Well Stimulation Using CO_2 Injection at the City of Apopka

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The city of Apopka operates three conventional raw water treatment plants within this Central Florida community, supplying about 2.2 billion gallons per year (about 6 million gallons per day) of treated water. Raw water for the plants is supplied from multiple on-site wells drilled into the Floridan Aquifer, a thick sequence of carbonate rock with highly permeable, sometimes cavernous water-bearing zones.

The city's Grossenbacher Plant relies on three Floridan wells – Wells 1, 2, and 3. Two of these wells, Well 1 and Well 3, had experienced a progressive decline in performance, as measured by yield and specific capacity. As a result, the reliability of raw water supply at the plant was compromised. Neither of the wells had been rehabilitated since their construction.

Alternatives for Treatment

Several options were considered for well rehabilitation, including the use of mineral acid (hydrochloric acid), mechanical methods, and carbon dioxide. The likelihood of successful workover was considered greatest with acid treatment; however, hydrochloric acid has several drawbacks, including the need for special precautions handling the acid, the need for managing well head pressures and gases generated during the workover process, safety, costs, and issues related to disposing of spent fluids.

Hydrochloric acid, the most common choice in acid treatment of wells in this environment, is fast-acting and aggressive. The chemical reaction between the acid and the rock causes the chemical breakdown and dissolution of significant quantities of carbonate material, generating byproduct gases and mineral salts in the process. All require special precautions in handling and disposal.

Fluids discharged from the well following acid treatment may have pH values near 2 immediately following the procedure, and must be contained and neutralized in leakproof vessels or pits. Gases generated during the procedure are often shut in at the wellhead, so that the pressure build-up can be used to force acid into the formation. These conditions, while manageable, pose risks, especially given that the plant lies within a residential area.

The decision to proceed with a treatment program using CO_2 for stimulating well performance was based on a number of factors. The use of CO_2 had been successfully demonstrated on similarly constructed wells, also completed in a carbonate rock aquifer. A recent well stimulation program undertaken by the Peace River/Manasota Regional Water Supply Authority at their Peace River Facility was highly successful in improving the performance of aquifer storage and recovery (ASR) wells (read *Improving the Performance of ASR Wells with CO_2 Injection* in the February 2004 issue of the *FWRJ*, pages 38-40).

It was postulated that similar improvements might be possible at the city of Apopka, despite the differences in the wells' operation (the ASR wells at the Peace River Facility are operated in both an injection and production mode, whereas the city's wells are used only for production).

Also, CO_2 is relatively safe and easy to handle, particularly important given the residential setting of the Grossenbacher Plant. Finally, it was anticipated that a reduction in pH of about 2 pH units with CO_2 would be sufficient to counteract the wellbore plugging responsible for loss in productivity, suggesting that the process would not require inordinately large quantities of the gas.

Figure 1: Wellhead piping at Well 3 for CO_2 injection. Note horizontal run of clear PVC connecting to 2-1/2 vertical steel tremie pipe. Injection was done through the tremie pipe terminating at a depth of 1,000 feet.

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Field Program and Results

Well 3

Well 3 was the first of two wells treated. Constructed in 1989, it was completed in the Lower Floridan Aquifer with a reported yield of 3,200 gallons per minute (gpm) and a specific capacity of 90 gallons per minute per foot (gpm/ft). The well is cased to a depth of 680 feet with 24-inch diameter steel casing. Open hole extends to a depth of 1,400 feet.

Well 3 is equipped with a 3,500-gpm pump, which was pulled and inspected to rule out pump performance issues. A borehole video log was obtained, but it revealed no structural problems in the wellbore (such as collapsed borehole). The video log also did not reveal any clear evidence of chemical, mechanical, or biological plugging of the open hole.

Precise well performance information on Well 3 prior to CO_2 treatment was unavailable, in part because of the need to treat the well on an emergency basis; however, plant operations staff estimated that the well was producing about 500 gpm. Intermittent water-level measurements at about the same time suggested a specific capacity of about 20 gpm/ft of drawdown.

A 2-1/2 inch steel tremie line was lowered into the well to a depth of 1,000 feet in order to inject the CO_2 solution. This depth was determined to be about the mid-point of the main water-bearing interval within the open-hole part of the well. A CO_2 injector installed at the surface was used to disperse the CO_2 into a 100-gpm stream of raw water taken from another on-site well.

The solution was introduced into the well under gravity conditions. The pH of the 100-gpm stream was monitored at intervals of 30 to 60 minutes, both upstream and downstream of the CO_2 injection point. The feed rate of the CO_2 was adjusted to achieve a pH drop of about 2 pH units. The pH of the raw water averaged 7.7, while the pH of the treated stream averaged about 5.5. The set-up for the injection piping at Well 3 is shown in **Figure 1**.

