Water Injection Problems in Waterflood Operation

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SATISFACTORY WATER INJECTION RATES

Before discussing the various types of problems which arise when water is injected during waterflood operations, it is advisable to define the term "satisfactory intake rate". This is not as easy to define as it might seem, and a clear definition which will fit all cases is not possible. Early in a waterflood operation (first few months), the water injection rate at a given injection well may be considered satisfactory if the rate is two or three times greater than the injection rate at the same well a year later, even though in each case the pressure applied at the well head is exactly the same.

This difference is explained by the fact that early in the life of waterfloods the reservoirs being flooded are at low pressures, possibly 100 psig to 200 psig. With continuous water injection, the reservoir pressure will be increased to as high as several thousand psig. Therefore, at constant water injection pressure, as the pressure in the reservoir increases the injection rates will decrease. This decrease in rate continues until the maximum reservoir pressure is reached. This reduction in rates is perfectly normal behavior for intake wells.

When the maximum reservoir pressure is reached and the rates stop declining, the injection rates are said to have "settled down" or the operation has "settled down" injection rates. Some waterflooders will not operate intake wells at constant pressure from the first day of water injection. Instead, they will gradually increase the well head pressure at intake wells to maintain a constant injection rate. This latter method is practiced if water supply is limited or if pressure pump capacities are not adequate to permit high initial injection rates. Some operators will voluntarily choose to initiate floods at low well head pressures.

<u>Early Appraisals</u>

It is important that operators make early appraisals of water injection well behavior. Due to the complex nature of the problem, however, simplified rules of thumb or charts will not substitute for experience in a given reservoir or field. Nevertheless, someone must make decisions when there is no prior experience in the area, or when an experienced waterflood engineer is not available.

For this purpose a chart, Fig. 1, is presented as a guide to the determination of the approximate satisfactory water intake rates for injection wells under various conditions of sand thickness and 5-spot size. This chart must be considered as a working rule-of-thumb and not as a scientific instrument suitable for exacting work. It was prepared from wide experience in waterflood work under various reservoir and field conditions of spacing, pressures, permeabilities and types of porosity. The greatest number of satisfactory waterfloods with good performance will have injection rates which fall into the segment of the chart marked "satisfactory intake rates." Most practicing waterflood engineers will agree that the ideal rate of water injection is that rate which is obtained by application of the well head pressure which falls just below the pressure required for formation breakdown.

It is assumed, of course, that the waterflood is operated at the correct well spacing or 5-spot size for practical waterflood operation. This rate for "settled down" or "filled-up" conditions usually ranges between 3/4 barrel to 1 barrel per day per acre-foot of floodable pay. This does not mean that waterfloods cannot be operated above or below these limits of injection rate. For various reasons low rates of water injection are not satisfactory for pattern waterfloods in depleted reservoirs, and rates that are exceptionally high by these standards can be uneconomic or abnormal, as will be discussed later.

<u>Reading The Chart</u>

The chart, Fig. 1, may be used in several ways. For example, with an existing waterflood with 20 acre 5-spots and twenty-five feet of floodable pay sand, the satisfactory range of intake rates for these conditions will be found to be between 375 barrels and 500 barrels per day per intake well. These rates are determined by starting at 25 feet on the left hand base horizontal scale and reading directly vertically to the 20 acre 5-spot diagonal line; then follow a horizontal path to the "satisfactory range of intake rates"; and read below at the intake rate per well on the right hand base scale.

Another way of using this chart would be in the determination of the proper 5-spot size if the pay thickness and the injection rate at a test well are known. For example, if a field test has been run and it is determined that a rate of about 400 barrels per day at an injection well is obtainable under settled injection conditions, the first step would be to read 400 barrels per day at the right hand scale and then vertically upward to the satisfactory range.

