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Enhanced Reservoir Description Through Application of Suitable Techniques using Core, log and Well Test data for Successful Water Injection Performance

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Summary

In oil industry throughout the world, the prime objective is to improve recovery of oil from known reservoirs using different techniques. Water injection is one such technique, primarily for reservoir pressure maintenance and to improve the oil recovery. Although it is most common technique, its success depends on proper implementation and surveillance.

A successful water injection scheme mainly consists of three components namely designing, implementing and monitoring. These include identification of source of water, water quality considerations and laboratory compatibility tests etc. While designing a water injection scheme, it has long been recognised that formation damage in reservoir rock arises from exposure of the formation to foreign fluids which are often incompatible with the reservoir minerals. Rock fluid compatibility tests by utilizing dynamic core- flow (return permeability) tests are conventionally performed in the laboratory to avoid formation damage in the reservoir. Another method which is relatively less time consuming but cost effective is the use of capillary pressure studies on native core samples. The injection water showing lower capillary pressure at each saturation level is considered as a better choice.

Once a water injection scheme is implemented in the field, various ways are available for effective monitoring of the same using pressure transient, log and production data. Pressure transient well test data can help in providing some idea of strength of fluid injection for pressure maintenance. Data generated from pressure build-up and draw down tests can be used to know the degree of strength of water injection in the reservoir. Another monitoring tool to evaluate performance of successful water injection is Log- inject-log or time-lapse logging procedure. It involves the use of two or more logging surveys run with the same tool before and after an induced change in formation conditions. It can provide a reliable measure of the magnitude and distribution of the mobile and residual oil saturations in the vicinity of a test well at any time during the producing history of a reservoir flooded by water injection. These reservoir saturations are considered to be more reliable than computed from the response of single log.

This paper discusses the above mentioned techniques which are simple and can be used for designing and monitoring of a water injection scheme in the field for enhanced reservoir description and production enhancement in an oil field.

Keywords*: Capillary Pressure, Transient well Test, Log-inject-log, Water Injection*

Introduction

The objective of any water injection operation is to inject water into the reservoir rock without plugging or permeability reduction from particulates, dispersed oil, scale formation bacterial growth, or clay swelling.

The injection of water for reservoir pressure maintenance or secondary recovery purposes is important to oil field development. Therefore, the effect of water quality on well injectivities continues to receive attention. The main physical processes of formation damage in water injection well can result from plugging by solids present in injection water, the entrainment and re-deposition of in-situ fines, and the precipitation and deposition of scale in the flow

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constrictions of porous media. The degree of filtration used to treat injection water, including seawater, with very low particle concentrations varies within the industry1-2 .

The various aspects of designing, implementing and monitoring of a successful water injection scheme are depicted in Table no.1. After identification of the available alternative sources of injection water, it is emphasized to carry out conventional compatibility test as well as the capillary pressure test on core plug samples from the formation where the water is to be injected. The capillary pressure studies would help in detecting the suitable source of water (with or without treatments seen in the available literature3-5. Further, estimation of successful water injection using Transient well test analysis and production logging tools6-7 has also been stressed upon in this paper.

Table-1: Water Injection Scheme

Designing	Implementation	Monitoring
1. Identification of Source	Water treating equipment / plant	1. Using transient well test data
2. Water Quality considerations		2. Using Log data
3. On-site experiments		3. Using Production data
4. Laboratory tests • Compatibility tests • Capillary Pressure tests		

Use of Capillary Pressure data for rapid comparison of Alternate injection waters or Fluids

It has long been recognised that formation damage in reservoir sands arises from exposure of the formation to foreign fluids which are often times incompatible with the reservoir minerals. It is a routine practice to determine the formation damage / stimulation potential of fluids prior to fluid application by utilizing dynamic core-flow (return permeability) tests. These tests can at times be prohibitively expensive and time consuming especially if several fluid samples and different reservoir lithologies are involved. There is a need to find a quicker method for matching formation rock and reservoir fluid characteristics to the properties of the treatment fluids in order to minimize reservoir damage. Geological techniques (SEM, XRD and thin section analysis) are handicapped by their inability to reveal the ease of fluid recovery after well completion especially in tight gas reservoirs, and to quantify the return permeability behavior.

