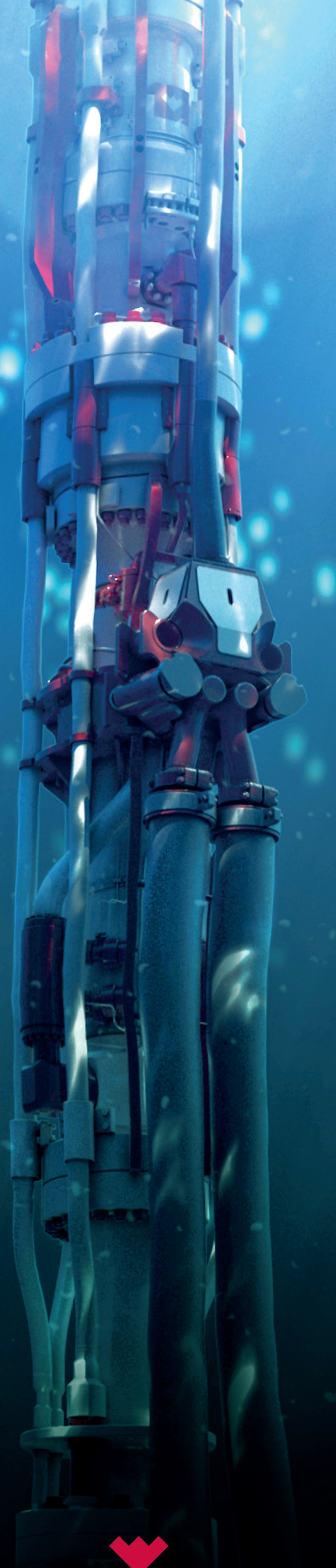
OILFIELD TECHNOLOGY

MAGAZINE | JANUARY/FEBRUARY 2020



VICTORY OVER DRILLING CHALLENGES

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A LIVING SOLUTION

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reveal how natural biosurfactant solutions are enabling greater oil recovery from tight sand reservoirs.

Technology advancements delivered by the upstream oil and gas industry, from smart drilling to automation and data management, have driven a need for more cost-effective oil and gas extraction and production. According to Rystad Energy, North American shale oil in 2015 had an average breakeven price of US$68/bbl. Today, the average breakeven price for the same oil is estimated to be US$46/bbl.[1] With the pressure on operators to extract more production from existing assets and live within their cash flow vs drilling new wells, new technologies are required to help meet this challenge and deliver profitable returns at mid-US$50 oil.

The focus in the US is on low-permeability unconventional reservoirs such as shale, where current recovery factors range from between only 2 – 8%. It is estimated by the US Geological Survey (USGS) that over 46 billion bbl of oil, 280 trillion ft^3 of gas and 20 billion bbl of NGLs are trapped in these low-permeability shale formations, making enhanced shale and tight oil recovery a valuable priority.

Whereas conventional sandstone and carbonate reservoirs have pore sizes in the range of 1 – 100 µm, shale reservoirs have pore throat radii in the range of 1 – 200 nm. Traditional enhanced oil recovery (EOR) techniques, such as water/polymer flooding, are typically not effective or economically viable for shale, since oil recovery through spontaneous imbibition is low if the rock matrix is fractured (low sweep efficiency) and remains saturated with oil.

In the past decade, gas injection, including huff and puff or cyclic gas injection, and gas flooding, have been demonstrated to be promising EOR methods for shale reservoirs, and Houston-based EOG Resources has boosted production from horizontal wells in its Eagle Ford Shale operations in south Texas, US. Laboratory studies have also shown that cyclic injection of chemical surfactants can also improve oil flow from shale wells after fracturing or re-fracturing. Surfactants reduce oil-water interfacial tension and wettability of the shale, which in turn can improve water imbibition, increase oil relative permeability and reduce water blockage at the matrix-fracture interface.

A potential new development under investigation by Locus Bio-Energy Solutions is the application of naturally-produced, sustainable biosurfactants to enhance shale EOR. Laboratory and field data have demonstrated how biosurfactants can outperform traditional surfactants in mobilising oil in conventional and tight sand formations. If this enhanced performance can be translated to ultra-tight formations, this technique may become a low CAPEX alternative technology to gas injection.

Surfactants are the corner stone of most of the chemical additives used in the oilfield today – from drilling and completions fluids such as flowback aids to production chemicals such as wax dispersants and reservoir stimulation chemicals. Surfactants aid oil recovery in reservoirs through wettability alteration and surface and interfacial tension reductions, effectively mobilising oil by reducing the 'drag' between oil and the reservoir rock surface.

