Ultraviolet Disinfection Effectively Controls Oilfield Sulfate Reducing Bacteria

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ABSTRACT

Bacteria control has recently become an important topic for discussion in the oil and gas industry as a result of the consequences of inadequate biocidal treatments. The consequences can range from souring the reservoir with hydrogen sulfide gas, to microbial-induced corrosion, or the loss of fluid stability during stimulation. As regulations become stricter on stimulation-fluid additives, there has been an increasing effort to reduce or eliminate hazardous chemicals, such as biocides that are present in these fluids. This challenge has also been complicated through water-use restrictions. The industry is under increasing pressure to move away from using fresh water and begin using nonpristine water sources, such as produced or flowback waters, which can often have high levels of bacterial contamination.

The use of ultraviolet (UV) light for disinfection has been established throughout various industries, including water-treatment facilities and medical-device sterilization. Ultraviolet disinfection has been recently introduced to the oil and gas industry for reducing the bacterial contamination in fluids used during stimulation operations. This technology has been proven to be successful with a pilot unit that has been operating in east Texas since early 2009. In many cases, a 99.9% reduction in the bacterial contamination can be obtained through the use of UV disinfection. Efforts have begun to improve the functionality of the ultraviolet disinfection system for field operations. A plethora of data is available on bacteria species that are human pathogens, and on the effectiveness of ultraviolet disinfection. However, for the oilfield, sulfate reducing bacteria (SRB) are a particular target of interest. There is little data published on the effectiveness of ultraviolet disinfection on SRBs. Collimated beam tests were conducted at a third-party laboratory to validate the effectiveness of ultraviolet disinfection against Desulfovibrio desulfuricans, a SRB that is commonly found in fluids used in the oil and gas industry. These studies verified that ultraviolet disinfection can be an effective treatment method for treating the target SRB species. This paper outlines some of the techniques used in the laboratory and field testing, and details the operational considerations unique to this application.

BACKGROUND

Well Stimulation

Many oil and gas wells require some type of stimulation treatment, such as hydraulic fracturing, to increase the well's production. In hydraulic fracturing (**Fig. 1**), a fluid comprised mostly of water and sand is mixed by a fracturing blender. Additional components of the fluid system are added at the blender to increase the fluid viscosity. The high viscosity allows the fluid to transport the sand particles. The fracturing pump forces this fluid into the reservoir under high pressure, fracturing the rock formation containing the oil or gas. When the treatment is complete, the water flows out of the well while the sand continues to hold the fractures open. This sand-laden fracture provides a porous path for the oil or gas to flow back to the well. Hydraulic fracturing is necessary for many wells to provide economical production.

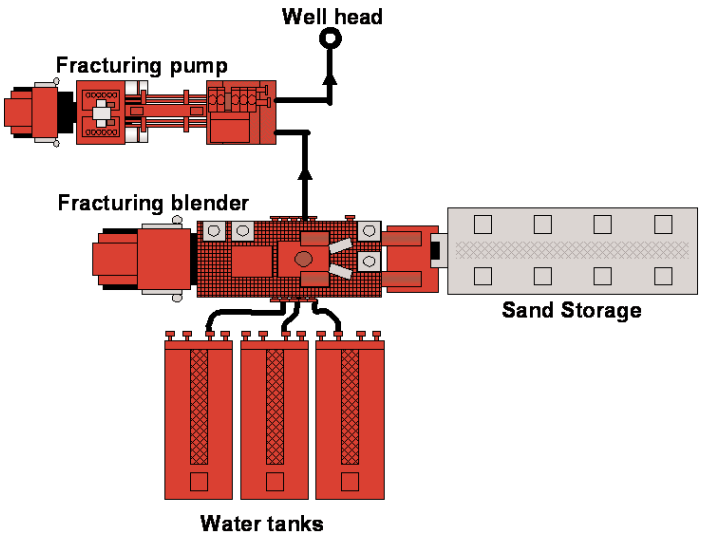

Figure 1: Typical equipment setup for hydraulic fracturing.

Current Biocide-Treatment Programs

Current biocides can broadly be classified as either oxidizing or nonoxidizing. A major downfall of the oxidizing biocides, such as sodium hypochlorite, is that they not only oxidize the cell walls of bacteria, but they can also oxidize the polymer in a fracturing fluid system, which ultimately leads to higher friction pressures (increasing the horsepower required to pump the fluid) or decreased viscosity (reducing the effectiveness of the stimulation treatment). Oxidizing biocides can also have negative effects on metals and elastomeric components of the pumping systems. Nonoxidizing biocides can interfere with polymer hydration or crosslinkers in the fracturing-fluid system and can be inactivated by particular chemical additives that are used in fluid systems, such as oxidizers (Boivin 1995; Clark et al. 1984).

