The Relation of Geology to Fluid Injection in Permian Carbonate Reservoirs in West Texas

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Fluid injection has come of age in West Texas. Millions of barrels of additional reserves have been generated in recent years through the creation of energy by fluid injection into Permian carbonate reservoirs. Sufficient performance history is now available so that certain general conclusions may be drawn and guidelines set for future project installation.

In the author's opinion, the fundamental precept necessary for evaluating these reservoirs for fluid injection is a working knowledge of their geology, together with an understanding of the regional geology in general. "You have to know the reservoir to do reservoir engineering." Norman Newell's book on the surface expression of the Permian in the Guadalupe Mountains, "The Permian Reef Complex,"[1] should be a must for any reservoir engineer involved in West Texas. It is easy to become spellbound with the strict mathematical approach to waterflooding. Some think that equations are the only real engineering answer. In reality, without knowledge of the rock and the quality of data available to describe it, equations are not worth the time it takes to solve them. Stiles, Muskat, et al, did not solve all of the problems associated with reservoir engineering.

TYPES OF PERMIAN CARBONATE RESERVOIRS

Most of the reservoirs of Permian age in West Texas were formed by a combination of structural and stratigraphic effects. In other words, the structural position of the area in question at the time of deposition in relation to the relatively stable Central Basin Platform and the sinking Midland or Delaware Basin governed the lithology. Superimposed on the primary lithology is a system of secondary porosity development and, generally, vertical fractures. It is possible, however, to geologically classify these reservoirs as to the dominant trapping mechanism as follows:

(1) Principally structural

(2) Combination structural and stratigraphic (stratigraphic traps on residual highs)

(3) Principally stratigraphic traps (lime bank or reef deposits on the hinge line between the Central Basin Platform and the sinking basins)

EXAMPLES OF FLUID INJECTION IN EACH TYPE

The chief characteristic of the principally structural trap is a limited aquifer of small areal extent which underlays all or most of the reservoir. The rock properties of the aquifer are comparable to those in the main oil column. In view of their small areal extent in relation to the high oil withdrawals, these aquifers furnished little reservoir energy. Two examples are the Goldsmith (San Andres) and Waddell Fields. These reservoirs are amenable to pressure maintenance by peripheral water injection below the oil-water contact. The Waddell Field is an excellent case in point. Injection began here in early 1959. To date, the producing gas-oil ratio has been reduced from approximately 1100 to 420 and the reservoir pressure increased from 840 to 1227. Water production has increased from 10 per cent at the start of injection in 1959 to some 30 per cent at the present time. Good lateral injected water movement out into the aquifer is indicated.

The stratigraphic trap formed on a residual high is mainly found in rocks of Lower Permian (Clearfork) age. Examples are the Goldsmith 5600' and Sand Hills (Tubb) Fields. The better reservoir rock is found on the crest of the old high, with flank limits caused by decreases in porosity and permeability. The water that is present is found in lower quality rocks on the flanks at the base. Large volumes are rarely encountered. An outstanding characteristic of these reservoirs is pay development in thin zones within the gross productive interval which do not appear continuous over wide areas. Black shale streaks are common. It is often possible to divide these reservoirs into several entities by correlative dense markers. In reality, these markers are generally "denser", not dense, so that communication is possible except in limited areas. Most of the gross pay interval appears connected by vertical fractures.

In water injection into this type of reservoir, the basic problem is putting the water into the zone that produced the oil. Pattern waterflooding seems to be the best approach. It appears that the five-and nine-spot patterns offer identical results. Peripheral flooding was tried in the Goldsmith 5600' Project, but results were discouraging because of loss of injected water outside the project area.

Injection water breakthrough is generally rapid in these reservoirs but is followed by oil rate increases. The net result is the production of large volumes of oil at water-oil ratios of 1-2. The Goldsmith 5600' Project has produced at a WOR of approximately 2 for the last three years.

The principally stratigraphic type of trap is chiefly found in rocks of Upper Permian (Grayburg) age and is exemplified by the McElroy, Dune, Foster, and North Cowden Fields. The boundary on the platform side is purely stratigraphic. The base of the reservoir is formed by dense rock. There is no active water. The rock characteristics improve basinward with the best porosity and permeability development generally found just before the beds plunge into the basin. There is some basinward thickening of the productive interval as would be expected. The oil column is limited on the basin side by edge water and/or facies change. The outstanding characteristic of these reservoirs is that the gross section is all productive; there is probably no such thing as "net pay."

