CARBONATED WATERFLOOD IMPLEMENTATION AND ITS IMPACT ON MATERIAL PERFORMANCE IN A PILOT PROJECT

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ABSTRACT

Carbonated waterflooding is an enhanced oil recovery process developed in the early 1950's that may have potential application in several West Texas reservoirs. The process consists of saturating injection water with CO_2 in order to swell the remaining oil-in-place, and thereby increase the amount of recoverable oil in a reservoir. The process usually involves less investment and CO_2 demand than miscible CO_2 flooding.

The effects of carbonated waterflooding on equipment material performance were monitored during a two well carbonated water injection pilot test conducted by Amoco Production Company in the Slaughter Field, Hockley County, Texas. Stainless steel and aluminum bronze material showed no deterioration during the test period. However, severe problems were encountered at holidays in the internal plastic coating of carbon steel pipe and fittings. Injection well material performance data and observations are presented to support these findings. In addition, the surface equipment design used to saturate injection water with CO_2 will be presented. No attempt will be made to discuss the impact of carbonated waterflooding on injection well or reservoir performance.

INTRODUCTION

Corrosion and plugging problems were encountered in wellhead equipment during operation of a two well carbonated waterflood injection pilot. The carbonated waterflood injection pilot, located within the currently active Central Mallet Unit CO_2 miscible flood, was placed in operation on July 25, 1985, and operated continuously until termination on March 4, 1986. Performance of surface injection wellhead equipment and materials during the 7½ month pilot period is provided along with recommendations for future carbonated waterflood wellhead equipment designs.

DESIGN DATA AND BACKGROUND INFORMATION

Initial design data for the two carbonated waterflood pilot wells is summarized below:

	Well A	Well B
Design Water Rate	1050 BWIPD	990 BWIPD
Desired Surface Operating Press.	1200 PSIG	1490 PSIG
Target Solubility	101 SCF CO_2/Bbl	104 SCF CO_2/Bbl

Prior to initiating carbonated water injection, both wells were on water injection at the design water rates and surface pressures noted in the table. The wells were equipped for CO_2 injection; however, neither well had been placed on CO_2 injection prior to carbonated water injection.

WELLHEAD EQUIPMENT DESIGN

Wellhead equipment for the carbonated waterflood pilot wells consisted of separate CO_2 and water injection skids upstream of a 316 stainless steel static mixing unit. The static mixing unit provided sufficient intimate contact to saturate injection water with CO_2 prior to entry into an aluminum bronze wellhead assembly. As shown in Figures No. 1 - 4, CO_2 was injected into the water stream through a 1/2" nozzle in the side of the static mixer prior to entering the mixing elements.

During wellhead equipment design, it was anticipated that CO_2 injection into the water stream would create an area of turbulence that might subject piping material to erosion. Erosive attack could easily damage the internal plastic coating and expose the bare carbon steel pipe to corrosive attack. Due to the potential for degradation of the plastic coating, the CO_2 injection port area of the water line was fabricated of 316 stainless steel, as shown in Figure No. 4. To streamline equipment design, the CO_2 injection port was fabricated as an integral part of the static mixing units installed at each carbonated waterflood pilot well.

Internally plastic coated carbon steel pipe, fittings, and flanges were installed upstream of the static mixer. Internally plastic coated carbon steel pipe, fittings, and flanges were also installed between the static mixer and the injection wellhead assembly. As designed and subsequently installed, the pilot wellhead equipment provided a comparison of the performance of internally plastic coated carbon steel, 316 stainless steel, and 9D aluminum bronze materials in a carbonated water environment.

CORROSION PROBLEMS

Extremely high corrosion rates occurred to some extent at all of the threaded and RTJ (ring type joint) flanged connections on the carbonated waterflood wellhead equipment. Plastic coated steel RTJ flange faces leaked excessively and were replaced with RF (raised face) flanges at Well B. Although several RTJ flange connections leaked throughout the carbonated waterflood test period at Well A, the leaks were not of a magnitude to require replacement of the RTJ flanges with RF flanges.

Leaks in the RTJ flanged connections occurred in the ring groove areas where plastic coating had been cracked, during tightening of flange bolts, by 316 stainless steel ring gaskets. The exposed steel corroded rapidly behind the coating cracks on the flange faces, and stainless steel gaskets could not provide an adequate seal with the resulting irregular surface in the flange groove. In addition, leaks occurred in the threaded connections of plastic coated nipples where carbonated water had leaked into threads and caused rapid corrosion of the exposed bare steel pipe.

