Good Bugs Vs. Bad Bugs

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Control of micro-organisms during completion of hydraulically fractured wells is a significant component in successful development of a production system. Detrimental bacteria—“bad bugs”—such as sulfate-reducing bacteria (SRB) introduced into the reservoir during drilling or completion, can facilitate biogenic sulfide production, resulting in souring of production fluids and gas, iron sulfide formation and SRB-associated microbiologically influenced corrosion (MIC).

Completing a well without an effective bacteria treatment program can eventually cause operational issues due to sulfide production and MIC, detracting from safety and increasing operating costs.

While routinely dosed at low levels into fracturing fluids to control microbe populations, biocides, by definition, are not well tolerated by certain aquatic organisms and so have potential environmental consequences. In an effort to improve the ecological profile of microbiological control in fracturing operations, a treatment system—SourShield H$_2$S control—for managing SRB was developed using nitrate and nonhazardous live nitrate-reducing bacteria (NRB)—“good bugs.”

SourShield H$_2$S control was administered to wells on three pads in the Marcellus Shale and proved as effective as successful biocide applications for controlling SRB activity, making it a more environmentally friendly alternative.

**Nitrate-based solutions**

Nitrate-based mitigation of SRB has been used as an alternative to biocide injection in the oil and gas industry for decades, particularly in waterflood programs. Nitrates stimulate the metabolic activity of the good bugs, NRB, which in turn can mitigate SRB activity by means of
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three primary mechanisms: competition for available carbon sources; direct metabolic inhibition through the generation of nitrite; and stimulation of specific NRB species, which directly oxidize biogenic sulfide.

However, while shown to be effective in continuously applied methods during waterfloods, nitrate-based programs had not been used during hydraulic fracturing until 2011 when these wells in the Marcellus Shale were treated using live NRB combined with a nitrate source.

‘Competitive exclusion’

In Marcellus Shale well completions, the lower formation temperatures, which typically range from 38 C to 66 C (100 F to 150 F) depending on the depth and regional location of the well, can provide growth conditions for many bad bugs, including organic acid-producing bacteria (APB) and SRB introduced via fluids or from drilling. In addition, environmentally efficient use of water in the Marcellus Shale has helped dramatically increase the reuse of produced water for hydraulic fracturing, allowing the possibility of bacteria making multiple trips downhole and back again, virtually ensuring contamination (Veil, 2010).

Historically, “competitive exclusion” techniques have been used successfully against SRB to mitigate reservoir souring during waterflood secondary recovery operations, where nitrate is added continuously to injection waters to stimulate the activity of NRB already present in seawater (Sunde et al., 2004; Thorstenson et al., 2002). These stimulated NRB are then in a position to competitively exclude SRB by populating the injection area and reservoir while consuming available carbon electron donors, the volatile fatty acids (VFAs).

Secondly, NRBs can dominate this competition by releasing nitrite, a common byproduct of nitrate reduction, which is a metabolic inhibitor of SRBs (Grigoryan et al., 2008).

To facilitate competitive exclusion in the Marcellus Shale wells, both live reservoir-specific NRB and sodium nitrate nutrient solution were introduced into the fracturing fluids during the fracturing operation, ensuring the “double-blow” of simultaneous inhibition of SRB activity and SRB starvation.

Application of treatment
The success of a competitive exclusion program for hydraulic fracturing depends on having sufficient numbers of NRBs capable of surviving under the reservoir conditions. For this reason, the SourShield H₂S control program in the Marcellus Shale wells used a liquid solution containing concentrated live active naturally occurring NRBs selected for their propensity to survive under the downhole conditions of the Marcellus Shale environment while being incapable themselves of producing sulfide.

The live NRB solution and aqueous sodium nitrate were coinjected during completion of the hydraulically fractured well to ensure the fracturing process would push the NRB/nitrate treatment into the fractured formation zones. This same basic application method was used for three well pads, with Pads A and C using a combination of freshwater and produced water for completion, while Pad B used only freshwater.

The wells were monitored for periods ranging from three to 18 months, depending on the date of completion, and treatment efficacy was evaluated by comparing data from the SourShield H₂S control wells to data collected from wells completed in the same manner and, in some cases, on the same well pad using a biocide that historically exhibited good microbial control.

**Treatment results**

In both the SourShield H₂S control and biocide-treated wells, SRB populations were below detectable limits, e.g., well below commonly acceptable levels of $10^3$ cells per ml; however, the NRB/nitrate-treated wells exhibited some advantages.

While most hydraulically fractured wells that would otherwise be susceptible to bacterial contamination and souring are currently being treated with conventional biocides in the Marcellus Shale, using live NRB strains in conjunction with sodium nitrate achieved equal-to-biocide control of wellhead souring as measured by gas phase sulfide and SRB populations.

To date, more than 100 wells have been treated using the SourShield H₂S control since the pilot wells began production in January 2011. The NRB/nitrate approach has been considered successful because general field monitoring did not recover SRB, and low levels of sulfide have been maintained.

No small measure of this success is attributed to use of a specialized strain of good bugs tolerant to field conditions. Without these proven NRB strains, the addition of nitrate alone could have been ineffective for the mitigation of souring and MIC.
The SourShield H$_2$S control offers an ecologically improved alternative to biocide if applied properly in a field comparable to the Marcellus Shale, and future work will include testing the application in other major North American shales as well as increasing the number of strains of NRB available for treatment applications.

**Acknowledgment**