At the same time, by reading vertically upward from 12 feet (the pay thickness in this example) until this vertical line intersects the 5-spot diagonal line, which is directly opposite the point already found in the satisfactory range of rates, the proper 5-spot size can be determined. In this example, the 5-spot size is found to be 40 acres. This means a flood can be satisfactorily operated with 12 feet of pay and 400 barrels per intake well per day water injection, by use

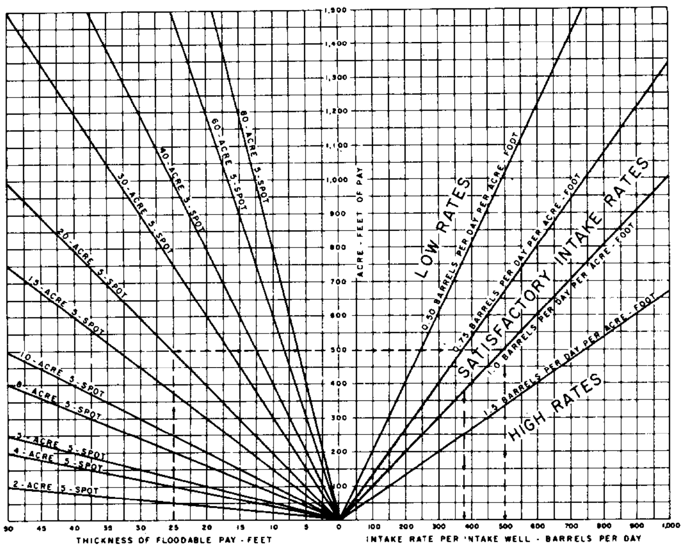

Fig. 1 CHART FOR DETERMINATION OF SATISFACTORY INTAKE RATES IN WATERFLOOD OPERATIONS

of 40 acre 5-spot. There is no reason to consider smaller spacing of wells. To consider 80 acre 5-spots for 12 feet of pay, about 750 barrels of water per intake per day must be injected.

The chart is not necessary, of course, for these figures can be calculated by considering about 3/4 barrel to 1 barrel per day per acre foot of floodable pay as a satisfactory standard rate. The chart is prepared for the convenience of anyone who will use it.

For the early (before fill-up) evaluation of intake well behavior, it must be remembered that rates should be considerably higher than under settled conditions at the same pressure. As an approximate rule, if the wells do not take water at the outset at hydrostatic head pressure only, at rates above the "satisfactory range", trouble probably will occur later in the flood life due to lower than satisfactory rates after fill-up.

ABNORMALLY HIGH INJECTION RATES

Today this problem is rare with water intake wells. Early in waterflooding practice (twenty years ago), this was a common problem. One reason it is rare today is that the cause of excessively high injection rates is understood, and the abnormality can be determined in the field quite readily. In general, excessively high intake rates are those which are due to a rupture in the formation which permits water to move directly from injection wells to producing wells without passing through the pay formation. This abnormal behavior may be detected by the appearance of water at producing wells within hours after water is injected at intake wells. It is also possible that water may appear at producing wells very soon after pressure is increased at intake wells, when an attempt is made to increase intake rates. This rupturing of the formation has occurred when an inexperienced operator has attempted to flood a shallow pay of low permeability.

Rupturing Of Formation

Wherever it is necessary to use a well head pressure on an intake well which is numerically greater in psig than the pay depth in feet, rupturing is likely. For example, if a 500 foot sand is operated at 550 psig pressure at the well head, rupturing can occur. This is an approximate relationship: rupturing has been known to occur at lower pressures and sometimes not until higher pressures than these are applied. With shallow reservoirs, this means that the well spacing must be small enough to permit the injection of satisfactory quantities of water to obtain the desired rate of 3/4 barrel to 1 barrel per day per acre-foot of pay without the use of high well head pressures. With deeper reservoirs this type of water break through is rarely a problem.

With pumping operations in shallow reservoirs, the abnormally high injection rates are less likely to occur undetected than in operations where the production is being flowed. This is because operators who flow their production attempt to compensate for the head of fluid at the producing well by increased pressure at the intake well. When this is done, rupturing or break through can occur without its being readily observed in a flowing operation.

An abnormally high injection rate may seem to occur if a flood is operated at smaller than optimum well spacing. Because of this spacing error, large volumes of fluid are handled at injection and producing wells. The obvious economic answer to this condition is the use of greater well spacing for better economic results, if reservoir conditions permit. In the case of very high rates in an installed flood, the injection rates may be lowered to the satisfactory range for better pumping practices. The more frequent error in well spacing or 5-spot size is too large spacing for reservoir conditions, resulting in low injection rates per acre foot for the conditions present.

ABNORMALLY LOW INJECTION RATES

Low rates of water injection have resulted in economic and physical failures in waterfloods in many of the waterflood areas over the country. The problem is a major one to waterflood operators, and much effort has been made to maintain satisfactory injection rates at intake wells in all flooding areas through the country.

