From Bacteria to Barrels: Microbiology Having an Impact on Oil Fields

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The production vessel used on Statoil's Norne field in the North Sea. It was the first offshore field where microbial treatments were used to enhance oil recovery.

The science behind the use of microbes to enhance oil recovery has advanced significantly, but it suffers from old associations.

After decades of trial and error, those working on microbial enhanced oil recovery have identified the "oil-eating" bacteria that laboratory tests suggest can change the properties in an oil reservoir, and know better how to put them to work. The increasing knowledge of the role microbial life plays in oil and gas reservoirs has also led to new approaches for controlling corrosion, managing bacterially produced hydrogen sulfide, and creating natural gas from coal.

EMERGING TECHNOLOGY

(In this story, "eat" is used to describe the metabolic processes of bacteria. For instance, oil eating is more precisely hydrocarbon oxidizing.)

But the greatest potential payoff and the most debate come from the idea of microbes for enhanced oil recovery (MEOR). "There is a much greater understanding of what microbiology is doing in a reservoir" and how that can be used to produce more oil, said Stuart Page, chief executive officer of Glori Energy, a company that has staked its future of convincing the industry that microbes can be used to recover more oil.

MEOR is still often associated with promoters promising better oil production by dumping molasses into oil wells. "From a historical point of view, it is seen as snake oil," Page said.

The image is darker than the history, which has been more hit and miss. For those in small companies, such as Glori, and big ones, such as Statoil, the challenge has been convincing experts in the field that promoting bacterial growth can be a consistent and effective way to produce more oil.

Work on using microbes to find oil goes back further than seismic imaging and the history of MEOR goes back more than 50 years.

Claude ZoBell, the scientist hired by the American Petroleum Institute who first discovered the microbiological origins of oil, patented his MEOR concept in 1957. His approach involved introducing high-performing bacteria into a reservoir. It is one of many that has been tried and failed as people slowly came to better understand the exotic life in reservoirs.

Interest in the microbiology of oil is on the upswing because of the need to extend the life of older fields, and indications that a better understanding of the microbiology of a reservoir can help do that. "We're in a renaissance of interest" in microbiology in exploration and production, said Tom Jack, a University of Calgary adjunct professor who has been involved in the field since 1980.

Statoil has long been a leader in this field. Shell, BP, ConocoPhillips, and DuPont are among the large companies supporting research and testing in microbiology and oil. The Norwegian company has effectively used microbial methods to treat well souring and enhance production in the North Sea. It was the first to do a MEOR project offshore, injecting nitrates, nutrients, and air into its Norne field, after testing the idea at an onshore field in Austria.

Statoil has formed a research partnership with Glori, a company founded with backing from one of the top venture capital firms in Silicon Valley, Kleiner Perkins. Glori uses technology initially developed in India and has added more over the years. With the deal, it will have access to Statoil's technology, and Egil Sunde, its reservoir microbiology specialist, will be advising Glori.

There is growing interest in MEOR, but microbiologists are still a rarity in the industry. Sunde said that when the subject of MEOR comes up, he frequently hears that "nobody else is doing it, so why should we?"

Making a Case for MEOR

The critiques of MEOR are often more direct. One skeptical reservoir expert summed up the challenge: "MEOR has been looked at for decades; none of the reputable scientists back it. There have been no validated results other than lab tests in tubes."

Sunde has heard and read the arguments that promoting microbes in an oil formation will not allow greater recovery. He points to case studies by Statoil and Glori that showed greater production where it has been tried, and says: "The point is MEOR obviously works."

But he admits the results are not explained by the current theories of how waterfloods work in older reservoirs. "They need to understand how residual oil can be mobilized in ways that are not presently accepted," said Sunde. He has written a paper explain-

Bringing Back the Dead: Gas Fields Revived Using Microbes

Microbial methods for pulling more out of oil and gas fields are typically tried on fields in dire straits. In Wyoming, Luca Technologies has taken it a step further by accumulating 1,350 coal seam gas wells in the Powder River Basin with little or no production.

