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**Integrated Approach Towards
The Application Of Horizontal Wells
To Improve Waterflooding Performance**

(Contract No. DE-FC22-93BC14951)

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OBJECTIVES

The overall purpose of the proposed project is to improve secondary recovery performance of a marginal oil field through the use of an appropriate reservoir management plan. The selection of plan will be based on the detailed reservoir description using an integrated approach. We expect that 2 to 5% of the original oil in place will be recovered using this method. This should extend the life of the reservoir by at least 10 years.

The project is divided into two stages. In Stage I of the project, we selected part of the Glenn Pool field - Self Unit. We conducted cross bore hole tomography surveys and formation micro scanner logs through a newly drilled well. By combining the state-of-the-art data with conventional core and log data, we developed a detailed reservoir description based on an integrated approach. After conducting extensive reservoir simulation studies, we evaluated alternate reservoir management strategies to improve the reservoir performance including drilling of a horizontal injection well. We observed that selective completion of many wells followed by an increase in the injection rate was the most feasible option to improve the performance of the Self Unit. This management plan is currently being implemented and the performance is being monitored.

Stage II of the project will involve selection of part of the same reservoir (Berryhill Unit - Tract 7), development of reservoir description using only conventional data, simulation of flow performance using developed reservoir description, selection of an appropriate reservoir management plan, and implementation of the plan followed by monitoring of reservoir performance.

By comparing the results of two budget periods, we will be able to evaluate the utility of collecting additional data using state-of-the-art technology. In addition, we will also be able to evaluate the application of optimum reservoir management plan in improving secondary recovery performance of marginal oil fields.

Successful completion of this project will provide new means of extending the life of marginal oil fields using easily available technology. It will also present a methodology to integrate various qualities and quantities of measured data to develop a detailed reservoir description.

SUMMARY OF TECHNICAL PROGRESS

During the last three months, we have continued to monitor the reservoir management plan in the Self Unit. Over the last three months, the production from the unit has remained steady up to 50 bbls/day (over 200% increase in the production). For Stage II of the project, we have expanded the scope of the project. Instead of concentrating only on Tract 7, we are evaluating all the areas currently operated by Uplands Resources. This way, we will be able to evaluate the best location for either multilateral or a horizontal well. The geological mapping is complete, and we have established an indexing procedure to determine the area of the highest potential. The geostatistical description and the flow simulation should begin soon. Although not part of this project, we are conducting a 3-D seismic survey on the Glenn Pool Field. This should help us in better evaluating the channel sand structure.

STAGE I PROJECT MONITORING

Last summer, we started implementing the reservoir management plan in the Self Unit. Last quarter, after evaluating each individual well, we decided to install electrical submersible pumps to produce three wells. The other three wells required the use of rod pumps. The production from the field improved significantly once the pumps are installed. Over the last three months, an average daily production has been approximately 50 bbls/day. Compared to a base line production of 13 bbls/day before the implementation, this is more than 200% increase in the production. Based on our current evaluation of the flow simulation results, we expect that the production from the unit should reach between 100 to 120 bbls/day once the implementation is complete.

Part of the reservoir management plan is to increase the water injection rate. We have installed the injection pump and have completed the piping to bring the water from the Arkansas river.

GEOLOGICAL DESCRIPTION

(By Dennis R. Kerr and Liangmiao Ye)

In the third quarter of 1996, geology activities of the Glenn Pool project focused on workshop preparation, facies map modification for Tract 7 area, completion of field scale cross sections, facies architecture evaluation for Tract 9, Tract 16, and Chevron Polymer Flooding acreage.

Facies Map Modification For Tract 7 Area

As we suggested earlier in this year, six additional cased-hole Gamma Ray logs were acquired. Five of them are in Tract 7 unit (well number: 7-97, 7-99, 7-100, 7-103, and 7-107), and the other one (11-82) is in Tract 11 unit. As a result of these additional well logs, the net sand isopach and facies maps developed earlier were checked and modified as necessary. Generally speaking, only very minor changes were needed. Also, interpretation of these additional logs indicates that the actual reservoir sandstone volume is a little bit higher than what was shown in original maps. For DGI E, F, and G, facies boundaries in original maps do not need to be modified, only net sand contours need minor modification. For DGI A, B, C, and D, both facies boundaries and net sand contours need minor modification. However, the general picture of these facies distributions holds unchanged.

Figures 1 and 2 compare the facies maps of original version and modified version for DGI C. As can be seen, only small variations exist in the original and the modified maps.

