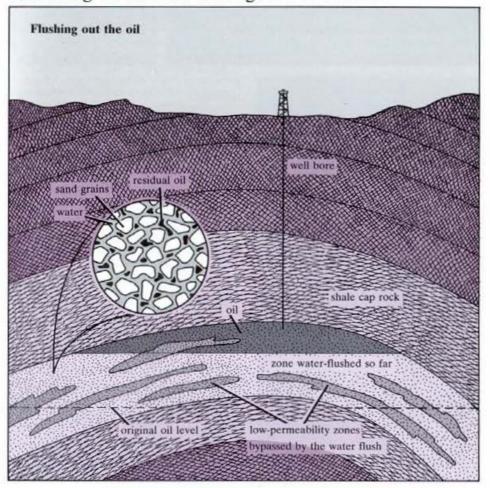
Bacteria to boost oil recovery

That popular image of the oil strike, with its huge gushing plume, tends to mislead people about the ease of extracting oil from its underground reservoir.



After the initial geyser settles down, wellhead pressure may drop so low that the oil has to be pumped out. The flow continues to drop until, towards the end of the well's economic life, water is forced into the system to try to flush out the remainder. Yet, despite all these efforts, the great bulk of the oil present at the time of the gushing discovery stays firmly in place, embedded in the pores of the sedimentary rock that first trapped it.

A lot of factors influence the amount that can be recovered from any reservoir. In rare cases 75% of the 'oil-in-place' (OIP to the oilman) can be brought to the surface; but, at the other extreme, with some reservoirs the oil only ever seeps out, and as little as 5% may be all that can be garnered. On average, the world-wide recovery rate is only 30% of the initial deposit.

In the past this dismal recovery figure

After the initial gush settles down, water is flushed through the reservoir to aid oil extraction. However, patches of low-permeability rock don't allow the flushing water entry and, where it manages to enter and pass through, oil droplets remain trapped in pores between the sand grains. As a result, much oil remains after the primary extraction. Some of this can be removed by surfactants.

caused little concern: oil was cheap and the 'exhausted' well was written off. And, with 500 000 exhausted wells peppering the United States countryside alone, obviously a huge volume of oil remains inaccessible using current technology.

Given these figures, it is only natural that scientific and commercial groups have become interested in finding ways to extract that trapped oil. Methods they have employed include lighting fires in the reservoir (the heat lowers the oil's viscosity and it flows a bit more easily) and injecting steam, carbon dioxide, or natural gas to increase the pressures within the well and drive more oil to the surface. However, such physical techniques present big problems: they consume a lot of energy and can have destructive effects on the local environment; the cost-benefit ratio is not always favourable, and the technology employed needs further refining.

The alternative is to use a chemical method. The oil trapped in an exhausted reservoir is in the form of tiny drops mixed with water and if a surfactant — a chemical that lowers the inter-facial tension between the two — is added, the water-oil mix flows more freely.

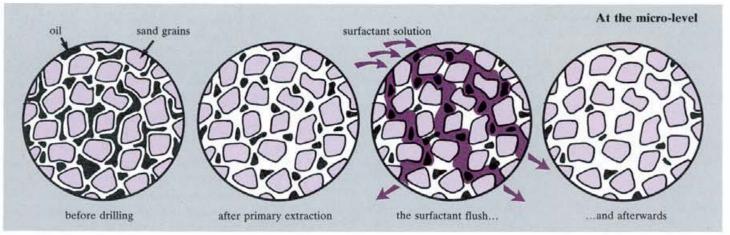
A huge volume of oil remains inaccessible using current technology.

Unfortunately the majority of surfactants available are derived from petrochemicals and, since they have to be used in large quantities to be effective, a substantial energy cost is involved. One estimate is that one-quarter of a barrel of oil is expended in producing the surfactant that will extract an extra barrel of oil. Not surprisingly, chemical methods are also financially expensive — costing approximately US\$15 per barrel of additional oil recovered. Added to that are major environmental costs: the surfactants are seldom biodegradable and heavy contamination of local waters can follow on their use.