Rose and Bruse3 have established that the character of the interstitial pore spaces as revealed by the capillary pressure function is intimately related to the physico-chemical properties of the saturating fluid. Oren and Eliot[4] have documented the influence of damage on capillary pressure.

Case study

Amaefule and Masuo[5] have determined the capillary behavior of cores exposed to various treatment fluids. They generated the oil-water capillary pressure data in the laboratory on Berea sandstone and field core samples with prior exposures to completion, drilling, and injection fluids, and acids by use of the ultracentrifuge in the presence of the few injection fluids. When compared to the formation water curve, the injection water appears to be compatible as indicated by their almost identical curves. The injection water plus 0.25% sodium dodecyl benzene sulfonate (NaDDBS), showed a much lower capillary pressure at each saturation level than the formation water as would be expected based on its lower interfacial tension. However, their end point residual saturations were quite identical (Fig.1).

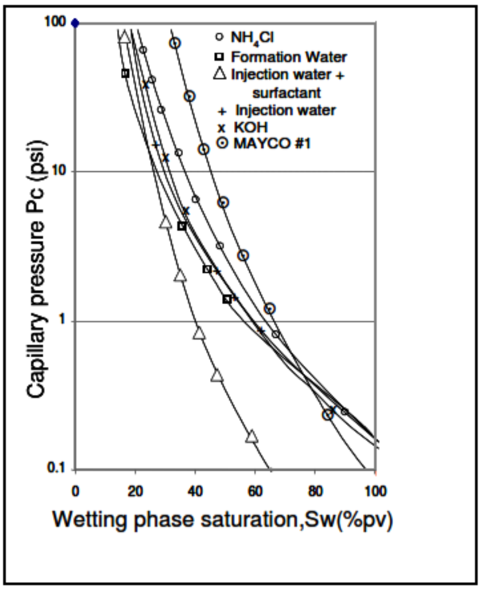

Fig. 1.

They have also correlated the air-water capillary data generated for few fluid-rock combinations with the fluid saturations and found that the fresh water saturated sample had substantially higher capillary pressure at each saturation level than the clay stabilized samples. Not only was the pore entry pressure higher in the presence of fresh water, the residual wetting phase saturation was also higher (Fig.2).

The relative magnitude of capillary pressures in the proximity of the wellbore as compared to the available reservoir pressure is particularly important in the determination of injection pressures for acid stimulation, fracture treatment and water injection operations. Capillary pressure can be quite significant especially in low permeability, low pressure reservoirs and could constitute additional barriers to flow. Neglect of capillary pressures could result in premature fractures of injection wells and bypass of reservoir regions with significant oil and gas reserves.

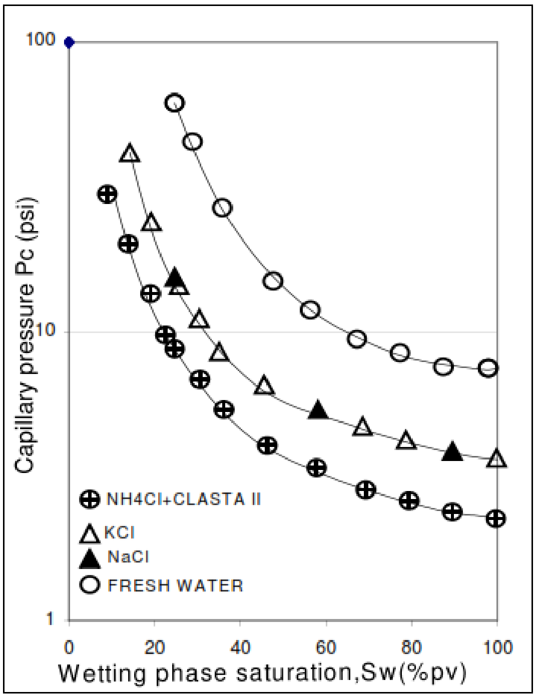

Fig. 2.