Overall, internal plastic coating on steel pipe and fittings performed satisfactorily where the coating was not damaged (i.e. RTJ flange grooves). Inspection of steel pipe and fittings following termination of the pilot project found that carbon steel RF flange faces and internal pipe areas were adequately protected from corrosion during carbonated water injection. For future carbonated waterflood wellhead equipment designs, RF flange connections would be recommended in lieu of RTJ flange connections to minimize the potential for cracks and holidays in the internal plastic coating on the flange face. In addition, the use of threaded connections should be minimized, since carbonated water exhibited a tendency to seep into, and rapidly corrode, the steel thread area.

The 316 stainless steel internally wetted surfaces of the static mixing units (one per well), ball valves, and RTJ flange gaskets removed from the wellhead equipment showed no signs of deterioration following exposure to carbonated water. Similarly, 9D aluminum bronze wellhead fittings and valves showed no signs of deterioration during the carbonated water pilot test. Based upon this performance, both materials appear suitable for use in future carbonated waterfloods.

PLUGGING PROBLEMS

During the carbonated waterflood test period, the 1/2" CO_2 injection nozzle in the side of the static mixer plugged with a precipitate at both pilot well locations. This plugging restricted the CO_2 flow area, and field personnel had to remove precipitates to keep pressure drops through the CO_2 injection nozzles to a minimum. To alleviate the CO_2 injection port plugging problem at Well B, the 1/2" nozzle in the side of the static mixer was covered with a blind flange, and the CO_2 was introduced into the water stream through a larger 2" port in the water line prior to entering the static mixer, as shown in Figure No. 5. The larger port minimized pressure drop and therfore the precipitate plugging problems. This modification of the CO_2 injection area at Well B was completed on October 16, 1985, in conjunction with the replacement of RTJ flanges with RF flanges. Modification of the CO_2 injection port in wellhead equipment at Well A was not attempted prior to termination of the carbonated waterflood pilots.

The carbon steel RTJ blind flange installed over the 1/2" CO_2 injection port on the Well B static mixer was internally coated with electroless nickel. Following 4 1/2 months of service, this electroless nickel coating showed no signs of deterioration. Based upon this performance, internal electroless nickel coating may provide a viable alternative to plastic coating of carbon steel for carbonated water service. However, additional testing of electroless nickel is necessary before it can be recommended for use in future carbonated waterfloods. As with all spray metal coatings, a reliable procedure to check for holidays in the coating surface has not yet been developed to assure coating integrity.

In addition to the static mixer injection port plugging problem, a grey precipitate accumulated in the mixing elements of the static mixers. Design pressure drops through the static mixing units of Wells A and B were 40 and 20 psig, respectively. However, actual pressure drops across both static mixers exceeded 100 psig by the end of the carbonated water injection period, due to precipitate formation. Field personnel had to reverse the flow through the static mixers, on approximately a bi-weekly basis, to remove solids buildup and reduce pressure drops. The main component of this precipitate was elemental sulfur, and this sulfur formation is common in the water injection system which serviced the carbonated waterflood pilot. Due to the potential for precipitate formation and resultant pressure drop increases, future carbonated waterfloods should employ static mixer designs that minimize pressure drops across mixing elements.

AUTOMATION EQUIPMENT PERFORMANCE

Automated control of the CO_2 and water injection skids was achieved using a remote terminal unit (RTU) at the wellhead location. The RTU controlled CO_2 and water streams independently during carbonated waterflood operation. Water injection was pressure controlled, and rate fluctuations were monitored at both pilot wells as part of a reservoir evaluation on the carbonated waterflooding process. CO_2 injection was rate controlled to provide a target CO_2 saturation, based on average daily water injection rates. The CO_2 rate was adjusted as necessary approximately weekly at both pilot wells.

It was necessary to input commands directly into the wellhead RTU in order to open or close CO_2 and water control valves, adjust CO_2 injection rates, or change the target water injection pressure. In this particular case, a central field computer could not be used to input control parameter changes since the necessary software did not exist to permit this. Adjustment of automation functions with this centrally located computer is the manner in which Amoco's field automation systems are normally operated, and employee travel (to adjust control parameters) to remote field locations is thus not normally required.

An improved software program for use with an RTU was utilized in October, 1985, at a second, larger scale, carbonated waterflood implemented by Amoco. This improved software program provided dynamic control of CO_2 rates as water rates fluctuate. With dynamic control, a constant CO_2/water injection ratio at a given target saturation can be closely maintained. In addition, the ratio control program allows control parameter changes to be input with a central field computer. Comparing the two control schemes, a dynamic ratio control software program is recommended for automated control of CO_2 saturation rates in future carbonated waterfloods.