For effective disinfection results, it is necessary to evaluate the water before the biocide application; this step is often overlooked and the water used for hydraulic fracturing is, in many cases, undertreated. Until recently, the issue of bacteria control was not addressed until a problem surfaced, largely resulting from a lack of microbiological expertise in the field (Maxwell 2005). Around the world, the majority of systems where biocides are applied are only minimally monitored, if monitored at all (Maxwell 2005). This approach leads to costly remedial treatments to remove iron sulfide, treat wells for hydrogen sulfide, and combat microbial-induced corrosion (MIC).

Regulations

Stringent regulations are being enacted which limit the chemicals that can be used in stimulation fluids, and certain areas require each chemical component to undergo strict testing to prove the safety of the material. Of all stimulation chemicals, biocides have been subject to the most scrutiny because of the hazards associated with their handling and transportation. Service companies are investigating environmentally friendly alternatives that allow for continued well stimulation while meeting the requirements of the ever-increasing regulations. Disinfecting the water used in well stimulation with UV light can greatly reduce or eliminate the need for the heavily regulated chemical biocides.

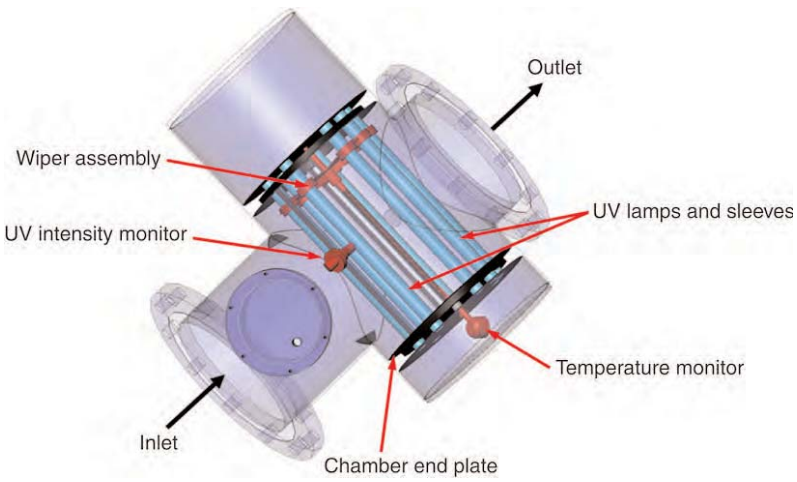

Figure 2: Typical UV reactor chamber.

UV-Reactor Chambers and Treatment-Trailer Design

UV light can be generated by a number of different methods; however, the most common is with the use of mercury-vapor lamps that apply a voltage across a gas mixture, resulting in the discharge of photons. The specific wavelengths and amount of the light emitted from the photon discharge is dependent on many factors, such as the elemental composition of the gas, pressure, voltage and temperature. A typical UV reactor (**Fig. 2**) contains multiple UV lamps that are housed in quartz sleeves. The sleeves penetrate both end plates of the reactor and are secured with watertight seals. The quartz sleeves are equipped with an automatic mechanical (and chemical if required) wiper system that prevents buildup, or even removes, residue from the quartz sleeves. Without an automatic wiping system, the intensity of the UV light would decrease over time (Clark et al. 1984). A UV-intensity sensor located on the top of the treatment chamber monitors the UV light output from the lamps. Each UV reactor requires a power supply and control cabinet. The operator can monitor the UV intensity and system status information, such as lamp faults from the display panel on the control cabinet.

The UV disinfection equipment described above is generally designed to be used in a fixed indoor installation (such as a water-treatment plant). Thus, standard UV disinfection equipment is not designed for exposure to the elements, or for shock and vibration loads. To provide maximum utility in the oilfield servicing business, the UV system must be mobile for frequent moves between well sites, capable of withstanding shock and vibration loads imposed by rough lease roads, capable of withstanding extreme temperature and altitude loads, and capable of generating its own electrical power.

To meet these requirements, the UV system components, along with the support equipment necessary to make the disinfection unit self sufficient (diesel generator set, weatherproof enclosure for the UV power and control cabinets, and a lab area where the bacteria levels can be measured), are placed on a trailer for transport (**Fig. 3**). The use of medium pressure-lamp technology fits the application requirements well because of its comparatively small footprint, capability to maintain disinfection performance under temperature extremes, and robust power supply. The UV reactor chambers and piping system are mounted on vibration dampeners to protect the UV lamps and quartz sleeves from breakage caused by road vibrations. Vibration testing was performed on the lamp and sleeve assembly to verify breakage would not occur. Covers were also constructed for the UV intensity and temperature sensors mounted on the UV reactor chambers for protection from the elements and water ingress resulting from cleaning with a pressure washer.