Its plan is to return them to service by pumping in water and nutrients to revive dormant microorganisms that produce gas from coal, said Bob Cavnar, the company's chief executive officer. Rather than calling the creatures bacteria, he prefers to use the more productive sounding "methanogens." The goal is to create conditions for the microbes to eat coal in a process that results in methane.

Luca is not alone in its interest. A competitor in Wyoming, Ciris Energy, is using a different coal-to-gas approach. In Canada, a research consortium, called the Hydrocarbon Metagenomics project, lists finding ways to speed the conversion of coal into methane among its primary goals. The four-year project involves four universities and two provincial science organizations.

Researchers also are working on using bacteria to turn heavy crude into methane. Going from oil to gas is not an attractive option at current prices, but it could be a useful skill in places where heavy crude would not be produced otherwise.

The challenge is finding ways to produce gas in real time. "Coal seam methane is associated largely from bacterial activity that occurs over geologic time," said Sean Caffrey, project manager of the metagenomics project. It is seeking to understand what varieties of naturally occurring microorganisms do the work and how to control their behavior.

Going from coal to natural gas is a multistage process with microbes eating coal to create hydrogen, acetates, and carbon dioxide. Ultimately this series of digestive events yields methane.

Luca, which has spent years on its methods, aims to prove that it can deliver in the field, starting with a group of 120 wells. Luca adds water—coal seam gas production requires removing the water that microbes need to thrive—mixed with a small amount of nutrients tailored to stimulate the varieties involved in turning coal into gas.

New sources of hydrocarbons come with new regulations. Water from coal seam gas fields can affect the water table so Wyoming will be among the first states to write water protection rules. Cavnar said the injected water contains minute quantities of nutrients, such as yeast extracts and phosphates, which are generally consumed by the microbes. To demonstrate that the formula will not harm drinking water, he drank a glass of the nutrient mix at a public meeting.

The first goal is a well producing 30 Mcf/D, which Cavnar said could be profitable even when gas sells for just under USD 4/Mcf. The economics reflect the desire of well owners to shed wells for little to avoid the liabilities associated with abandonment.

"We think of ourselves as the photo negative of the big shale players that drill huge well and have huge capital and high production costs, but high declines in production," Cavnar said.

Tanks like this one are used by Glori Energy to pump its nutrient mix into an oil field. The blend is customized to encourage the growth of certain bacteria said to promote production in older fields.

ing his theory that he has submitted for delivery at a future SPE meeting.

Page of Glori said the challenge of proving how enhanced oil recovery works is shared by other methods, such as low-salinity waterflooding.

MEOR requires expanding the populations of oil-eating bacteria native to oil formations. The population explosion, which uses up a small amount of oil, is thought to encourage oil production in a variety of ways.

Molasses can also encourage growth, but the microbes that thrive on sugar are not thought to provide any benefit for oil production. The exact formula of the mix added to the water used in flooding is a trade secret for companies in the field. The mixes, based on the conditions in each field, commonly include ingredients found in fertilizers, such as nitrates and phosphates, which are in short supply in oil reservoirs.

Lab tests have found that the bacteria can affect everything from the wettability by loosening the bond of the oil on the rock, to the interfacial tension separating the water and the oil, thereby allowing the water to sweep it away. Much of the attention has been on how the growth of the bacteria can change the relative permeability in the formation, directing more of the water through zones holding oil for better profile control.

Ganesh Thakur, a vice president at Chevron Energy Technology Company and an expert on waterflooding, said microbial techniques show promise for profile control. But it needs to be demonstrated on a large field scale to convince the industry of the technology's viability, he added.

A Field Test

Glori has seen a significant rise in interest since it reported on a test of the technology at SPE's Enhanced Oil Recovery Conference in July. The paper (SPE 144205) shows production gains after its MEOR treatment, called the Aero System, was tried in a field owned by Merit Energy.