TUBING AND PACKERS

The tubing and packer have not been removed from Well A for examination since termination of the carbonated waterflood pilot project. The tubing and packer removed from Well B following termination of the carbonated waterflood pilot showed no signs of corrosive attack or material degradation. Internal wetted surfaces of tubing joints, tubing couplings, and injection packer parts were plastic coated for corrosion resistance. To date, the plastic coating appears to have provided an effective deterrent to corrosive attack.

CONCLUSION

A summary of the findings documented in this paper on wellhead material and automation equipment performance is provided in Table No. 1. With proper material designs, it appears that carbonated waterflooding can be feasibly implemented without unreasonable demands on operating manpower or equipment maintenance.

ACKNOWLEDGMENTS

The author wishes to thank Amoco Production Company for permission to publish this paper and also G. H. Adams, T. N. Libson, J. A. Merritt, R. L. Winfrey, J. D. Johnson, and F. W. Kinnison for their help, hard work, and encouragement during implementation and subsequent documentation of project performance.

Table 1
Summary of Findings
Carbonated Waterflood Pilot Project

Item No.	Description
1	Internal plastic coating on steel pipe and fittings performed satisfactorily where coating integrity was not damaged (i.e. RTJ flange grooves).
2	The use of RF flanges in lieu of RTJ flanges is recommended to minimize cracks and holidays in the plastic coating on flange faces.
3	Both 316 stainless steel and 9D aluminum bronze showed no signs of deterioration and appear suitable for use in carbonated waterfloods.
4	The use of threaded connections should be minimized, since carbonated water exhibited a tendency to seep into, and rapidly corrode, the steel thread area.
5	Carbonated waterfloods should employ mixer designs that minimize pressure drops due to the potential for precipitate formation and resultant pressure drop increase in the static mixers.
6	Following 4 1/2 months of service, electroless nickel coating showed no signs of deterioration.
7	A ratio control program to be used in conjunction with a wellhead RTU is preferred to independent control of CO_2 and water streams.
8	Internal plastic coating of injection tubing and injection packer parts appeared to provide an effective deterrent to corrosive attack.

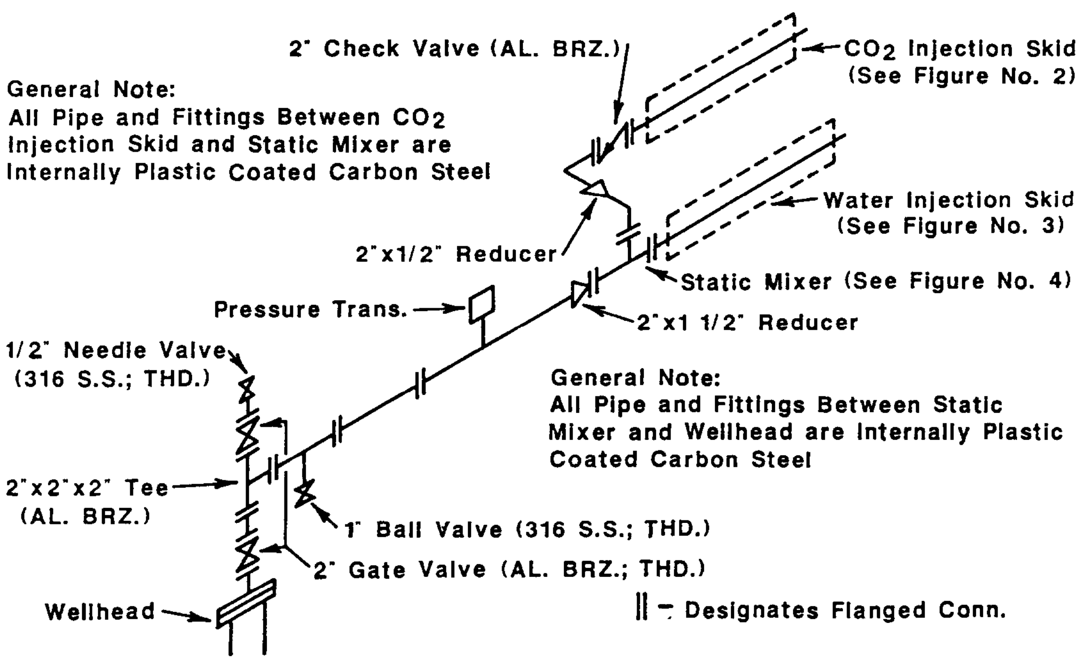
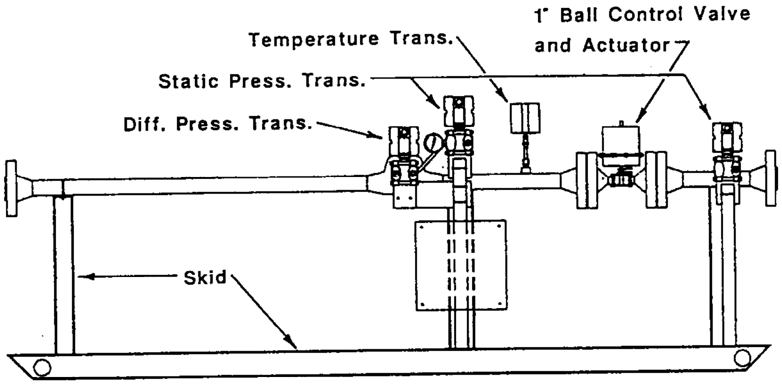
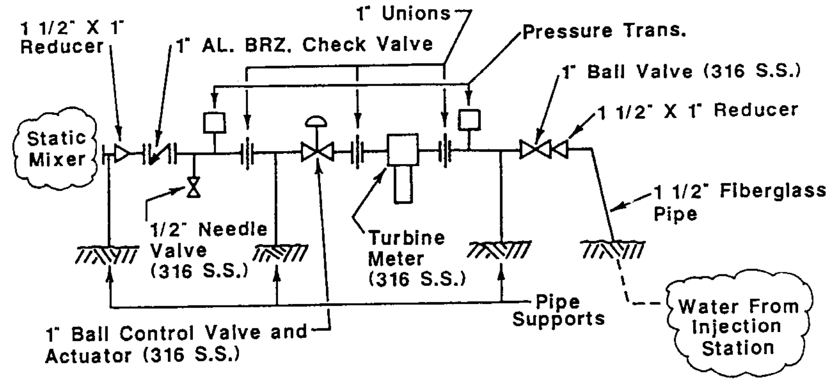


