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DESIGN AND IMPLEMENTATION OF A CO₂ FLOOD UTILIZING ADVANCED
RESERVOIR CHARACTERIZATION AND HORIZONTAL INJECTION WELLS
IN A SHALLOW SHELF CARBONATE APPROACHING WATERFLOOD
DEPLETION

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Design and Implementation of A CO₂ Flood Utilizing Advanced Reservoir
Characterization and Horizontal Injection Wells in a Shallow Shelf Carbonate
Approaching Waterflood Depletion

By
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OBJECTIVE

The first project objective is to utilize reservoir characterization and advanced technologies to optimize the design of a carbon dioxide (CO₂) project for the South Cowden Unit (SCU) located in Ector County, Texas. The SCU is a mature, relatively small, shallow shelf carbonate unit nearing waterflood depletion. The second project objective is to demonstrate the performance and economic viability of the project in the field. All work during the second quarter falls within the demonstration project.

SUMMARY OF TECHNICAL PROGRESS

BUDGET PHASE II

TASK V FIELD DEMONSTRATION

Reduce Reservoir Pressure (not included in DOE funding)

Subtask V.1.9 of the Revised Statement of Work included funds for the deepening of water injection wells inside the Unit boundary, to the lower San Andres, to handle increased water injection capacity. This subtask, however, was specifically excluded from Department of Energy (DOE) funding.

South Cowden Well No. 2-18 is scheduled to be deepened and completed in the Canyon and potentially the Clearfork intervals for use as a water disposal well. Work is currently being done to review these intervals and their use for water disposal, and awaiting partner approval.

An additional 3 wells in the vicinity of the South Cowden Unit (SCU) are being reviewed for water disposal potential, as are the options to lay pipelines to other leases (Phillips operated and non-operated), where water injection volumes are required.

Increase Throughput

The main concern at South Cowden is the lack of productivity from wells. The lack of withdrawal rates from producing wells has reduced throughput throughout the reservoir, increasing average reservoir pressure and limiting CO₂ injection.

Lack of productivity is caused, in the majority of wells, by an increase in effective skin factor due to build up of scale and heavy end hydrocarbons in the wellbore. A successful sampling, analysis and chemical treatment is now under way in producing wells to improve productivity. This commenced in March 1998 with wells 2-25 and 7-08, followed by treatments in June and early July in wells 2-02, 6-17, 7-01, 7-02, and 7-09. All wells improved producing rate, with an average rate increase for the 7 wells of 92%. All 7 wells have reached there "target" liquid rate, which are rates we would expect with no significant skin damage.

Wells 2-01, 2-17, 2-22, 6-14, 8-02 and 8-19 were treated between July 15 and 20, and are awaiting

additional well test data to provide feedback on their success.

Wells 5-07, 6-02, 6-19, 6-20, 6-24, 7-15 and 8-13 are scheduled for treatment before the end of July. Another method of improving productivity has emerged within the last few months. New technology to create lateral boreholes in existing wellbores using coiled tubing and jetting technology has been developed. Three producing wells (7-13, 1-07 and another as yet undecided well) are scheduled to use this technology during August. Productivity improvements from these wells will be closely monitored before further production and injection wells are scheduled to use this technique.

Well No. 6-29 is scheduled to add perforations in the zone of interest followed by a stimulation during July, to improve throughput in the area south of 6-28.

Injectivity and Out Of Zone Injection

As discussed in the previous quarterly report, surface injection pressures were maintained below reservoir fracture pressures:

Injection profile surveys in vertical injection wells indicated significant out of zone injection into the highly transmissible, and water wet, 'A' zone or 'Grainstone', the lowest zone in the reservoir. Injecting above fracture pressures initiated fracturing downward into the Grainstone, causing CO₂ wastage.

Surface pressures for water injection wells were therefore limited to 650 pounds per square inch gauged (psig), and CO₂ injection wells to 1150 psig, to ensure injection below fracture pressures, starting in late 1997.

Injected volumes and surface pressures were closely monitored to observe injectivity. The table below summarizes some of the individual CO₂ well injection rates.

	SCU 6C27	SCU 6C26	SCU 2C26	SCU 2C27	SCU 6C-25H	SCU 7C-11H
	Rate mcf/d	Rate mcf/d	Rate mcf/d	Rate mcf/d	Rate mcf/d	Rate mcf/d
Jul-97	0.0	876.9	938.5	372.8	3371.5	3456.3
Aug-97	0.0	971.1	537.8	371.3	2882.5	2932.4
Sep-97	19.0	793.3	727.3	294.2	2717.9	685.5
Oct-97	998.8	896.2	934.8	387.0	3494.7	2797.1
Nov-97	985.7	874.1	945.7	554.1	3456.9	3451.7
Dec-97	481.7	441.0	480.5	183.7	2147.5	1689.6
Jan-98	135.5	397.1	290.0	0.6	1312.0	1115.8
Feb-98	84.8	620.7	354.0	0.0	1113.4	1140.4
Mar-98	32.6	631.0	316.0	0.4	1010.4	1190.0
Apr-98	19.6	1058.8	522.8	5.3	2347.1	2319.2

May-98	0.7	466.0	156.7	0.5	2475.6	2431.0
Jun-98	0.0	489.7	143.2	0.0	2547.2	2400.8

Actual injection rates have therefore reduced since limiting surface pressures, most noticeably in vertical wells.