A microbial approach

Back in 1948, Dr Claude ZoBell from the University of California suggested that microbes capable of producing surfactants could, when injected into the reservoir, help overcome the problems associated with synthetic surfactants. This suggestion received little attention until recently, when research groups around the world — fuelled by the oil shortages of the 1970s and well aware of the potential in microbial manipulation — began making serious attempts to isolate and characterize surfactant-producing microbes that were adapted to life in an oil well.

Within Australia a group from the Baas Becking Geobiological Laboratory — a research organization funded by the Australian Mining Industry Research Association (AMIRA), CSIRO, and the Commonwealth Government's Bureau of Mineral Resources (BMR) — has been researching microbiologically enhanced oil



A surfactant solution injected at pressure into an oil well chooses the easiest path through the sandstone and can bypass significant quantities of oil. The microbial system promises to give higher recovery rates.

recovery (MEOR), using funds provided by AMIRA and the National Energy Research Development and Demonstration Council. The Baas Becking team is led by Dr Bohdan Bubela and includes Dr Craig Davis and Miss Andrea Blanks, of CSIRO, and Mr Brian McKay of the BMR.

The oil industry has had some uncertainty about the value of deliberately injecting microbes into oil wells. Some oil well microbes produce corrosive sulfur compounds that have deleterious effects on drilling equipment, or else downgrade the oil quality. However, according to Dr Bubela, careful selection of microbes avoids such problems and the big advantage in MEOR, at least in initial tests, is that the surfactant-producing microbes congregate precisely where they are needed: at the water-oil interface.

A number of oil companies are interested in applying microbiologically enhanced oil recovery technology.

In an exhausted reservoir one barrel of oil (approximately 200 litres) is dispersed throughout 100–10 000 cubic metres of rock in the form of some 100 billion tiny droplets. To try to 'sweep' up this oil, large quantities of surfactant — typically somewhere between 100 and 1000 tonnes, in a 1–5% solution—are forced down the well.

The problem with the high-pressure injection of such a large volume is that the reservoir is usually riddled with fault lines (from natural geological processes) and there is also great variation in the rock's

permeability. In practice the reservoir is not a uniformly porous vessel and the indiscriminate injection of synthetic surfactants sees the solution take the easiest path through the rock. Consequently it can bypass large pockets of oil. Something similar happens at the pore level, with the sweeping fluids choosing the path of minimum resistance and bypassing the oil trapped in adjoining pores (see the diagrams on page 6 and above).

With MEOR, a small number of bacteria in a small volume of nutrient solution are injected, under low pressure, into the system. The bacteria, supported by the nutrients in the solution, selectively seek out and grow at the oil-water interface, producing surfactants that slowly alter the physico-chemical properties of the water-oil mix so it can be more easily flushed out later on.

What microbes?

The environment within an oil well is hardly one of the more salubrious climes on this earth. Extremes of temperature and pressure, and an array of toxic organic chemicals and heavy metals, mean that only bacteria with unique abilities survive.

In earlier studies some Eastern-bloc countries used either raw sewage or microbes isolated from sewage in their tests of MEOR. This approach produced some successes, but the Baas Becking group decided to investigate other environments where production of surfactants and adaptation to extreme conditions could be found in bacteria. Samples from oil wells and refineries, from coal storages, and even from an insect's intestine were cultured and their bacteria isolated.

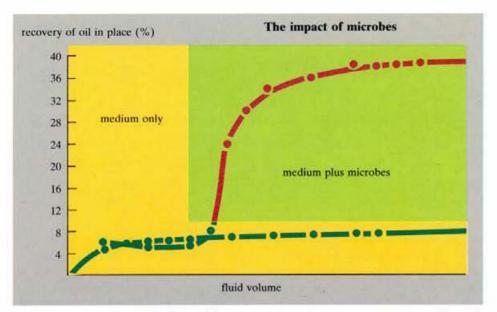
These microbes were then tested for their ability to produce surfactants. The easiest way to do this is to streak the bacteria across a sterile agar gel that contains essential nutrients and has been further amended with red blood cells. As the culture grows, any surfactants that are produced diffuse into the surrounding medium and, since surfactants alter the red blood cell's membrane, they destroy cells in the immediate area; the effect is seen in a cleared area adjacent to the bacteria, surrounded by the blood red of the normal medium.