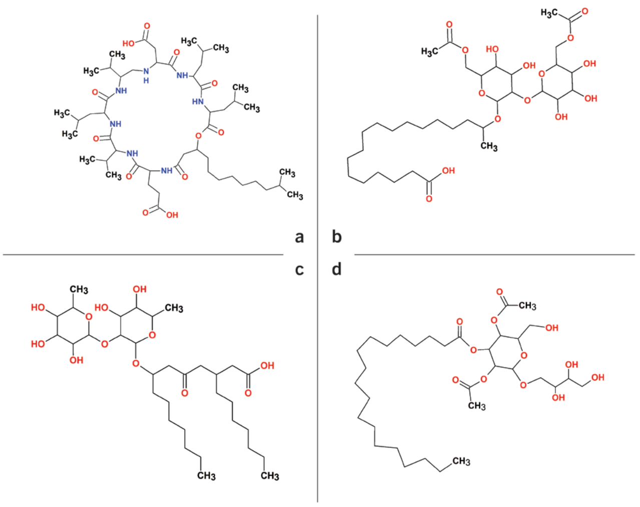

Figure 1. *Examples of biosurfactants demonstrating the structural diversity of naturally produced molecules: (a) a surfactin, (b) a sophorolipid, (c) a rhamnolipid, and (d) a mannosylerythritol lipid.*

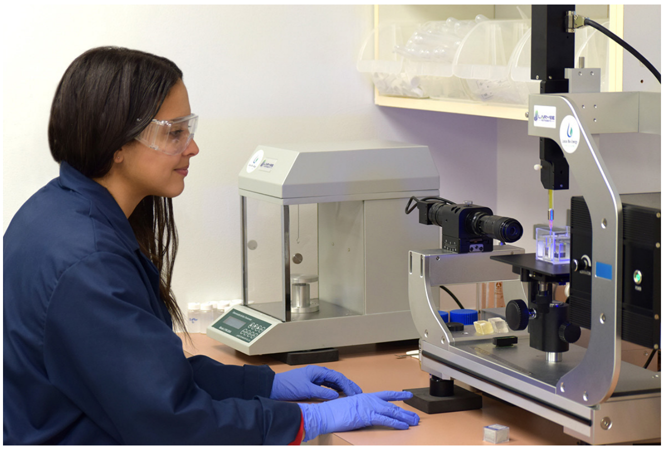

Figure 2. *Modern drop shape tensiometers are modular and capable of performing all surface and interfacial tension as well as contact angle measurements.*

Biosurfactants are 100% natural products that have many identified advantages over traditional, hydrocarbon-based surfactants, such as low critical micelle concentrations (CMC), very low effective dosage rates, very low toxicity, and high activity at extreme temperatures. Of equal importance is that they are biodegradable, sustainable, and compatible with the environment. Biosurfactants are amphiphilic molecules produced by microorganisms (yeasts, bacteria, and fungi) that use renewable resources such as carbohydrates and natural oils as a carbon source.

Biosurfactants have been effectively used for some time in a wide range of applications from EOR, bioremediation, oil mobilisation, skincare preparations, cleaning product formulations and emulsifying agents, among others. Four major groups are generally considered: lipopeptides and lipoproteins (e.g. surfactin), polymers (e.g. emulsan), particulate (e.g. vesicles and fimbriae), and lipid-containing amphiphilic molecules. The latter category can be further divided into various subcategories according to the nature of the hydrophilic headgroup (glycolipids, phospholipids, fatty acids, etc.).

Glycolipids are among the largest, most interesting and investigated groups of biosurfactants to date due to their higher fermentation yields and versatility in applications. Significant work has been conducted to date on rhamnolipids, mannosylerythritol lipids, and sophorolipids, currently the most important compounds in the field. Examples of the chemical structures of key biosurfactants are shown in Figure 1.

Surface/interfacial tension reduction is a key measure of a surfactant's performance, along with its ability to alter surface wettability. There are three main methods used to measure equilibrium surface and interfacial tensions. Two of the methods (Du Noüy ring and Wilhelmy plate) are based on force tensiometers, while the third is an optical method: pendant drop. The shape of the drop hanging from a needle is determined from the balance of forces, which include the surface tension of the liquid being investigated.