Strength of Water drive or Fluid injection from Transient Well Test data

Several important questions are of concern to a practical reservoir engineer. Is there a way to estimate the strength of water drive early in the life of a reservoir ? How effective is a given fluid injection program for pressure maintenance? What kind of well draw-down and build-up pressure behavior would be obtained under these conditions ? It has been demonstrated by several investigators that well test behavior under a constant pressure condition (full injection case) at the reservoir boundary is quite distinct from that under usual depletion or closed reservoir boundary systems. Hazebroek et al.6 studied pressure fall off in water injection wells located in isolated five spot patterns.

Case Study

Anil Kumar[7] has presented a unified general scheme for characterizing well pressure behavior in closed, water drive and partial, full, or excess fluid injection reservoir systems and the inter relationships that exist among them. Superposition in well rates was used to generate the pressure draw-down and build-up behavior at the central well in a finite square reservoir. He introduced a parameter f to characterize the strength of water drive or fluid injection. This parameter is determined directly from a graph of the (p*-pi) function, shown in Fig.3, where p* is the pressure obtained at infinite shut-in-time, or time ratio of unity, by extrapolation of the build-up straight line on a Horner graph, pi is the initial reservoir pressure, psi and tDA is the dimensionless time. It can also be estimated from build-up pressure behavior using the Horner graph as well as from draw down pressure data.

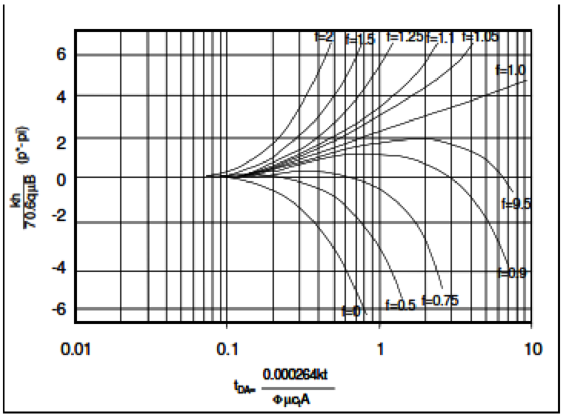

Fig. 3.

The reservoir conditions represented by various values of f are;

f=0	Closed reservoir
0< f <=0.5	Partial water drive or enlarged drainage area
0.5< f <1	Partial fluid injection
f=1	Full injection or constant pressure drainage boundary case
f>1	Excess fluid injection

It is evident from Fig.3 that (p*-pi) is always negative for f <= 0.5, indicating that p* is always less than pi for such values of f. For f>=1, (p*-pi) is always positive. Therefore, producing times greater than 0.1 are necessary to calculate f. In field applications, the dimensionless producing time of 0.25 is recommended for a reliable determination of f.

Use of Log-inject-log procedures to evaluate water flood residual oil saturations

A logging procedure that involves the use of two or more logging surveys run with the same tool before and after an induced change in formation conditions can provide measures of reservoir saturations that are more reliable than can be computed from the response of single log. Log-inject-log or time-lapse logging procedures have been developed to measure oil, gas, and water saturations at any time during the producing history of a reservoir.

The log-inject-log procedure used to measure the residual oil saturations in the field examples that had been flooded by water injection involved logging the well with a pulsed neutron log after injecting fresh water and again after injecting salt water.

