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1.0 ABSTRACT

The West Hackberry Tertiary Project is a field test of the concept that air injection can be combined with the Double Displacement Process to produce a tertiary recovery process that is both low cost and economic at current oil prices. The Double Displacement Process is the gas displacement of a water invaded oil column for the purpose of recovering tertiary oil by gravity drainage. In reservoirs with pronounced bed dip such as those found in West Hackberry and other Gulf Coast salt dome fields, reservoir performance has shown that gravity drainage recoveries average 80% to 90% of the original oil in place while waterdrive recoveries average 50% to 60% of the original oil in place. The target for tertiary oil recovery in the Double Displacement Process is the incremental oil between the 50% to 60% waterdrive recoveries and the 80% to 90% gravity drainage recoveries.

In previous field tests, the Double Displacement Process has proven successful in generating tertiary oil recovery. The use of air injection in this process combines the benefits of air's low cost and universal accessibility with the potential for accelerated oil recovery from the combustion process. If successful, this project will demonstrate that utilizing air injection in the Double Displacement Process will result in an economically viable tertiary process in reservoirs (such as Gulf Coast salt dome reservoirs) where other tertiary processes are presently uneconomic.
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2.0 EXECUTIVE SUMMARY

Air injection on the west flank of West Hackberry Field commenced in November of 1994 and reservoir pressure has increased by 350 pounds per square inch (psi) as a result of air injection. Initial oil production is expected to occur on the west flank after sufficient air has been injected to push the oil rim down to the structurally highest producing well.

On the north flank of the field, oil production averaged 180 to 210 barrels of oil per day (BOPD) in the months preceding initial air injection. After injection began on the north flank in July of 1996, oil production steadily increased to 370 BOPD as of October, 1996. In addition, water cut declined from 50% to 35%. Currently, air injection is ongoing with roughly half of the 4.0 million standard cubic feet (MMSCFD) of available injection capacity going to the west flank and half going to the north flank.

3.0 INTRODUCTION

The following report is the Quarterly Technical Progress Report for the fourth quarter of 1996. The West Hackberry Tertiary Project is one of four mid-term projects selected by the United States Department of Energy (DOE) as part of the DOE's Class 1 Program for the development of advanced recovery technologies in fluvial dominated deltaic reservoirs. Over an 82 month funding period from September 3, 1993 to July 2, 2000, Amoco and the DOE are implementing a field test of the theory that air injection can be combined with the Double Displacement Process to create a tertiary oil process that is economically viable for the domestic oil industry. As part of the project, the Petroleum Engineering Department at Louisiana State University (LSU) has been subcontracted to provide independent study and technology transfer support.

West Hackberry is a salt dome oil field located in Southwestern Louisiana about 30 miles southwest of Lake Charles. Although the project originally targeted Oligocene Age reservoirs on the west flank of the field, Amoco and the DOE agreed to expand the project to the north flank during 1996. Injection on the west flank of the field is testing the process in higher pressure (2500-3300 psi) reservoirs which have watered out. Injection on the north flank is testing the process in low pressure (350-800 psi) reservoirs that are approaching depletion. The low pressure north flank reservoirs exhibit slow water encroachment, possess large low pressure gas caps and contain thin oil rims.

4.0 RESULTS AND DISCUSSION

4.1 West Flank Performance

The current injection strategy is to split the 4.0 MMSCFD of available air injection capacity between the west flank and the north flank of the field. On the west flank, air has been injected into two fault blocks, Fault Block II and IV. Out of over 1.5 billion standard cubic feet (BSCF) of air injected in the project to date, over 1.2 BSCF of air has
been injected into Fault Block IV. A plot of cumulative air injected versus time is included as Figure No.1. The most upstructure producer in Fault Block IV still produces a 98%-99% water cut and no evidence of nitrogen breakthrough has been seen. Production response is expected in Fault Block IV after sufficient air has been injected to push the oil rim down to the most upstructure producing well, the Gulf Land D No.44.

The injector for Fault Block IV is the Gulf Land D No.51. In July of 1996, Gulf Land D No.51 plugged up with sand fill. In October, a repair was completed which included cleaning out the wellbore and gravel packing the completion interval. The repair was successful and injection in the Gulf Land D No.51 has been trouble free since the repair. A plot of injection rates and pressures for the Gulf Land D No.51 is included as Figure No.2. Although the oil rim has not yet reached the producer in Fault Block IV, reservoir pressure has increased by 350 psi since the start of injection. A plot of bottom hole pressure versus time is included as Figure No.3.

Within the first six months of project startup, Fault Block II exhibited early nitrogen breakthrough with no increase in oil production. As a result, the injection strategy was modified to inject in Fault Block II only when the air injectors in the other fault blocks are incapable of taking the project's full 4.0 MMSCFD capacity.