CO_2 injection continued intermittently over a span of about 10 days. During this time, a total of 4,000 pounds of CO_2 was injected, indicating a dosing rate of about 400 pounds per day.

Following treatment, the well was equipped with a rebuilt 3,500 gpm pump. Water initially produced from the well contained large quantities of silt-sized, black particulates. Turbidity of the produced water exceeded 100 NTUs, while pH was in the range of 5.8 to 6.0 with virtually no improvement in the quality of produced water, even after several hours of development.

A dramatic improvement in quality was noted only after about 3 million gallons had been pumped from the well. At that time, turbidity dropped to less than 1 and pH returned to its normal range of 7.7 to 7.8.

Following the improvement in raw water quality, the well was cleared through bacteriological testing and was returned to service. While production from the well is not metered, measurements of flow following treatment using a temporary flow meter indicated the well was producing about 3,200 gpm.

Well 1

Well 1 was constructed in 1966. The well is cased to a depth of 500 feet with 10-inch diameter steel casing. Open hole extends to a depth of 700 feet and produces from the Upper Floridan Aquifer. While performance records from the time of its construction were unavailable, testing of the well in 1989 indicated a yield of about 1,000 gpm and a specific capacity of 170 gpm/ft.

Well 1 is equipped with a 1,000-gpm pump, which was initially set at a depth of 135 feet. It was subsequently reset to a depth of 150 feet in an attempt to avoid breaking suction while pumping. The well continued to break suction intermittently and a decision was made to attempt stimulation with CO_2.

In the case of Well 1, it was decided to attempt CO_2 injection through the pump column. The well was treated with a total of 4,000 pounds of CO_2 over a period of five days, mixed with a 120-gpm stream of treated water at a feed rate needed to achieve a pH reduction of about 2 pH units. The setup for injection at Well 1 is shown in **Figure 2**.

Figure 2: Piping for CO_2 Injection at Well 1. White PVC pipe provides water supply for CO_2 feed. Injection was done through pump column. Pump installed at a depth of 150 feet. CO_2 shown in 400-pound cylinders.

As with Well 3, water produced following the CO_2 treatment was highly turbid with high concentrations of black, silt-size material. The transition to clear water was similarly abrupt, occurring after about 1 mg had been produced from the well—and, as with Well 3, this transition in quality coincided with a return of pH to levels associated with native water quality.

Specific capacity, the best measure of well performance, was improved from 20 gpm/ft before treatment to 340 gpm/ft after treatment. The profound improvement achieved at Well 1 suggests that the treatment affected conditions in the wellbore other than a simple reversal of wellbore plugging – it is postulated that new flow paths to the wellbore may have been opened in the workover process.

Summary

Both wells were treated with 4,000 pounds of CO_2. The cost for CO_2 on a per-well basis was ten 400-pound cylinders (4,000 pounds) @ $85/cylinder = $850. The furnishing and installation of temporary piping for the first well, including installation of a tremie pipe to a depth of 1,000 feet, was provided under contract to a local drilling firm at a cost of $12,000. Plant operators, however, expressed confidence that the setup for injection through the pump column, as was done at Well 1, could be accomplished by plant operations staff in two to four hours.

By comparison, the cost for well treatment using a mineral acid program is estimated to be in the range of $15,000 to $20,000 per well, depending on well depth, access, and requirements for disposal of spent fluids.

One additional factor that needs to be considered in comparing these alternatives is the time required to complete the servicing and the resulting loss of water production during this period. In general, mineral acid is relatively fast-acting, and the full program can be completed in a period of two to three days, whereas the CO_2 is relatively slow-acting and may require a week or more before the well can be returned to service.

Results of the CO_2 injection program are summarized in **Table 1**.

Based on the results of this pilot program, CO_2 injection can be a highly effective means for treating and restoring capacity of production wells completed in a carbonate rock environment. It appears that CO_2 can be injected successfully in open-hole, or it may be introduced through the pump column of an installed pump, avoiding the need to pull the pump.

These results indicate that a pH reduction of about 2 pH units in the stream used to carry the CO_2 down hole is sufficient to achieve the chemical changes in the borehole needed to improve borehole permeability and restore well productivity.

Table 1: CO_2 injection program results.

Well	Well Discharge (gpm)		Specific Capacity (gpm/ft)	
	Before Treatment	After Treatment	Before Treatment	After Treatment
1	600	1,100	20	340
3	500[a)]	3,200	20[a)]	120