The McElroy Field Project affords a look into water injection in these principally stratigraphic traps. Waterflood performance has been outstanding in the platform side of the project where the pay is uniformly tight. However, there have been a few cases of channeling in an east-west direction. This has been isolated to a thin sandy zone at the top of the pay. A five-spot pattern and high injection pressure have been utilized to insure adequate injectivity. Injection into the better part of the field (the aforementioned area just adjacent to the start of the basinward plunge) was initially begun on wide spacing (four injection wells per 160 acres). Problems have been twofold:

(1) Rocks overlying the main pay become productive in this area and contain highly permeable zones which are correlative. Injection into converted oil wells which are open hole in this zone has not been successful.

(2) There are "perched" water zones in the middle of the oil column located on the basinward side of the subject area. Successful water injection will require isolation of these zones at the injection wells.

GUIDELINES FOR FLUID INJECTION PROJECT INSTALLATION

In summation, the following guidelines should be helpful for those who will be planning fluid injection projects in Permian carbonate rocks.

(1) Characterize the reservoir geologically as well as possible as to type of trap, lithology of reservoir rock and areal and vertical variations, vertical distribution of oil saturation, nature of the base of the reservoir. Are there any highly permeable zones that correlate from well to well? What about "perched" water? Do not overlook old sample logs and cable tool well records. These often give a better insight to the nature of the reservoir than "modern" tools.

(2) Estimate which portion of the pay contains the bulk of the recoverable oil and concentrate on it. Be especially mindful of the effects of gypsum on cores analyzed at high temperature and on neutron logs.

(3) In line with the above, bear in mind also that the developers of these fields had a good idea where the best pay was. Be careful about extensive deepening or additional perforating programs before large scale fluid injection starts.

(4) Select an injection pattern and start

with a pilot, or better still, a pilot in each area of different rock characteristics. The injectivity information alone will be invaluable.

(5) Remember, also, that in pattern flooding it is better to start out with wide spacing that is amenable to tightening rather than a tight pattern initially. Directional permeability may well be present.

PERFORMANCE PREDICTIONS

Geologic considerations are also important in recovery calculations, particularly with regard to the presence or absence of true permeability stratification (highly permeable zones which are correlative from well to well). The author has found no permeability stratification calculation procedure that is sufficient to predict water injection performance, especially the water-oil ratio, in these reservoirs. The state of the art of reservoir engineering is just not that good. It is possible, of course, to duplicate the performance of any flood by these "layer cake" techniques if the number of layers is selected judiciously and a good guess at areal sweep efficiency and relative permeability is available. It is possible to condemn waterflooding in large projects in West Texas by use of the commonly accepted "layer cake" predictive techniques.

There are two approaches available for the estimation of fluid injection recovery which the author has found useful. The first approach is by analogy after a study of the geology. Carefully evaluated pilot performance is also helpful.

The second approach, with a good analogy or a pilot, or for property purchase consideration, would involve the following:

(1) Characterize the reservoir geologically as well as possible.

(2) Predict the ultimate recovery by the method suggested by F. H. Calloway in his paper "Evaluation of Waterflood Prospects"[2]. This excellent paper considers the effect on waterflood recovery of five primary variables: Primary recovery efficiency, connate water, sweep efficiency, residual oil saturation, and crude shrinkage. Next decide which of these variables could reasonably be considered fixed and vary the others accordingly. Treatment in this manner results in a maximum-minimum anticipated recovery.

(3) Relate the maximum, average, and minimum anticipated recoveries to time by assuming fluid out/fluid in ratios and water-oil production relationships taken from injection projects in similar reservoirs. The effect of various injection rates can be incorporated in this step if desired.

(4) Risk as measured from a desired rate of return or payout time, etc., can then be determined from the cash flow schedules generated by this approach.

SUMMARY AND CONCLUSIONS

1. A detailed knowledge of reservoir geology is necessary for proper fluid injection project installation, particularly in the Permian carbonate reservoirs of West Texas.
2. Permian carbonate reservoirs can be characterized by the dominant trapping mechanism into three types. Different performance histories may be anticipated for each type.
3. Sufficient performance history of each type is available so that guidelines for future project installations may be drawn and reasonable predictive procedures developed.

REFERENCES

1. Newell, N. D., et al, **The Permian Reef Complex of the Guadalupe Mountains Region, Texas and New Mexico,** W. H. Freeman and Co., San Francisco, 1953.
2. Calloway, F. H.: "Evaluation of Waterflood Prospects", AIME Paper No. 1258-G, Permian Basin Oil Recovery Conference, 1959.