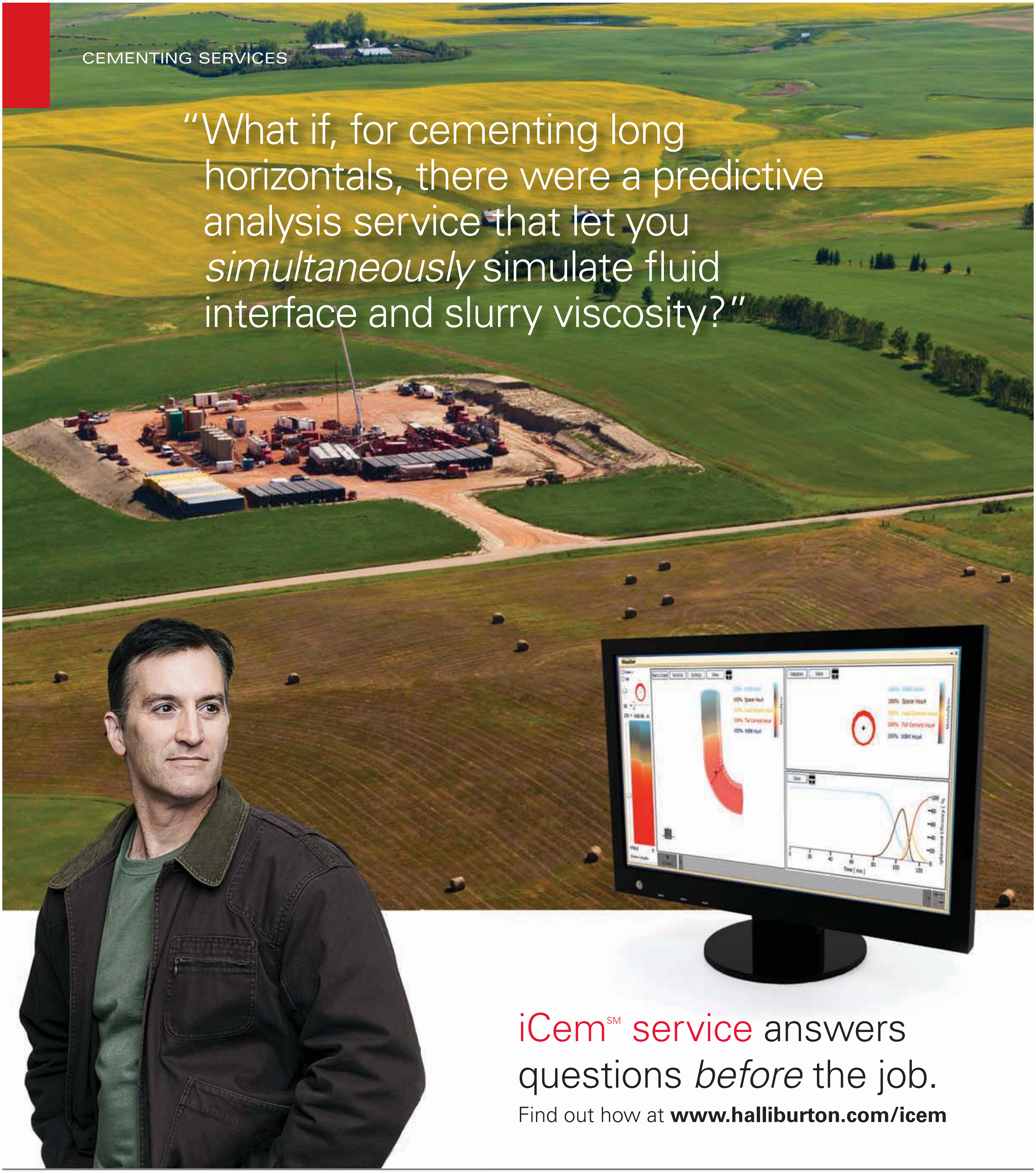
Statoil also was involved in the test involving eight wells in the Stirrup field in southwest Kansas. About 90% of the output from that part of the 26-year-old field was water. Over one year, the company reported a net gain of 750,000 gallons of oil (17,900 bbl). The company recently reported the treatment has added more than 250,000 gallons (6,000 bbl) of output through September.

Most of the gain came in a single well, 12-2, where the oil output settled at 60% higher. The water produced did not rise as much, resulting in a reduced percentage of water produced. The gains reduced the water cut from 91% to 88% for the wells studied.

