UTILIZING SPECIAL AND CONVENTIONAL CORE ANALYSES IN RESERVOIR DEVELOPMENT AND CHARACTERIZATION OF HIGH CONTRAST CLASTIC SANDSTONE (UNAYZAH RESERVOIR, SAUDI ARABIA)

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ABSTRACT

The heterogeneity of petroleum reservoirs and the consequent variation in petrophysical properties remains a major problem for the oil-industry. Reliable and accurate petrophysical parameters have high impact on investment, development and reservoir management decisions. Thus, both special and conventional core analyses represent main sources for determination of crucial petrophysical parameters required for proper production strategies. In this study, a comprehensive program consisting of special and conventional core analyses was conducted to fully characterize Unayzah reservoir (Central Area Fields, Saudi Arabia). The results of conventional core analysis show high contrast and variation in basic core properties (K and ϕ). Large differences in relationships between porosity and permeability support the complexity of Unayzah reservoir. Porosity and permeability variations from well to well within the same area and within the same formation are significant in a single well. Relative permeability results of several wells using composite cores at reservoir conditions indicated that oil recoveries ranged from 38 to 85 % of original oil in place while residual oil saturations range from 16 to 27 % of the pore space. The results of modified Amott wettability tests and USBM wettability indices revealed intermediate to water-wet character of Unayzah reservoir. Mercury injection tests showed that Unayzah reservoir can be classified into trimodal pore systems with different capillary character and median pore radii varying from 0.1 to 4 microns.

INTRODUCTION AND BACKGROUND

Saudi Aramco has an interest in several central area fields that produce from the Upper Carboniferous and Lower Permian Unayzah reservoir. The producing fields are Hawtah, Ghinah, Umm Jurf, and Hazmiyah. The Unayzah formation is a complex succession of continental clastics consisting of braid-plain, fluvial-eolian sands, and flood plain silts (Evan D. S., et al., 1997). Due to the economic importance and complex stratigraphic & sedimentologic nature of this succession, it has become essential for reservoir modeling and future exploration to accurately define the petrophysical properties and core analysis data. The need for accurate reservoir characterization is important, not only because of the geologic complexity but also because of the field development methods. Reservoir characteristics have a direct effect on fluid flow behavior. Proper remedial strategy for a specific reservoir depends on understanding the factors controlling the fluids. Good core coverage, full use, and analysis of core data are required to characterize the lithofacies changes in the Unayzah reservoir.

EXPERIMENTAL APPROACH

Core Preservation, Sample Selection, and Test Fluids

In our tests, core material from the Unayzah reservoir was cut with a KCl brine and packed under de-aerated KCl brine in plastic tubes. Basic core analyses, geological examination, brine permeability at residual oil saturation, and CT scans were performed to assist in sample selection. Cores that were fractured, broken, or displayed brine permeability less than 1 millidarcy (mD) were excluded from further testing (Siddiqui S., et al., 2006). Wellhead oil from Unayzah reservoir which displayed low GOR was used as the oleic phase, while the aqueous phase was synthetic Hawtah-Unayzah aquifer water.

Relative Permeability Test

The procedure of relative permeability measurements included the use of composite core (Huppler, J. D., 1969) assembled from core material. The unsteady-state relative permeability tests were conducted at simulated reservoir conditions using Unayzah oil and synthetic Hawtah-Unayzah aquifer water with the automated flood system.

Wettability Test

Wettabilities of preserved core plugs were measured by modified Amott method (Amott E. 1959). The Amott method combines imbibition and dynamic displacement that performed under ambient condition with simulated formation brine and stock tank oil. United States Bureau of Mines (USBM) method was used to measure wettability. USBM wettability index is obtained from hysteresis loop analysis of centrifuge capillary pressure curves (Donaldson et. al., 1969).

Mercury Injection Capillary Pressure Test

Mercury injection capillary pressure and pore size distribution were measured using a Ruska mercury injection system. The samples were placed in sample chambers and subjected to incrementally increasing pressure of mercury and corresponding volumes injected were recorded.