Figure 1 - Original design for carbonated waterflood wellhead equipment



General Note: All Pipe and Fittings Bare Carbon Steel

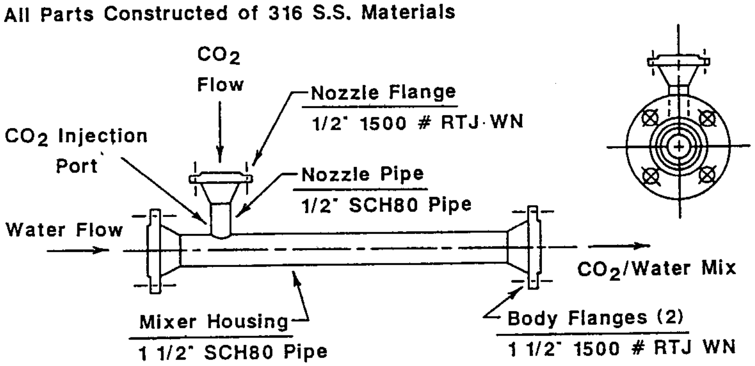
Figure 2 - CO_2 injection skid design



All Pipe and Fittings are Internally Plastic Coated Carbon Steel Unless Noted Otherwise.

Figure 3 - Water injection skid design

All Parts Constructed of 316 S.S. Materials



316 Stainless Steel Mixing Elements Located Between Nozzle and Downstream Side Body Flange

Figure 4 - Static mixer design

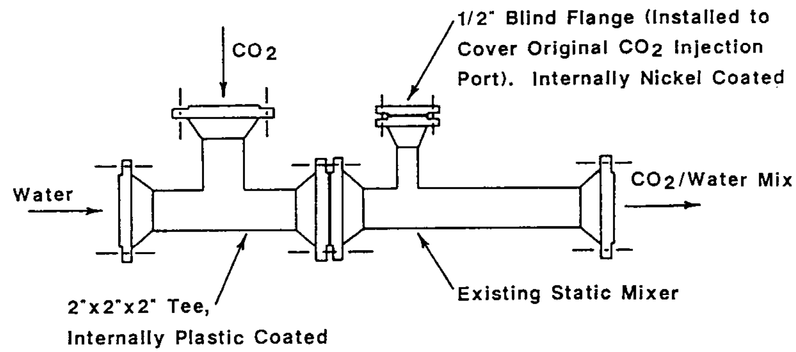


Figure 5 - Static mixer design following modifications