There are two reasons for poor injection rates:

- 1) High reservoir pressure in the zone of interest causing lack of pressure differential between well bore and reservoir, reducing the wells capacity to inject CO₂.
- 2) Lack of injectivity, due either to skin damage or poorer reservoir quality than anticipated.

As discussed above, high reservoir pressure is caused by lack of throughput within the project area and lack of off lease produced water disposal. Methods for improving throughput and productivity were discussed above.

Lack of injectivity is of more concern for vertical injection wells. Continued monitoring of injection volumes and pressures for these wells will determine if further intervention work or methods to improve injectivity will be required. It is anticipated, however, injection volumes will increase once throughput and reservoir pressures improve.

As a result of the cut back of surface injection pressures reduced volumes of CO₂ were required during the report period.

Horizontal injection well 7C-11H has out of zone injection in the toe of the well, which was determined after logging and fall off tests. Methods being evaluated to isolate this section of the well include packers, crosslinked polymers, cement, foamed cement, monomers and sodium silicates.

Purchase CO₂ and Operation of Recycle Compression Facilities

The CO₂ recycle compression facilities have been in continuous operation during the second quarter, 1998.

Gas injection volumes for the for SCU injection wells and the three co-operative lease line injection wells for the last 12 month period are reported below. These volumes have been updated and corrected from previous reports.

GAS INJECTION

	<u>Jul 97</u>	<u>Aug 97</u>	<u>Sep 97</u>	<u>Oct 97</u>	<u>Nov 97</u>
Monthly mcf	309,844	255,958	157,118	294,766	308,048
Daily Avg. mcf/d	9,995	8,257	5,237	9,509	10,268
Cumulative mcf	2,943,129	3,199,087	3,356,205	3,650,971	3,959,019

	<u>Dec 97</u>	<u>Jan 98</u>	<u>Feb 98</u>	<u>Mar 98</u>	<u>Apr 98</u>
Monthly mcf	168,149	100,782	92,772	98,593	188,185
Daily Avg. mcf/d	5,424	3,251	3,313	3,180	6,273
Cumulative mcf	4,127,168	4,227,950	4,320,722	4,419,315	4,607,500
	<u>May 98</u>	<u>Jun 98</u>			
Monthly mcf	171,447	167,425			
Daily Avg. mcf/d	5,531	5,581			
Cumulative mcf	4,778,947	4,946,372			

Unit Production

	----- PRODUCTION -----			----- INJECTION -----	
<u>Quarter</u>	<u>BOPD</u>	<u>BWPD</u>	<u>MCFPD</u>	<u>BWIPD</u>	<u>MSCFPD CO2</u>
1st 1996	383	3,944	90	3,944	0
2nd 1996	356	3,528	89	3,528	0
3rd 1996	337	4,303	91	4,622	3,667
4th 1996	376	4,928	102	4,928	8,579
1st 1997	443	6,110	612	6,110	8,123
2nd 1997	425	6,466	929	6,466	8,584
3rd 1997	446	6,498	1,114	6,498	7,830
4th 1997	487	8,624	1,504	8,624	8,400
1st 1998	463	7,066	974	7,066	3,248
2nd 1998	463	7,000	1,026	7,000	5,795

Monitor Project Performance

Close monitoring of production data has shown the area around horizontal injection well 6C-25H has the best response to CO₂ to date. Suggesting areas where a) zonal isolation of injected CO₂ into the zone of interest, and b) high injectivity are possible will have the greatest benefit from CO₂ injection.

The well was drilled horizontally into the zone of interest, and has no indications of out of zone injection, unlike its twin well 7-11H, where a fracture system is taking the majority of injected gas. The well is also capable of high injection rates, compared the other wells in the field, typically over 3 MMSCF/D at the injection constraint of 1150 psig surface pressure.

Other areas of the field, such as around vertical injection well 2-27, suggest CO₂ has less response

to nearby wells. Well 2-22 appears to have earliest CO₂ breakthrough, suggesting the highest transmissibility between the pair. Other wells surrounding 2-27 have shown little indication of CO₂ response.

Response from nearby wells to the toe of 7-11H suggest they are also responding to CO₂, so some percentage of the injected CO₂ must be entering the zone of interest, the majority, however, entering the fracture system and out of zone. Methods to improve in-zone injection are discussed above.

Interference Testing

An additional pulse test between wells 2-26 and 6-28 was undertaken in June. This was to confirm an October, 1997 pulse test between the two wells that suggested communication, and 2-26 as the source of early breakthrough seen at well 6-28.

The June test, however, gave a conflicting response, suggesting no definite communication between these wells. With the lowering of injection pressures in well 2-26, from late 1997 onwards, the communication path seen during the October pulse test may have been eliminated. The data is still being analyzed to extract as much communication information as possible.

TASK VI TECHNOLOGY TRANSFER, REPORTING, AND PROJECT MANAGEMENT

An abstract entitled "Transient Test Analysis Case History for Two Horizontal Miscible Gas Injection Wells" was submitted by T. F. McCoy, K. J. Harpole, and K. B. Dollens to the selection committee for the Sixth International Oil and Gas Conference and Exhibition in Beijing, China, on November 2-6, 1998. This paper was accepted as an alternate paper, but will not be presented or included in proceedings now.