RESULTS AND DISCUSSION

Core Analysis

A good understanding of porosity (ϕ) and permeability (k) distributions, both within wells and areally, is critical in planning and implementing waterflood in oil reservoirs. Distribution of permeability with depth for two selected wells (A and B) is shown in Figures 1. Wide variations with depth and also from well to well are clearly observed. For example, at depth interval of D-1 to D-2, the permeability values varied between 123 mD and 9,800 mD in well-A (Figure 1); while they ranged from 0.3 to 455 mD in well-B.

Porosity distribution with depth is shown in Figure 2 for both well-A and well-B. Similar trends of variation of porosity values are also indicated in both wells.

Porosity and permeability data are keys to assessment of reserves, potential production, and ultimate recovery. The combination of ϕ and k data in terms of reservoir quality index (RQI) provides a convenient starting point to address the differences between samples and between reservoir zones. The concepts rely on determining two functions RQI and NPI, (Amaefule and Altunbay, 1993), defined as follows:

$$RQI=0.0314\sqrt{\frac{K}{\phi}} \quad \ldots\ldots(1)$$

Where; RQI = reservoir quality index (μm), K = permeability to (md), ϕ = porosity (%).

Normalized porosity index, NPI, is defined as:

$$NPI=\frac{\phi}{1-\phi} \quad \ldots\ldots(2)$$

RQI and NPI functions are used to quantify the flow character of a reservoir and provide an association between petrophysical properties at micro and macro levels of tested samples. Using RQI and NPI, a "Flow Zone Indicator" (FZI) is defined as:

$$FZI=\frac{RQI}{NPI} \quad \ldots\ldots(3)$$

It was found that point calculations of RQI and FZI did not reveal any depth dependence of the rock family. Hence, a modified technique was developed by plotting RQI values on a normalized cumulative sum basis versus depth to differentiate between flow zones. For each individual point the RQI is calculated and the normalized-cumulative sum is plotted versus depth. The technique is based on observing changes in slope on a plot of the normalized-cumulative sum versus depth. The changes in slopes on a plot of the normalized-cumulative sum of the reservoir quality index as a function of depth were observed for core material of Unayzah reservoir as shown in Figure 3 for the two selected wells (well A&B). The Y-axis is depth while the X-axis is defined by:

$$X_i=\frac{\sum_{x=1}^{i}\sqrt{\frac{Ki}{\phi i}}}{\sum_{x=1}^{n}\sqrt{\frac{Ki}{\phi i}}} \quad \ldots\ldots(4)$$

Where; n = total number of data, i = number of data points

Consistent RQI zones are characterized by straight lines with slope of the line indicating the overall reservoir quality within a particular depth interval: The lower the slope, the better the reservoir quality.

Relative Permeability Results

Reservoir condition unsteady-state water-oil relative permeability tests conducted on composite core material indicated considerable oil recoveries with substantial oil recovery beyond breakthrough (Balobaid, Y. S., et al., 2001). Relative permeability results of several wells indicated that oil recoveries ranged from 38 to 85 % of original oil in place while residual oil saturations range from 16 to 27 % of the pore space.

The relative permeability results suggested intermediate to water-wetting core material based on Craig's rule of thumb (Craig, F. F., 1971): (**a**) initial water saturations (S_{wi}) were higher than 20 % of PV, (**b**) crossover points at which $K_{rw}= K_{ro}$ were greater than 50 %, and (**c**) relative permeability to water at residual oil saturation (K_{rw} at S_{or}) ranged from 52 to 63 percent. These are clearly demonstrated in Figure 4, which shows a typical relative permeability curves for Unayzah reservoir.

Wettablity Results

The results of wettability tests showed full range of wettability indices that ranged from -0.09 to 0.35. The distribution of wettability index with depth is shown in Figure 5. The scale of the plot is from –1 (strongly oil wet) to +1 (strongly water wet). The plot in Figure 5 showed that Unayzah core material varied in wettability character from neutral to slightly and strongly water-wet in character with a tendency for increasing water-wet characteristics with depth.