Completion Of Field-Scale Cross Sections

Perforation and initial production information were added to the six-field scale cross sections constructed earlier this year. The cross sections include a interval from Pink Lime marker to Brown Lime marker. A copy of these completed cross sections were made and submitted to Uplands Resources, Inc.

Facies Architecture Reconstruction For Other Units

Facies architecture reconstruction is being undertaken for Tract 16, Tract 9, and Chevron Polymer Flooding acreage. The purpose of this work is to generate a uniform picture, in terms of facies distribution, for the entire area that has potential for drilling a horizontal well. With completion of this task, the area mapped for detailed facies architecture over the course of the project will be about 1500 acres.

ENGINEERING EVALUATION

(By Sanjay Paranjhi and Mohan Kelkar)

This section presents the work done during the last three months of the project. Based on the old as well as newly collected logs, we have concluded that the gas cap does not exist in the Tract 7 or the surrounding areas. Further, based on the evaluation of the adjacent area operated by Chevron, we believe that significant potential exists for additional oil recovery in the upper DGI's. We have developed a simple procedure to grade the areas of high and low potential based on the available data.

Perforation Maps

The DGI interpretation for tract 7 and adjacent areas was used to observe how the field was completed over it's life. The DGI interpretation gives the depth of each DGI (A through G) at each well location where the log data are available.

To estimate DGI depths at other locations where no logs are available a kriging procedure was used. This was done by dividing the area of interest into 10x10 feet gridblocks. The area of interest is approximately 5280x5280 feet. The depth of each DGI was then estimated for each of those 10x10 feet gridblocks. By knowing the nearest gridblock location the DGI depths at all the wells were estimated. Since the depths of the individual DGI's do not vary widely, kriging procedure was deemed adequate for such estimation purposes.

Perforation maps are then generated for each DGI displaying only those wells that have been completed in that DGI with an estimate of the interval that has been completed out of the thickness of the DGI under consideration. The density of completed wells decreases dramatically as we move from lower DGI's to upper DGI's. The apparent reason for this completion strategy is the fear that upper DGI's are occupied by a gas cap. The existing density neutron logs do not show any evidence of gas cap. Further additional cased hole pulse neutron logs at three wells confirm the non-existence of gas cap.

Perforation Maps For The Chevron Acreage

To further confirm the non-existence of the gas cap, we studied the Chevron acreage adjacent to the area under investigation. Chevron conducted a successful Micellar/Polymer flood project in early 1980's in the William Berryhill unit which is located northwest of the study area. To investigate the completion practices in that unit we plotted the perforated intervals before and after 1980. It should be noted that data used for this comparison is not complete and the records on most of the wells completed before 1942 are unavailable. However by comparing the data with other parts of the Berryhill unit it is reasonable to assume that prior to 1942 the wells are completed in the lower DGI's, namely in F and G.

During the implementation of Micellar flood Chevron did not complete any additional wells in DGI G. Instead, it concentrated on the upper DGI's. Several more wells were completed in the upper intervals. It is not known whether the success of Chevron's

project was due to better chemical flooding or due to improved infill drilling practices. However it is clear that some of the additional oil recovery must have come from the additional completions. After completing the wells in the upper DGI's, the production improvement was remarkable. Compared to Chevron's acreage, tract 7 and it's adjacent areas are on a structural high. As evidenced by the logs, if the gas cap is not present in those tracts, the potential for additional oil recovery is significant.

Screening Test For High Potential Areas

Once a preliminary determination is made with respect to the potential recovery, a procedure was developed as a screening test to identify the areas with high potential for oil recovery in terms of the petrophysical properties. The following sections detail the method devised.

Mapping Of Petrophysical Properties

Porosity. Logs were collected and digitized wherein the combination of logs for a particular well is sufficient to make a reasonable estimation of porosity and saturation. The number of such wells is extremely small. Typically a combination of Spontaneous potential, Gamma ray, Density and Neutron logs is used to compute porosity. The computation validity is then established by comparing it with the core porosity data for the lower intervals since the upper intervals are predominantly uncored. The porosity values at the well locations are averaged for each DGI. These average values are kriged to estimate porosity values at all other gridblocks for a particular DGI. The result is seven areal slices (DGI A-G); Each slice represents a particular DGI.

Permeability. Log permeability v/s porosity relationships are established for each DGI individually by combining all available core data. Permeabilities are evaluated based on the above relationships for all wells where porosity is computed. The permeability values at the well locations are averaged for each DGI. Precautions are taken to strip any unreasonable permeability value. These average values are kriged to estimate permeability values at all other gridblocks for a particular DGI.