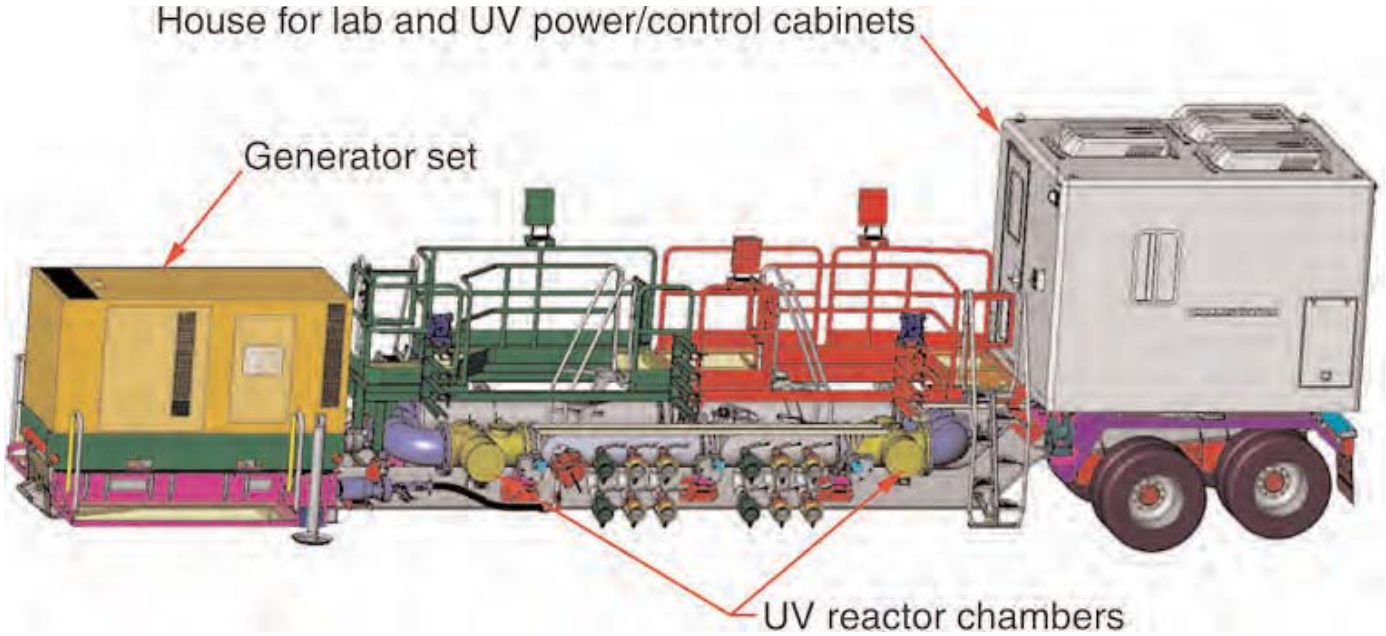

Figure 3: Oilfield UV disinfection trailer.

In addition to equipment design features that ensure mechanical robustness in the oilfield-servicing business, it is important to consider the capability of the power supply and control system to maintain functionality of the treatment process. The extreme environmental conditions in which this equipment operates necessitates a number of special design features not found in typical indoor UV applications. A key feature is the control of lamp output power, not only in the traditional sense of managing the UV dose that is applied to the process water, but also in terms of managing water temperature.

The available water sources in the field are extremely varied with a wide range of quality parameters. UV-transmissivity values can vary from below 10% to greater than 90%. Similarly, wide variations in total suspended solids, turbidity, and mineral content can be seen from location-to-location. However, the UV equipment must provide adequate treatment under all conditions. Thus, having a clear understanding of the UV equipment sizing is critical. The following section details the work completed on determining accurate microbial UV dose-response characteristics. In addition to this laboratory work, the full-scale system design utilized bioassay and computational fluid dynamics (CFD) models of the UV reactor chamber. This combined information, along with the capability to control the UV dose applied to the process water, helps ensure over- or under-treatment is avoided.

UV Dose-Response Determination

There is little data published on the effectiveness of ultraviolet disinfection on SRBs; therefore, collimated beam tests were conducted to validate UV effectiveness against D. desulfuricans, a SRB that is commonly found in fluids used in the oil and gas industry. As described in the previous section, although medium-pressure technology fits the application well, an additional research goal was to compare the relative effectiveness of low-pressure (monochromatic UV at 254 nm) versus medium-pressure (polychromatic) UV. The following sections outline the laboratory work undertaken.

