ACID TUNNELING STIMULATION IN OKLAHOMA LIMESTONE USING COILED TUBING

J. Strasburg and J. Clark
BJ Services Company

ABSTRACT

With the recent increases in price of a barrel of oil and the growing scarcity of easily exploited oil, efforts to improve productivity of older wells have intensified. Some options for accomplishing this include re-stimulating the well and/or adding laterals that extend past the original wellbore. In open-hole limestone formations, one innovative technique can achieve both of these goals simultaneously, creating pre-stimulated "tunnels" that bypass existing near-wellbore damage to make contact with new reservoir rock.

The new technology relies on limestone's acid solubility and a coiled tubing-conveyed bottomhole assembly comprised of components that tilt the tool toward the formation. A high-pressure nozzle then jets acid to extend new tunnels from the wellbore. The technique is applicable in all open-hole wells drilled in carbonate formations and can be used to remediate old wells or complete multiple drainage tunnels in new wells.

This acid tunneling technique and tool have been utilized around the world. They were first used in the United States to create three additional tunnels in an Oklahoma well that has been producing since 1924. This paper will describe the acid tunneling tool and design along with: an operational timeline, summary of lessons learned during the United States operation, comparison of pre- and post-job production information for the treatment.

INTRODUCTION

The world's formations are made up of roughly 30% carbonate formations. These formations contain roughly 60-65% of the world's hydrocarbon reserves.

Acid has been the choice for stimulation of several geological formations for many years. Most commonly, acid is used for matrix or fracture acidizing on carbonate type formations. A unique technology has been patented which allows tunnels to be created inside the well thru the use of acid and a bottomhole assembly (BHA) with common oilfield components.[1]

The purpose of the acid tunneling process is to create a series of holes, or tunnels, branching off from the main wellbore. This, in effect, begins to create a type of dendritic system which allows more hydrocarbons to flow to the main (mother) wellbore through a series of daughter conduits. The additional flow, or production, can be calculated using the effective wellbore radius increase.

Carbonates have high mechanical integrity, which is useful in the drilling process. However, carbonates are hard to drill and slow to drill as well. The acid tunneling process takes advantage of the mechanical properties of the carbonate formations and their solubility to hydrochloric acid (eqn. 1 and 2). Acid tunneling is performed via two mechanisms:

- Chemically, through dissolution of the carbonate rock by acid reaction.
- Mechanically, by high velocity fluids created through high differential pressure orifices.

Eqn 1 – Calcite - $2HCl + CaCO3 \rightarrow CaCl2 + H2O + CO2$
Eqn 2 – Dolomite - $4HCl + CaMg(CO3)2 \rightarrow CaCl2 + MgCl2 + 2H2O + 2CO2$

After the logs are analyzed and the zones of interest determined, the process is performed using coiled tubing. A kickoff tool and nozzle are placed at the desired depth. As pump pressure is increased, the kickoff tool orients the nozzle against the formation face to start a borehole. The high differential pressure nozzle and hydrochloric acid are used to initiate a new hole off the mother bore. The assembly is pushed into the hole until friction lockup between the rock and coiled tubing is achieved, or until the BHA reaches a non-carbonate formation barrier that impedes further progress using acid. The BHA and coiled tubing are then pulled out of the daughter hole, moved to the next desired depth within the mother bore, and the process is repeated.

MATERIALS AND METHODS

Tool Design

The tool is 2 1/8" OD with two pressure-activated knuckle joints that kick over in the same orientation.

The angles and space between the knuckle joints are variable and can be optimized for a particular well diameter. Nozzle sizes range from 2-1/8 to 3.5" and are optimized for the application. The nozzles contain replaceable orifices to optimize jet velocity. This is important because the two variables that make this process work are the acid's dissolving power and the pressure washing of the rock face.

Acid Design

When mixing the acid, certain additional chemicals are needed: A corrosion inhibitor to protect the coiled tubing, the tool, and well tubulars that may come in contact with the acid; iron control agents to keep any iron suspended in solution from reaching the wellbore; and other chemicals that may be needed to suit special circumstances of the well, including silt suspenders or chemicals to bypass near-wellbore damage.

It has been found that both 10% and 15% acid can create tunnels at nearly the same rate of penetration, so long as the acid exits the nozzle at high enough velocity to etch the virgin limestone.

Procedure

The typical operation has two components. During the preparatory period, the logs are analyzed, the zones of interest are identified, the acid is designed and a schedule is worked out. The pumping operation follows this preparation period. The first period can take a considerable amount of time, whereas the actual field operation may last only a few hours. This paper will focus primarily on the few hours of field operation.

After the coiled tubing unit arrives on location and rigs up, the tool can be tested on the surface to show that the tool functions properly. Typically, the tool has already been tested at the shop to ensure that the knuckles kick over in the same orientation, and at the right pressure.

The coiled tubing will then carry the acid tunneling tool to the terminal depth (TD) of the well and the depth will be correlated to the logs. From this point the tool can be moved to the initial desired tunneling depth and begin making a tunnel.