Modern computational methods using iterative approximations allow for solutions of the Young-Laplace equation to be found. Thus, the surface or interfacial tension between any two immiscible fluids with known densities can be determined. For optical tensiometry, the size of the droplet is important, and it should have a tear or pendant shape. The sessile drop method is by far the most commonly used method to measure contact angle. Contact angle is one of the common ways to measure the wettability of a surface or material. Wetting refers to how a liquid deposited on a solid (or liquid) substrate spreads out, or the ability of liquids to form boundary surfaces with solid states – a key parameter to measure in order to determine oil mobilisation potential. The degree of wetting is determined by measuring the contact angle, which the liquid forms in contact with the solids or liquids. The larger the wetting tendency, the smaller the contact angle and consequently the surface tension are. A wetting liquid is a liquid that forms a contact angle with the solid which is smaller than 90˚, whereas a non-wetting liquid creates a contact angle between 90 – 180˚ with the solid. Modern drop shape tensiometers are modular and capable of performing surface and interfacial tension as well as contact angle measurements.

Biosurfactants are amphiphilic compounds produced by living microbes, mostly on cell surfaces, or are excreted extracellular hydrophobic and hydrophilic moieties that accumulate between fluid phase to reduce surface and interfacial tensions in a similar manner to chemical surfactants. The CMC of biosurfactants range from 1 to 2000 mg/L, whereas interfacial (oil/water) and surface tensions are respectively approximately 1 and 30 mN/m. High-performing surfactants are able to reduce water surface tension from 72 to 35 mN/m and the interfacial tension of n-hexadecane from 40 to 1 mN/m. The biosurfactant

Surfactin possesses the ability to reduce the surface tension of water to 25 mN/m and the interfacial tension of water/hexadecane to < 1 mN/m. Biosurfactants can be used at high temperatures and pH values ranging from 2 to 12. They also tolerate a high salt concentration of up to 10% (or higher), whereas 2% sodium chloride (NaCl) is enough to inactivate some common synthetic surfactants.

In a study conducted by Locus Bio-Energy, surface tension reduction of water by a biosurfactant was compared to a commercially-available chemical surfactant (a mixture of alcohol ethoxylates) using the Du Noüy ring method. Due to its very low CMC, the biosurfactant was able to reduce surface tension at much lower concentrations when compared to the chemical surfactant (Figure 3).

In another study, the efficacy of biosurfactants in reducing the interfacial tension (IFT) of dodecane-water was demonstrated at various dosage rates as a function of time using a drop shape analysis method. As shown in Figure 4, the biosurfactant reduced IFT from approximately 50 mN/m to approximately 13.5 mN/m at 30 ppm within 200 seconds.

Production increase from tight sand reservoir using cyclic biosurfactant treatments

Legacy oil production from an Appalachian Basin lease had been declining since 2013. A 2.5 year, field-wide study was undertaken by the company with the cooperation of an independent operator in the Northeast US, to evaluate the field performance of a biosurfactant-derived programme. More than 70 wells were scattered on the formation, consisting of various Upper Devonian-aged sandstones, and the productive zones had 7 – 15% porosity. Both vertical and horizontal wells were treated with vertical depths ranging from 2500 – 4500 ft, and lateral lengths up to 2000 ft. Wells were producing 1 – 30 bpd of oil and the gas oil ratio (GOR) was approximately 10. Water cut averaged at 10% and brine salinities ranged from 40 000 to 150 000 ppm.

Production peaked in late 2013 when the operator stopped new drilling, and production decline began at a 45% annual rate over 2.5 years. Maintenance treatments to remove organic deposits were applied using BTEX solvents/Diesel batch or drip methods, with no impact on production increase while a few HSE incidents occurred.

After a comprehensive laboratory evaluation, a field-wide biosurfactant treatment programme commenced in mid-2016 and continues today. Locus's AssurEOR treatments were applied at intervals of 1 to 2 months as cyclic biosurfactant imbibition for well stimulation and EOR. 95% of the wells exhibited increased production rates during the treatments, resulting in an approximate overall 46% average increase over baseline. Exponential decline curve analyses of the field results forecast a substantial increase in projected future oil production, reducing the annual decline rate from 45% to 8.8% and thereby increasing the operating asset value. The results and trends are illustrated in Figure 5. Of particular interest is the area between the solid black and dotted green lines, which indicates a higher oil recovery rate since the start of the new treatments, and a predicted 2-year future production increase of 241%.