Propagation of D. Desulfuricans

D. desulfuricans subsp. *desulfuricans* 29577 was acquired from Dr. Ralph S. Tanner at the University of Oklahoma in Norman, Oklahoma, and was grown in a SRB medium using a modified Baar's medium for sulfate reducers. The culture was incubated in an anaerobic environment ($\leq$1% oxygen) at 30°C until a black precipitate formed. Once propagated, 1 mL aliquots in cryogenic vials with ~300 µl of glycerol were stored in -80°C freezer for long-term storage. Stock D. desulfuricans was enumerated on modified iron sulphite agar (mISA) (Mara and Williams 1970).

Preparation of Seeded Suspension for Irradiations

For each exposure, a 6-mL suspension was decanted into a petri dish, which was immediately placed in an irradiation chamber purged of oxygen (see collimated beam procedures). The petri dish was stirred during irradiation with 2.5 × 12 mm stir bars.

UV Collimated Beam Dose-Response Determination

Both low-pressure and medium-pressure irradiations were made on samples using standard methods accepted in the field of UV disinfection (Bolton and Linden 2003). However, because of the anaerobic nature of the target organism, the petri dish was placed in a 65-mm diameter irradiation chamber (**Fig. 4**) that was supplied through a side port with nitrogen gas at a rate of 4 scfh to purge the chamber environment of oxygen. The irradiation chamber was fitted with a 70-mm diameter quartz disk cover that was transparent to UV light.

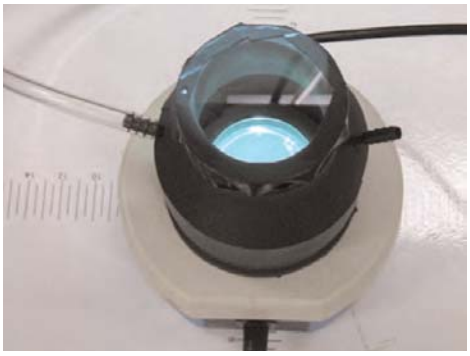

Figure 4: UV irradiation in quartz-covered nitrogen-flooded chamber.

Radiometer readings were taken with the detector placed within the nitrogen-flooded irradiation chamber to account for any absorbance or reflection by the quartz cover or absorbance by the nitrogen gas. Overall irradiance distribution was then determined relative to the center reading. This value was used in the calculation of average irradiation incident to the water surface. Factors influencing average irradiation to the entire volume include reflection from the water surface, depth of the water, and UV absorption of the inoculated test water. The latter was measured at 254 nm by spectrophotometry (Spectronic Genesys 10uv™). UV dose was defined as the irradiation multiplied by the exposure time.

Sample Enumeration

After exposure, samples were serially diluted by injecting 1 mL of sample into prereduced, 9-mL dilution blanks until the desired dilutions were achieved and then transferred into sterile 1.5-mL microcentrifuge tubes. From each of these, 0.1 mL of sample was inoculated into a mISA tempered agar tube for enumeration by pour-plate method. At least two, and as many as three, dilutions of each sample were assayed. All dilutions were plated in triplicate and incubated at 30°C in an anaerobic chamber for five days. Colony counts were then made, with each colony-forming unit (**Fig. 5**) representing one surviving bacterium.

Figure 5: Pour plate with D. desulfuricans colonies.

RESULTS AND DISCUSSION

Low-pressure and medium-pressure dose-response curves are compared in **Fig. 6**. The tailing of inactivation at or above 3.5 log is often seen in dose-response studies, and might have been exacerbated by the low UV transmittance noted in the anaerobic bacterial suspensions. In general, medium-pressure UV was more effective at inactivation of *D. desulfuricans* than was low-pressure UV, achieving higher inactivation levels at any given UV dose.

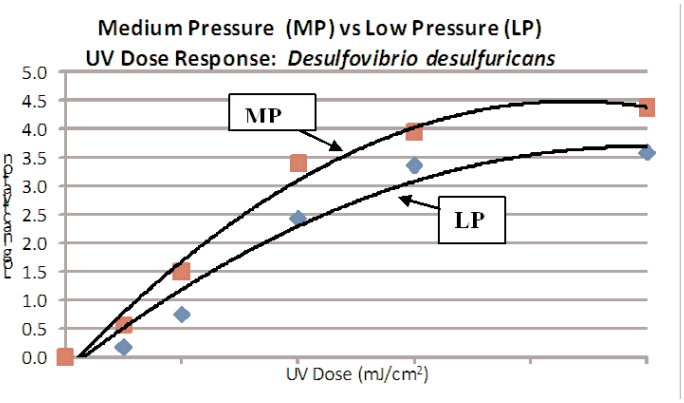

Figure 6: Log inactivation versus medium-pressure and low-pressure UV dose.

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