but these calculations are difficult because the system will be needed before actual production performance can be obtained.

In addition, it must be determined if the produced water and the injected water should be mixed or kept in separate systems, and only studies based on the characteristics of the two waters can answer this question. For the handling of the mixed or produced water two choices are available: a closed or open system.

If a closed system is chosen then there are problems of keeping the water from coming into contact with air from the time when the water is produced until it is back in a reservoir. However, if the water is collected in tanks, gas and/or oil blankets may be used. But any point to which the water is transferred or pumped becomes a point ot possible contact with air. Close surveillance of the entire system should be maintained to see that any leak or loss of gas or oil blankets are corrected as quickly as possible. No system is entirely closed all the time, but the more nearly the system is kept completely closed the less are the chances of corrosion. It is generally accepted that if a closed system is practical, it is more economical from an initial and operational investment cost basis than is an open system.

On the other hand, if an open system is chosen, the problem of water treating presents itself.

CONCLUSIONS

This paper does not include all problems which will be encountered in developing and operating a pressure maintenance or water flood project. However, it does call attention to some of the problems generally encountered and points to some of the factors which should be considered in their solutions It is intended to point out that many of the estimates and calculations required in judgment, and experience made more dependable with increasing years of experience by the more discerning petroleum engineer.

Acknowledgment

The author would like to acknowledge and express appreciation to Mr. H. H. Allen, Manager, SACROC Unit, for assistance in the preparation of this paper.