Conclusion

Consistent lab and field results show that biosurfactant treatments can be a viable solution for enabling cost-effective oil and gas extraction and production from low-permeability unconventional reservoirs such as shale. This offers the real prospect that the productivity of shale wells can be significantly increased from the current 2 – 8% of original oil in place (OOIP) recovered, thereby continuing the viability of the US's shale reserves for decades to come.

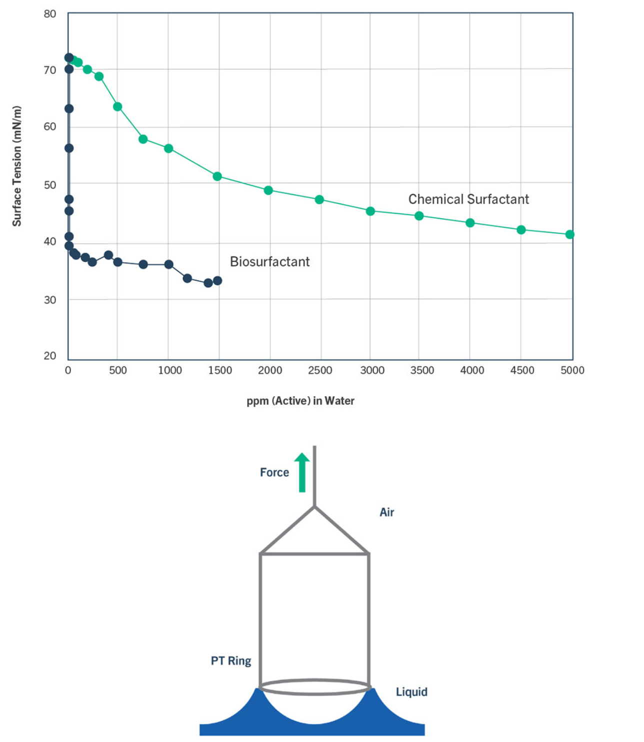

Figure 3. *Comparison of surface tension reduction of water by a biosurfactant vs a chemical surfactant using the Du Noüy ring method.*

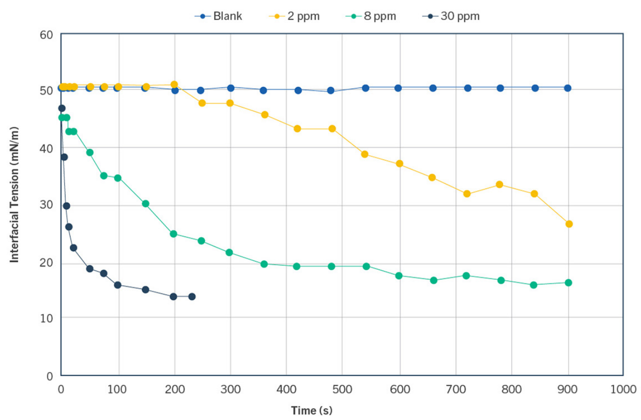

Figure 4. *Interfacial tension of dodecane-water measured as a function of biosurfactant concentration and time using drop shape analysis method showing efficacy at even 2 ppm activity level.*

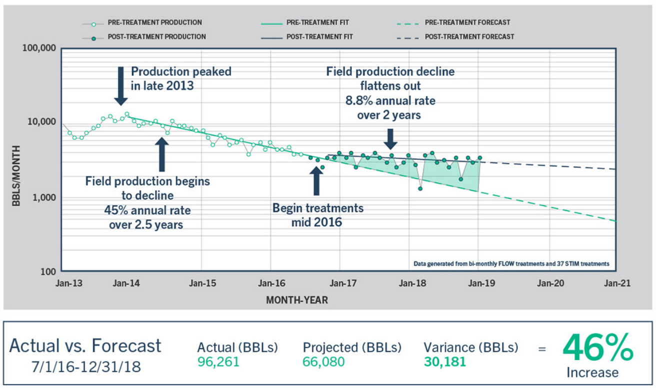

Figure 5. *Composite production analysis summary for more than 70 wells treated with a biosurfactant programme indicating that the treatment yielded additional 46% oil recovery compared to historic decline predictions.*

Reference

1. Rystad Energy, 'Rystad Energy ranks the cheapest sources of supply in the oil industry', https://www.rystadenergy.com/newsevents/news/press-releases/Rystad-Energy-ranks-the-cheapest-sources-of-supply-in-the-oil-industry-/ (09/05/19).