While the test was ongoing, the field's waterflood system injecting the nutrient mix into the field was modified. One well used to inject water was taken out. Analysis of the field suggested a fault prevented water from that well from pushing oil out of the production wells. One production well was converted to an injection well to serve two producers apparently not served by the remaining injection well.

Page said the results since then have been encouraging. He added that the analysis showed the gains could only be explained by microbial EOR. He pointed to the reduced water cut as a sign that the treatment had an effect.

Merit's exploitation manager at the field, Brad Bauer, said they saw good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Microbes in the Oil Field

Bacteria that have an impact on the oil and gas business fall into two columns—helping and hurting. On the bad side, bacteria cause corrosion and sour wells with hydrogen sulfide. On the good side, they have been used to find oil, mitigate the problems other bacteria cause, and quite possibly produce more oil and gas.

Finding Oil and Gas

The use of microbes in oil exploration goes back to the days before seismic imaging became the dominant exploration tool. Soil samples are still tested by some for hydrocarbons, such as trace amounts of methane seeping to the surface, or the bacteria that dine on it.

This practice, which has some of its oldest roots in Russia and eastern Europe, was studied by investor-owned oil companies in the 1950s. Where the geology is relatively uncomplicated, it can point to the presence of oil or gas underground. It must be used in conjunction with other methods because it cannot predict how far down the hydrocarbon is.

One such method is used by Geo-Microbial Technologies, one of about 20 consulting firms looking for oil using microseepage. Dietmar "Deet" Schumacher, director of geochemistry, said the company's study of nearly 2,800 wells using the method in conjunction with traditional tools including seismic, concluded that it is 89% accurate in predicting dry holes and right 82% of the time in predicting where to drill.

Fighting Corrosion

Studies that showed bacteria can cause corrosion in oil fields and pipelines go back more than 25 years. Oil-eating microorganisms can damage steel by producing acids or iron sulfides as a byproduct. Some even eat iron, said Gary Jenneman, corrosion management supervisor at ConocoPhillips.

The company has used the growing understanding of how bacteria form destructive biofilms to develop better focused, less toxic ways of preventing the damage. One method combines biocides and natural control approaches.

To gain a better understanding of the microbes causing the problems and the traits that may be used in control strategies, ConocoPhillips and Total helped found the University of Oklahoma Biocorrosion Center, which is studying what bacteria cause corrosion and how they can be controlled.

The goal is to use the knowledge for more targeted approaches that use fewer toxic chemicals and cost less than biocides designed to kill all varieties of bacteria. "In our labs, we are testing biocides and how effective they are against biofilms and corrosion," said Jenneman. "We're not interested in killing bacteria; we are interested in controlling corrosion."

Souring Solutions

As injection wells using seawater have grown, so have problems associated with well souring. The problems stem from injection water containing sulfates, which certain bacteria in oxygen-free environments convert into hydrogen sulfide, which is toxic, corrosive, and flammable.

Treatment options include investing in water treatment to remove the sulfates or going after the sulfate-consuming bacteria underground. Biocides often do not work because they can be absorbed in the formation and are difficult to deliver throughout a field.

In the North Sea, Statoil turned to a biological option: Crowd out the sulfate-reducing bacteria by building up the population of competitors. It did so initially by pumping air into the formation, said Egil Sunde, a reservoir microbiology specialist at Statoil. A more common solution, which has also been used by companies such as Shell, BP, and Maersk, is mixing in nitrates into the injection water to encourage the compound to consume bacteria that crowd out the sulfate eaters.

Making and Eating Methane

In ponds holding wastewater from oil sands production, bacteria show up on both sides of the ledger. They aid in settling these lake-sized bodies of water. In the process, some produce methane, while others living near the surface can consume the greenhouse gas.