One fundamental nature of an oil reservoir, which cannot be ignored, is the effective permeability of the pay formation. With low permeabilities, the spacing between wells must be carefully selected to permit the use of satisfactory rates of water injection without the use of the pressure which will rupture the formation. Some reservoirs cannot be flooded economically because the cost of wells is too great for the potential oil reserves which might be obtained by flooding.

Plugging of the pay formation by minute particles of material during the flooding operation can cause abnormally low injection rates. This plugging can occur at three places: 1. at the sand or lime face in the well bore of intake wells; 2. at the sand face of producing wells; and 3. within the reservoir. The first two conditions mentioned are more frequently encountered than the latter one. There are many different causes of plugging action in waterfloods but a full discussion of the subject is beyond the scope of this paper.

Types of Plugging Action

Common type of plugging action at the sand face of injection wells results from materials suspended in the injection water. These materials may be finely divided rock particles or dirt, iron sulfides, iron oxides, carbonates, organic materials including algae, bacteria, or small droplets of oil. A simple method which can be used to detect this type of plugging will be discussed. If plugging materials are carried by the injection water, the plugging action will be cumulative in its effect. That is, the plugging action will gradually reduce the intake rates at injection wells. This is a common occurrence.

If an operator is alert he will be able to observe from intake well data that the rates are decreasing with constantly applied pressure. This gradual reduction in rate must not be confused with the effect of pressure buildup in the reservoir, which was discussed previously. The plugging action can be detected if the rates continue to decrease below the range of satisfactory intake well performance as defined in Fig. 1. With pressure buildup, the normal intake well will exhibit rates that will reach a "settled rate" which sould be near the satisfactory rate of water injection. After this the rate will not decline further.

Another reason for low intake rates at the well bore of injection wells is sand face damage incurred during drilling. In this case, the well will not take water at satisfactory rates from the start of water injection.

Another method of detection of plugging action or formation damage at the sand face of intake wells is the use of the pressure fall-off techniques. These methods have been described by several authors previously.

The second type of trouble which causes low injection rates occurs at the producing well. This trouble can be caused by deposition of gypsum (or other solids), or by water blocking, or because of other damage to the outlet face of the pay formation in the waterflood operation. If some deposition occurs at the producer and causes plugging at the sand face, two observations will be made: 1. a gradual or fairly sudden reduction of rate of total fluid production will occur with continued water injection and 2. there will be a fairly rapid reduction in injection rates after the normal fill-up period has past. That is, the injection rates settle down to a satisfactory rate, and then, about the time that water production starts producing wells, the intake rates start a period of decline. These two effects, happening together, one at the injection well and the other at the producing well, are very strong evidence of plugging action at the sand face of producing wells.

ACCIDENTAL WATER INVASION

If a producing well is located in a part of a reservoir which has had accidental water invasion of the pay formation prior to the start of waterflooding, the producing rates will be lower than expected. This water blocking can cause a lowering of injection rates. In this case, the observation made is low oil and water production relative to original water injection. A similar condition can result from sand face damage by drilling. Hydraulic fracturing has been used in many places to overcome this type of low producing rates at producing wells.

If a 5-spot size which is too large for reservoir characteristics is chosen for flooding, low injection rates will not only delay the recovery of oil, but the producing well will show poor behavior characteristics.

The third and last type of plugging to be discussed is one which, fortunately, does not occur very frequently. Plugging, however, can take place in the reservoir between injection wells and producing wells. The swelling of clay minerals or the leaching of salts near the injection wells and the deposition of these salts near producing wells, are examples of problems that may occur.

The detection of these damaging effects is difficult. In each case the injection rates are lowered. A formation with high clay content or high salt content should be carefully studied before waterflooding is attempted. Then, if flooding is practiced, the observation of abnormal declines in injection rates at most of the intake wells may be attributed to the salt or clay content. The salt problem can be detected by observing, first, an increase in injection rates at constant pressure and then, a subsequent decline in producing rates and injection rates after the salt deposition takes place.

CONCLUSION

This discussion is not intended to present remedial suggestions for the problems outlined. Papers have been written on remedial work. It is hoped that operators will evaluate the injection rates in actual operations to determine the types of problems that may be causing trouble in their own waterflood operations. In this way, the proper type of remedial work can be done. If a correct evaluation of the cause of abnormal injection rates is not made, it does not seem possible that good corrective measures can be taken.