When the tool reaches the desired depth, the acid is pumped at the rate that will give the correct pressure across the nozzle to achieve tool kickoff. This rate is determined by a coiled tubing force and circulation analysis simulator. Once the acid reaches the bottom of the coiled tubing it is decided whether to shut in the well or leave it open. Shutting in the well gives the acid every opportunity to leak off into the formation for stimulation.

When the acid comes in contact with the limestone, it will begin to dissolve it, but it will not begin to create a channel that will easily carry a string of coiled tubing fitted with a pressure-activated tool and a nozzle. It takes time to create a pilot hole that the tool can enter. Each well is different due to impurities in the rock, near-wellbore damage, and other factors. The way to determine if a pilot hole has been started is by stacking weight on the coiled tubing and watching the weight gauge for a loss of weight that does not immediately come back. When this is seen, the tunneling can begin at whatever penetration rate the limestone will dissolve.

Once the coiled tubing unit lays off enough weight and the coiled tubing will not move any farther, it is determined that the coiled tubing is friction locked. This is the point when any additional acid that is pumped is not creating a tunnel that can be tracked.

The coiled tubing is then pulled out of the newly created tunnel and begins a new tunnel wherever it is determined one should go.

CASE HISTORY

In July of 2008 the acid tunneling technique was used on a well in Eastern Oklahoma that was originally drilled in 1924. A second well had the technique used on it in December of 2008. The timelines follow for each job:

- Each daughter tunnel follows the same steps
    - Move Acid Tunneling tool to desired depth
    - Bring acid online at desired rate
    - Once acid reaches end of coil begin initiating pilot hole
    - After some time, the tool will penetrate far enough to establish a pilot hole
        - Pilot hole is determined by laying off weight on the coiled tubing that does not immediately return
    - Lay weight onto acid tunneling tool to initiate daughter tunnel
    - Monitor weight indicator to continue daughter hole length
    - Once it is determined that the coiled tubing is friction locked then the acid tunneling tool will no longer create new tunnel
    - Pull out of daughter tunnel and move acid tunneling tool to next desired depth

- The timeline for the first of these two wells is as follows
    - Initiate first daughter tunnel 1 ft from terminal depth (TD)
        - 28 feet of tunnel is created
    - Initiate second daughter tunnel 10 ft from TD
        - 36 feet of tunnel is created
    - Initiate third daughter tunnel 45 feet from TD
        - 44 feet of tunnel is created
    - A total of 108 feet of new daughter tunnel is created

- The timeline for the second of these wells is as follows
    - Initiate first daughter tunnel
        - 28.1 feet of tunnel is created
    - Initiate second daughter tunnel
        - After 46 feet of tunnel there is no resistance to the tool
            - Possibility of reentering the mother wellbore
            - Possibility of finding a natural fracture
        - 46 feet of tunnel is created
    - Initiate third daughter tunnel
        - 36 feet of tunnel is created
    - Initiate fourth daughter tunnel
        - 5 feet of tunnel is created before there is no acid left to pump
            - The goal was to make 3 tunnels
    - A total of 115 feet of new daughter tunnels were created with the possibility of bringing the well in contact with a natural fracture

DISCUSSION

There are several benefits that come from using the acid tunneling technique.

- The acid is selectively placed - The acid tunneling technique can spot the acid in specific areas of the wellbore, rather than all of the acid going into the path of least resistance. Coiled tubing depth is set where the tunnel will be started. The daughter hole begins at a downward angle, and the number of feet achieved is determined by lockup. It is not known what path the coiled tubing takes once it starts, but it most likely follows the path of least resistance through the rock, as far as the coiled tubing and the tool will allow.
- Increased wellbore contact area - Due to the number of tunnels created and that the beginning locations are known, it can be determined a minimum amount of rock that had to be dissolved with the acid tunneling technique. The best case scenario is that a tunnel reaches a natural fracture which would drastically increase the wells contact with the reservoir

- Cost of treatment - Because it is known where the acid is being placed, the acid can be used more efficiently, unlike a traditional bullheaded acid fracture or matrix acidizing treatment where the acid is most likely to follow the path of least resistance. The acid tunneling technique is significantly less expensive than either an acid fracture or matrix acidizing treatment.[2]
- Footprint size - Coiled tubing footprint is relatively small when compared to directional drilling and size of equipment footprint is proportional to safety exposure

SUMMARY

This acid tunneling technique and tool have been utilized around the world and have been used in the United States recently. The first well showed an initial increase in oil production of 110% and a sustained increase of 80%. The well also increased its gas production. For the second well, initial production and post acid tunneling information have not been release by the operator at the writing of this article. Due to the cost of, and the benefits from the treatment, it is possible that additional producers will see the benefit of stimulating desired portions of the limestone, rather than the sections that might get treated in a conventional stimulation process.

REFERENCES

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2. Rae, P., and DiLullo, G., "Acid jetting tunnels through rock," E&P, March 2007.