The CSIRO-Bureau of Mineral Resources group has about a dozen surfactant-producing microbes isolated from a variety of locales. Most of these are bacteria from the genus *Pseudomonas*; but, since they have great commercial potential and are patentable, little further detail is available.

In one instance Dr Davis noticed that a single bacterial colony — out on its own, away from the main bacterial growth — had a lot of surfactant activity associated with it. Purification of this colony, and further testing, revealed that the mutant had ten times the surfactant-production

After 'exhaustion', microbes can help squeeze out more oil.





In an experimental core, flushing with surfactant-producing microbes had a much bigger impact on oil recovery than flushing with the culturing medium alone.

capacity of its parent strain; further selection should improve the other cultures as well.

Testing MEOR

Given the past problems with microbes, there is no possibility of large-scale testing until all the variables influencing MEOR are fully explored. In practice this means laboratory studies, and lots of them.

In an early test of one of the first selected bacteria on a core of oil-bearing rock from the Surat Basin in south-eastern Queensland, a water sweep removed 49% of the OIP; subsequent flushing with the bacterial culture improved the recovery to 70%. This was an encouraging first trial, but the routine use of field cores in laboratory studies is generally avoided because of their great variability: cores sampled almost side by side can differ radically in their physical characteristics.

Furthermore, the scientists need to perform studies on oil and water pathways and the location of micro-organisms, and rock is hardly the ideal medium. As an alternative, they devised a system where sintered glass discs, commonly used for filtering solutions, are sandwiched together to form a 'core' 18 cm long, with known physical characteristics, that can be disassembled, studied, washed, and then used again.

In a typical laboratory trial the core, under temperatures and pressures set by the experimenter, is saturated with water before being infiltrated with crude oil. The oil trapped in the pores of the filtering discs is then subjected to the sorts of processes that commonly occur in a natural oil reservoir.

Normal water sweeps generally only extracted 30–40% of the oil in the oil-saturated core, a recovery figure common in commercial fields. However, subsequent flushing with the bacterial culture removed 54–56% of the OIP.

The bacteria selectively seek out and grow at the oil-water interface.

Subsequent trials have compared the efficiency of the bacterial cultures against synthetic surfactants — showing that the bacterially derived surfactants have a marked advantage over the more conventional chemicals. But, being more of a head-on-head test, this compares only the chemical effectiveness of the two groups and doesn't take into account the mobility advantage that bacteria-derived surfactants have.

Further trials are in progress to select out more effective surfactant-producing strains of the bacteria already isolated. Additional experiments on nutrient requirements of the microbes and the effectiveness of a cocktail of selected bacterial strains are also being performed.

Back to the well?

A major problem in applying any sort of enhanced-recovery technique — physical, chemical, or microbial — is the great variability between oil wells. Physical factors that have to be considered include the oil-bearing rock's permeability, pore size distribution, and degree of saturation, and the viscosity of the oil and the temperatures and pressures it is under. Chemical influ-

ences from dissolved salts, heavy metals, and the concentrations of carbon, phosphorus, and nitrogen must be taken into account. Another important factor, still being studied, is the role of the indigenous microbes.

Dr Bubela and Mr McKay have developed a schedule that can be used to assess whether a reservoir is a suitable candidate for MEOR. For example, MEOR won't work at temperatures greater than 85°C, at least with the bacterial strains that are currently available; if heavy metal concentrations exceed 50 p.p.m. the tolerance of the bacterial strains may need to be tested.

A number of oil companies, in both Australia and the United States, are interested in applying MEOR technology. A big incentive is the cost: preliminary analyses suggest that the cost of MEOR will only be of the order of US\$1 per additional barrel of oil recovered.

And the amount of oil that's awaiting recovery is startling: in the United States three hundred thousand million barrels are still in place - nearly three times the amount of oil that country has ever produced - but only one-tenth of this is recoverable using conventional techniques. Australian oil fields give up their treasure a little bit more easily, but there is still considerable scope for MEOR: three thousand million barrels are still in place, with more than half of this recoverable using present technology. Even a few percentage points improvement in the amount of oil recovered would boost world oil supplies substantially.

Wayne Ralph

More about the topic

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