Case Study

Murphy et al.[8], considered 12 field examples to find the evidence of relatively significant amounts of oil remaining in water flooded reservoirs. In 8 of these field examples, the wells did not produce oil when tested before water injection. Therefore, it was assumed that the injected waters did not displaced oil but only displaced the formation water or the flood water that has been used in the field flood. In another 4 wells from which oil was produced, the in-place or oil saturation in the formation before water injection was determined by a modified procedure. In one such field example, when the well was placed on production, only water was produced, thus indicating that all the permeable intervals of the formation in the vicinity of the test well had been flooded essentially to a residual oil saturation. The results of log-inject-log and core analysis in this well are shown in Fig.4.

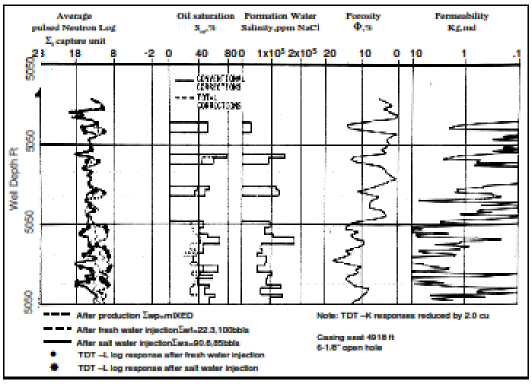

Fig. 4.

It is seen that the log derived saturation profiles do not consistently correlate with either core permeabilities or porosities, that is, contrary to expectations, high residual oil saturations were measured in some higher permeability and porosity intervals. The results of this well indicate that additional diffusion correlations under a variety of conditions are needed to improve the accuracy of the calculated oil saturations.

Thus, the success of the log-inject-log procedure depends largely on the proper preparation of a well for logging and on the ability to inject into and displaced fluids in the matrix of the zones of interest. The accuracy of the residual oil saturations computed from the logs in the field examples is considered to be in +/- 5% saturation, provided that the neutron diffusion corrections used are correct.

Using Production Data

Effective management of reservoir is vital for success of any water injection scheme and that too for a complex multi layered reservoir. By virtue of production logging carried out in different wells, it is now possible to solve several production problems and to understand the layer wise production and injection performance to a greater extent.

The ultimate success of water injection can be monitored through production data. The quantitative success of water injection can be estimated by voidage calculations using production and injection data from the field. It is calculated as,

$$\text{Voidage} = Qo\ [(\ Bo + (Rp - Rs)Bg\ ] + Wp$$

Where, Qo = Oil production rate, Bo = Oil formation volume factor, Bg = Gas formation volume factor, Rp = Produced gas oil ratio, Rs = Solution gas oil ratio and Wp= Water produced. Voidage > Qinj, indicates that partial water injection is going on in the field. Here, Qinj is the water injection rate.

Case Study

Water injection performance in an oil field is depicted in Fig.5. It is seen that there is no voidage created after March'11 due to sufficient quantity of water injection in the field. Since Voidage < Qinj., voidage replacement ratio (VRR) exceeds 100%.

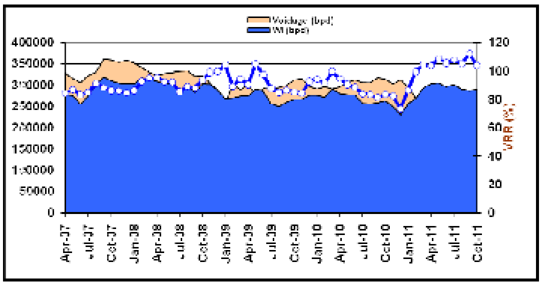

Fig. 5.

Conclusion

Different techniques using Core, log and Well Test data for Enhanced Reservoir Description to understand the dynamics for a Successful Water Injection Performance have been discussed.

Use of capillary pressure test for selection of suitable injection water is relatively less time consuming but cost effective method in comparison to conventional return permeability tests performed on native core samples.

Pressure transient well test data can help in providing some idea of strength of fluid injection for pressure maintenance. Another monitoring tool to evaluate performance of successful water injection is Log-inject-log or time-lapse logging procedure.

These techniques are simple and can be used for designing and monitoring of a water injection scheme in the field for production enhancement.

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