Mercury Capillary Pressure and Pore Size Distribution

Mercury injection capillary pressure results show that Unayzah sandstone materials display trimodal pore systems as indicated in Figure 6. Such distributions reflect complex nature of Unayzah sandstone reservoir. Figure 7 presents a plot of cumulative wetting phase saturation vs. the pore entry radius of plugs from Unayzah reservoir. It indicated that the median pore radius ranged from 0.1 to 4 microns.

CONCLUSIONS

1. High contrast and large differences in basic core properties $(K \text{ and } \phi)$ support the complexity of Unayzah reservoir.
2. An efficient grouping of special core analyses samples with similar petrophysical properties was obtained using a modified RQI technique.
3. Modified Amott wettability results and USBM wettability indices revealed intermediate to water-wet character of Unayzah reservoir with a tendency for increasing water-wet characteristics with depth.
4. Wettability characteristics of Unayzah sandstone rock material described by K_{rw}/K_{ro} results in agreements with USBM and Amott results.
5. Mercury injection tests showed that Unayzah reservoir can be classified to trimodal pore systems with median pore radius vary from 0.1 to 4 microns.
6. The SCAL results were used extensively in building simulation model for field development and recovery study. Relative permeability and capillary pressure relationship have been developed for the Unayzah reservoir.

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REFERENCES

Amaefule, J. O., and Altunbay, M.,: “Enhanced Reservoir Description: Using Core and Log Data to Identify Hydraulic (Flow) Units and Predict Permeability in Unrecovered Intervals/Wells” SPE 26456, presented at 68th Annual SPE Conference and Exhibition, Houston, October 3-6, 1993.

Amott, E. (1959): “Observation Relating to the Wettability of Porous Rock”, Pet. Trans. AIME, V. 216, 156-162.

Balobaid, Y. S., and Al-Rashidi, H. N.,:“Relative Permeability Study for Unayzah Reservoir, UMJF-43” Internal Report, L-3197, 1997, Saudi Aramco.

Craig, F. F., :"The Reservoir Engineering Aspects of Waterflooding" SPE Monograph 3, Richardson, TX., 1971.

Donaldson, E., Thomas, R., and Lorenz, P. (1969): “Wettability Determination and Its Effect on Recovery Efficiency”, SPEJ, 113-20.

Evans, D. S., Bahabri, B. H., and Al-Otaibi, A. M., (1997): “Stratigraphic Trap in the Permian Unayzah Formation, Saudi Arabia”, GeoArabia, Vol. 2, No.3, 1997.

Huppler, J. D.,“Waterflood Relative Permeabilities in Composite Cores” JPT (May 1969), 539-40.

Siddiqui, S., Okasha, T. Funk, J., and Al-Harbi, A. “Improvements in the Selection Criteria for Representative Special-Core-Analysis Samples”, December 2006 SPE Journal of Reservoir Evaluation & Engineering.

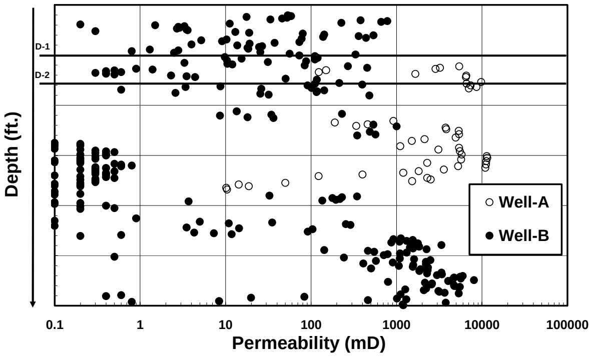

Figure 1: Permeability Distribution Vs. Depth for Wells A & B.

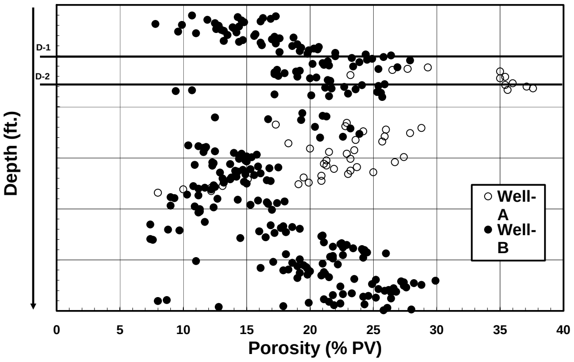

Figure 2: Porosity Distribution Vs. Depth for Wells A & B.