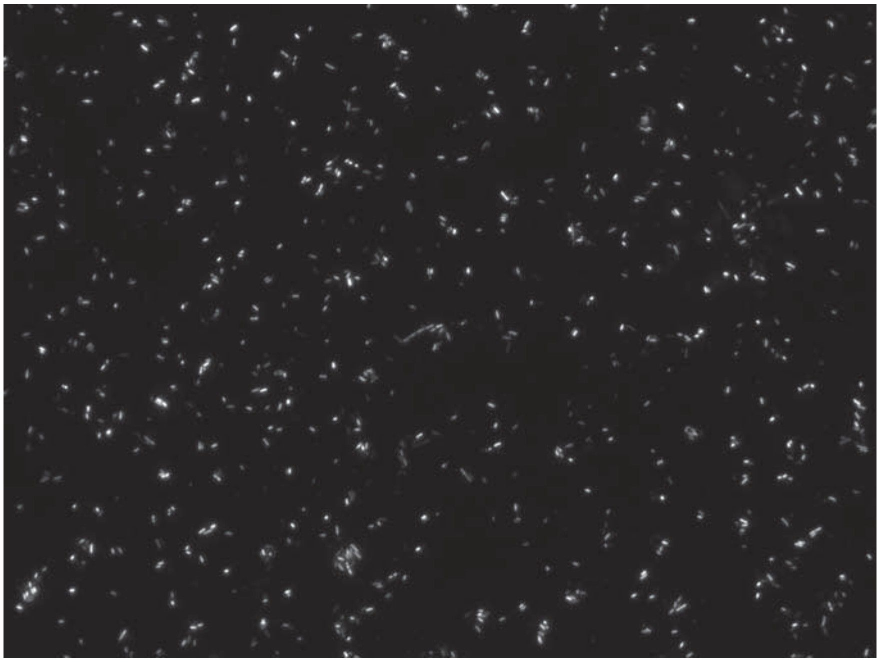
The Hydrocarbon Metagenomics project, which is building a database of the species found in a wide range of habitats, hopes to apply this knowledge to problems such as methane emissions in the tailings ponds. The goal is to balance the bacterial populations so the methane produced by one variety is consumed by another, said Sean Caffrey, who manages the metagenomics project. They are also seeking varieties capable of breaking down toxics, such as toluene.

The project is also studying how groups of methanogens are able to turn coal into methane. There are companies out to prove that they can profitably speed the work on these natural gas producers enough to revive old coal seam gas fields.

Using Microbes for More Oil

The idea that promoting the growth of certain microbes can mean more oil production has been around for a long time. But the science needed to understand why it works, or not, is still developing. It is thought that MEOR can increase production by rerouting the waterflood into areas where oil remains, loosening its hold from the rock, thus loosening the bonds between the oil and the rock.

One advantage of MEOR is the cost—the only equipment needed is a tank for the nutrients that are pumped in via the existing waterflood system. Results have been reported within weeks. Skeptics question the inconsistent results from past tests. The science behind this field has advanced, but more field testing is needed to show that it can consistently deliver, and research is needed to show how it can be tweaked to deliver more.



A magnified image of bacteria from an oil field suggests the challenge of identifying the varieties and behavior of microorganisms in an extreme environment.

indications. "To the best of our ability, through a very careful look at the current projections, and what it was doing when the project started up, we feel the most likely explanation for the impact on Well 12-2 is MEOR," he said.

Bauer said it is difficult to nail some things down because production from each well is not continuously measured in the Stirrup field. The cause and effect relationship between MEOR and production changes is hard to establish in a field trial. Jack of the University of Calgary said, "EOR is problematic. It is hard to show it works in the lab and it is hard to show in the field."

A 5% production gain for a field would be considered a good outcome considering the relatively low cost of MEOR. Proving that the bacteria were the cause is complicated by the way fields often are changed during testing.

The need to modify operations to maximize daily production will normally trump plans for a controlled field experiment, said Sean Caffrey, project manager of the Hydrocarbon Metagenomics project, a Canadian research consortium set up to broaden the knowledge of microbes found in oil, gas, and coal formations. "For microbiologists, it is hard to do testing. They are lucky to get a well."

In order to gain control, Glori bought an old field in Kansas it calls the Green Field, which will be its proving ground to test the effectiveness of its microbiology research and ways to improve the technology.