4.2 North Flank Performance

4.2.1 Cam C Sand
Air injection was initiated on the north flank of West Hackberry in the Cam C sand in July of 1996. The target reservoir possesses a thin oil rim bordering a large low pressure gas cap. Reservoir pressure in the project area falls between 350 and 550 psi. The air injector for the north flank Cam C is the SL 42 No.155. A plot of north flank air injection rates and pressures is included as Figure No.4. On the north flank of the field, oil production averaged 180 to 210 barrels of oil per day (BOPD) in the months preceding initial air injection. After north flank air injection began in July of 1996, oil production steadily increased in three nearby producing wells to 370 BOPD as of October of 1996. In addition, water cut declined from 50% to 35%. A plot of injection and production rates versus time for the north flank Cam C is included as Figure No.5. As noted on the injection plot, on December 4, 1996, air injection was stopped in the Cam C to begin injection in the Bol 3 sand. Corresponding to the reduction in air injection rates in the Cam C, oil production has also decreased. Air injection will resume in the Cam C during January of 1997 in an effort to return production to the levels seen in October of 1996.

Injecting air into the low pressure Cam C is increasing oil recovery by: 1)pushing the oil rim downstructure to the structural location of existing wellbores, 2)repressurizing the reservoir and 3)obtaining tertiary oil recovery through the double displacement process. Although nitrogen, carbon dioxide and natural gas have been utilized to increase oil recovery in Gulf Coast reservoirs in the past, this project is unique in the use of air as the injection gas.
Several of the wells surrounding the air injector, the SL 42 No.155, have seen an increase in nitrogen and a minor amount of oxygen in the produced gas. As expected, the increased nitrogen and oxygen content moderated after the air injection rate in the SL 42 No.155 was reduced. The oil production rate also declined during November and December as a result of reduce air injection. In the upcoming months, the focus of north flank injection strategy will be to find an acceptable air injection rate for the Cam C that maximizes oil production while keeping nitrogen and oxygen production at a manageable level.

4.2.2 Bol 3 Sand

As noted in the previous section, air injection began in a low pressure Bol 3 sand on the north flank on December 4, 1996. The upsstructure well that serves as the injector for the Bol 3 is the Gulf Land A R/A C No.245. The downstructure producer for the Bol-3 is the Gulf Land D No.46. The volume of air injected during December of 1996 has not been sufficient to increase oil production in the Gulf Land D No.46. The need to inject a sufficient volume of air to generate production response in the Bol 3 will have to be balanced with the effort to maximize oil production in the Cam C.

4.3 Operation and Maintenance of Air Injection Surface Facilities

Air compression consists of an Atlas-Copco ZR-6 two stage oil-less screw compressor in series with an Ariel JGK-4 five stage reciprocating compressor. Air is compressed from atmospheric pressure to 4000 psi. Both compressors are driven by Waukesha GL series lean burn natural gas engines.

The only major cause of downtime last quarter was a problem with the Waukesha 5108 GL engine on the screw compressor. A leaking packing ring on a cylinder sleeve was allowing communication of the cylinder coolant with the crankcase oil causing water contamination of the oil. When the cylinder and piston assembly was removed and inspected, the top of the piston showed indications of possible detonation. The cylinder sleeve had no damage or abnormal wear and was installed with new packing rings and a new piston. The old piston was sent to Waukesha for inspection and analysis. The fuel gas is also being analyzed to determine if the quality and octane rating has changed. Upon startup, after the cylinder repair, coolant was still being lost. Further inspection found a cracked water cooled exhaust manifold which was allowing coolant to be lost through the exhaust. A new exhaust manifold was installed. Total downtime for the diagnosis and repair of the cylinder, piston and exhaust manifold was nine days. Two additional days of downtime were incurred for regularly scheduled preventative maintenance.
4.4 Technology Transfer Activities
Amoco's Reza Fassihi presented a short talk on air injection which included a discussion of the West Hackberry project at the Society of Petroleum Engineers' (SPE) Annual Technical Conference and Exhibition in Denver, Colorado in October of 1996. After obtaining DOE approval, news releases documenting the project's increase in oil production were sent to the SPE's "Journal of Petroleum Technology" ("JPT") and the "American Oil and Gas Reporter." The information sent to "JPT" is expected to be published in the Technology Digest portion of the February, 1997, issue.

5.0 CONCLUSION

Air injection is continuing on both the north and west flanks of the field. The project is generating a significant production increase in the Cam C on the north flank. Although no production response has been noted in the Cam C on the west flank, response is expected when sufficient air has been injected to push the oil rim down to the nearest producing well. Air injection in the Bol 3 on the north flank only began in December of 1996 and it is too early to see production response at this time.
Cumulative Air Injected vs. Time

W. Hackberry Tertiary Project

Figure No. 1

Air Injection Rate & Wellhead Pressure

Gulf Land D No. 51 (FB IV-west flank)

Figure No. 2
BHP vs. Time (West Flank)
West Hackberry Air Injection Project

Figure No. 3

North Flank Injectors (SL 42 No. 155 (Cam C) & GLAC No. 245 (Bol 3))
(155 was shut-in when 245 began injection on 12/4/96)
Air Injection Rate and Wellhead Pressure

Figure No. 4
Figure No. 6

SI Metric Conversion Factors

psil x 6.894 737
psi x 6.894 757

cubic feet x 2.831 685
bbl x 1.589 873

cubic meters

cubic meters

Figure No. 5

BOPD, % Water & MMSCF of Air

Cum Air Inj.
% Water
BOPD

North Fork Cam C Producers

W. Hackberry Air Injection Project