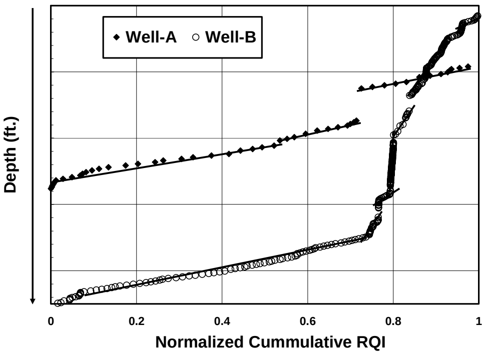

Figure 3: Normalized Cumulative Reservoir Quality Index (RQI) Vs. Depth for Wells A & B.

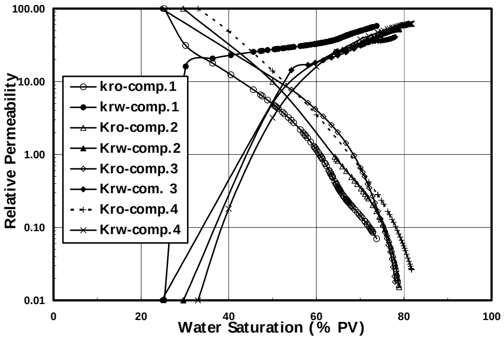

Figure 4: Typical Relative Permeability curves for Unayzah Reservoir.

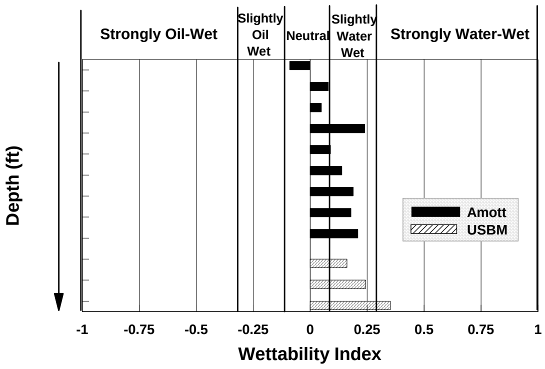

Figure 5: Amott and USBM Wettability Indices Distribution for Unayzah Reservoir.

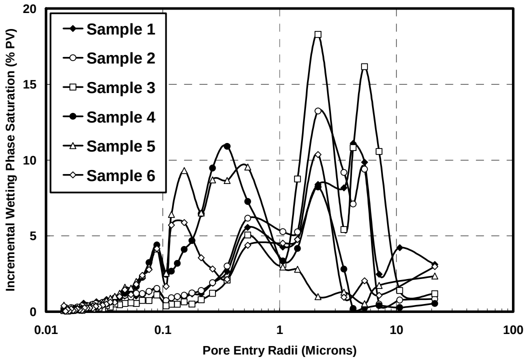

Figure 6: Incremental wetting phase saturation vs. pore entry radius.

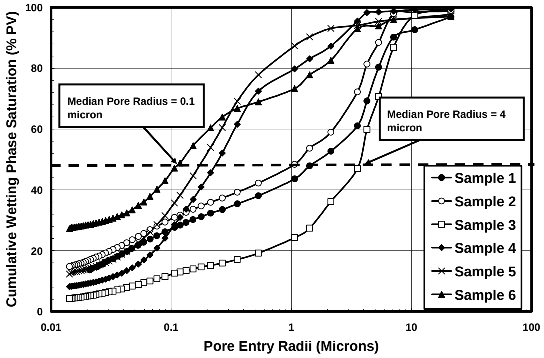

Figure 7: Cumulative Wetting Phase Saturation vs. pore entry radius for Unayzah Reservoir.