Microbial Enhanced Lab Testing

Lab testing offers multiple reasons why microbes may matter. Statoil reported that it has found that bacteria were able to create a significant reduction in the interfacial tension normally separating the water and oil. Oil-consuming bacteria live in water near oil. Statoil said the microorganisms are able to straddle that boundary by creating a natural biosurfactant called tenside. A laser light scattering technique is used to measure the change in the interfacial tension, which the company described as "notoriously difficult" to do.

DuPont's lab testing found little change in that measure. In a paper (SPE 129657), the company reported that "some drop in interfacial tension is possible," but not enough to cause the emulsification that would facilitate significantly higher production. The tests did indicate the microbes can alter the wettability of the rock. The lab tests observed that growing populations of microbes reduced the flow in channels where water had been bypassing the oil. This change in the relative permeabilty redirects the waterflood into passages with oil.

The lab test supports a widely held theory of why MEOR can increase production. Others are studying conditions in formations to see if what goes on there resembles the lab setup.

Testing to see what happens on a microscopic level and then scaling that up to what goes on in a field is a challenge. Creating more realistic tests of what goes on in a reservoir is a long-term project for the Energy Biosciences Institute, which is funded by BP.

The group has spent three years working on a variety of projects, ranging from new lab testing methods to more accurately simulate what goes on below to comparative studies of the bacterial life in mature oil fields with places that have never been drilled before, said Susan Jenkins, managing director of the institute, who said the work could take another decade or more.

Making MEOR work will require a greater understanding of the conditions needed to control both the populations of select bacteria and changes in the waterflood likely to produce more oil, said Li Li, an assistant professor at Pennsylvania State University who is working on computer models of these processes. "It is a complicated problem. We are dealing with bacteria, and dealing with reservoir properties—porosity and permeability—that vary."

A Hybrid Approach

Developing improved microbial recovery methods starts with bringing a range of talents often not found in an oil company—microbiologists, reservoir engineers, chemical engineers, and geophysicists. To work effectively, the specialists need to learn how to communicate in each other's language.

"The point is in the past, these ideas on microbiology were proposed by engineers who didn't understand much about microbiology, or a microbiologist who didn't know anything about reservoir engineering," said Bart Lomans, principal researcher at Shell. When he joined Shell, he embarked on a program to learn reservoir engineering.

These sorts of collaborations have paid off for the industry. A better understanding of the bacteria at work in oil fields is changing the methods used for corrosion control and well souring.

When Sunde joined Statoil in the mid-1980s, the company was beginning to deal with well souring caused by bacteria that eat sulfates, producing hydrogen sulfide. More precisely, these anaerobic sulfate-reducing bacteria are using the chemical as an electron acceptor, just as aerobic creatures use oxygen.

The goal of microbial souring techniques is to promote the growth of other bacteria that crowd out the sulfate-reducing ones. Statoil did it by injecting air from the surface, adding oxygen to the microbes' environment. More often calcium nitrate is added to the waterflood.

Gary Jenneman, corrosion management supervisor at ConocoPhillips, said a greater understanding of the microbial life in reservoirs has helped deal with souring, which often cannot be effectively treated using biocides.

He sees the research work into the biological origins of oilfield problems creating more options based on a better understanding of what works. For instance, ConocoPhillips in collaboration with the University of Calgary has created combinations of biocides and chemicals such as nitrites that have been found to inhibit the activity of corrosion-causing bacteria that are less toxic to the environment, cost less, and are as effective.

"We can't eliminate biocides. We can lessen the amount of chemicals used with a combination of these strategies," said Jenneman. "Microbiology has been an area that is sometimes overlooked. It does impact corrosion and souring and potentially, there could be other opportunities." **JPT**

For further reading:

SPE 144205 *• "Field Experience From a Biotechnology Approach to Water Flood Improvement" by B.G. Bauer, Merit Energy, et al.*

SPE 129657 *• "Microbial EOR: Critical Aspects Learned From the Lab" by Scott C. Jackson, DuPont, et al.*

NACE 04760 *• "H_2S Inhibition by Nitrate Injection on the Gullfaks Field" by Egil Sunde, Statoil, et al.*

SPE 129657 *• "Biogenic Gas Generation From Shallow Organic-Matter-Rich Shales" by M. Cokar, University of Calgary, et al.*

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