Saturation. Typically a combination of porosity, induction or resistivity logs is used to compute saturation.

The saturation values at the well locations are averaged for each DGI. The computation validity is then established by:

- Comparing the log derived profile with the core profile.
- Comparing S_w averaged for each DGI with TDT saturations using compatible R_w and σ_w values.

The average values are kriged to estimate saturation values at all other gridblocks for a particular DGI.

Potential Index Estimation

The potential for a particular location is a cumulative effect of the production capacity, storage capacity and access to the existing wells. The potential should be directly related to the production, storage capacities and inversely proportional to the access by other wells.

Conductivity Index (CI). This index quantifies the production capacity and is related to the product of permeability and thickness ($K \times h$). Since K and h are defined at all gridblocks in all the seven DGI slices (A-G) the productivity can be estimated at each gridblock. Since F and G have been drained considerably further indexing is done only from DGI's A-E. The productivity data for the DGI's A-E are then combined to establish quartiles X_{25} , X_{50} and X_{75} . Ranks are then assigned from 1-4 by comparing data points at each gridblock with the quartiles. For instance if the productivity for a particular gridblock is less than X_{25} then it is assigned a rank 1, if it is between X_{25} and X_{50} then the gridblock is assigned a rank 2 and so on.

Storativity Index (SI). This index quantifies the storage capacity and is related to the product of porosity, oil saturation and thickness ($\phi \times S_o \times h$). Since porosity, saturation and thickness is defined at all gridblocks in all the five DGI slices (A-E), the Storativity can be estimated at each gridblock. The storativity data for the DGI's A-E are then combined to establish quartiles X_{25} , X_{50} and X_{75} . Ranks are then assigned from 1-4 by comparing data points at each gridblock with the quartiles as was done for the conductivity index.

Accessibility Index (AI). This index defines the access by drilled wells. It is assumed that a fully penetrated well in a particular DGI contacts 10 acres. If partially penetrated, the area is proportionately reduced. If a gridblock is contacted the accessibility index is assigned 0 and if gridblock is not contacted, the accessibility index is assigned 1.

Potential Index (PI). The Productivity and Storativity data are combined by summing up their individual ranks at all gridblocks. The maximum value of the sum is 8 denoting that the area has the highest potential both in terms of its productivity and storativity. Conversely the least value of the sum is 0 denoting low potential. Since the essence of the procedure is to identify areas of high potential it was decided to use a combined sum of 4 as the index of demarcation between high and low potential areas. Hence if the sum is greater than 4 the gridblock is categorized as 1 (high potential) and if sum is less than 4 the gridblock is categorized as 0 (low potential). The category value is then multiplied by accessibility index to calculate the final potential index as,

$$PI = (CI + SI) \times AI$$

Irrespective of a gridblock having a high or low potential if the area is being contacted by a well its accessibility is 0 which also reduces the PI value to a 0. By including the accessibility, we essentially mask all the regions that are being drained and treat them as being equivalent to areas having zero potential.

Cumulative index is estimated by adding the PI values at corresponding gridblocks for all DGI's A-E. For each areal location 5 indices are added corresponding to each DGI. By collapsing all the DGIs into one unit we can examine which areas have the highest potential both areally and vertically. Figure 3 shows a map of the cumulative potential index for DGI's A to E. The areas of high potential and low potential are delineated. These need to be validated with additional geostatistical and the simulation work.

TECHNOLOGICAL TRANSFER

As most important part of the technology transfer program, workshops regarding this DOE Glenn Pool project are being offered in Tulsa, Denver, and Houston. Workshop material will include a note book containing a brief summary of all the presentations as well as copies of the overheads. In addition, we also intend to provide the attendees with a copy of a software to generate reservoir description.

Also as part of technology transfer, two invited abstracts were submitted to professional meetings. "Reservoir Characterization And Improved Water-Flood Performance In Glenn Pool Field: DOE Class I Project" was invited for the 1997 AAPG Annual Meeting to be held in Dallas in April, 1997. "Application Of Borehole Imaging For Reconstruction Of Meandering Fluvial Architecture: Examples From The Bartlesville Sandstone, Oklahoma" was invited by the Fourth International Reservoir Characterization Technical Conference to be held in Houston in March, 1997.

Net Sand Isopach and Facies Map, DGI C

(Tract 7 & adjacent area, original version)

Figure 1

Net Sand Isopach and Facies Map, DGI C

(Tract 7 & adjacent area, modified version)

Figure 2

Figure 3 Cumulative Potential Index Map for DGI's A-E