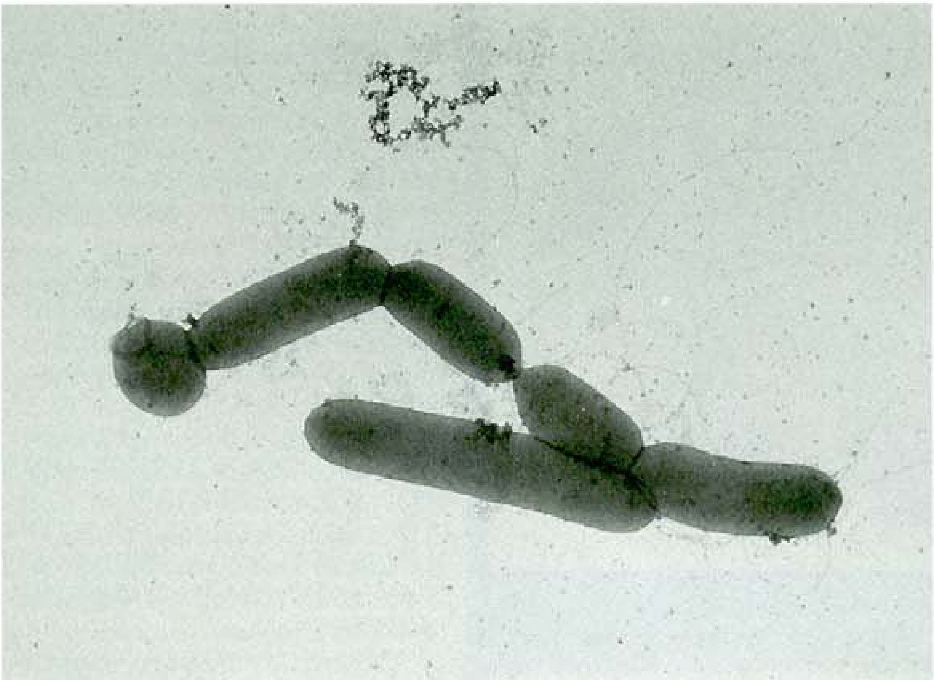
Encouraging more oil to flow



An electron-microscope view of some of the rod-shaped bacteria that Mr Sheehy and his team isolated from deep within a well.

First there was EOR, then MEOR, and now there's BOS! In a world crammed with confusing new acronyms, you could be forgiven for pleading ignorance of these. Unlike many new terms nowadays, these don't refer to computers; rather, they have to do with something even more fundamental to our present way of life — oil.

In some places, including Australia and the United States, the life-blood of modern transport is becoming more and more difficult to extract. Plenty remains in the ground; the problem is getting it out.

Oil seldom exists in pure form as a vast lake beneath our feet. The popular notion that you need but drill a hole and it will all gush forth — making you an instant millionaire — is rarely correct nowadays. Even if you have an initial geyser, the pressure will quickly drop so low that you will soon need to push the oil out, in one way or another.

Sand and rock grains hold oil between them in a way similar to a sponge holding water. When the sponge is no longer freely dripping, plenty of water still remains trapped inside. All you need is a means to extract it.

As a global average, production from a reservoir usually ceases when only 30% of the oil it contains has been brought to the surface (the figure varies considerably from well to well depending on geology). This is because it becomes too difficult — and hence uneconomic — to force oil out. As a result, reservoirs are written off as 'exhausted' with the bulk of their oil still there. The remaining oil is 'spread out' in the form of tiny droplets scattered through strata of rock and sand. In such cases, one barrel of oil (about 160 litres) could be dispersed through a quantity of rock ranging in volume from 100 to 10 000 cubic metres.

Tricks of the trade

Various well-tried means exist to keep the oil flowing after the first gush ceases. Such 'secondary production' techniques include injecting water or gas down a hole drilled parallel to the production well, and hoping that the resulting pressure will act to force oil through the porous rock and into the well. A number of factors can stop this from being as effective as it sounds, and so enhanced oil recovery (EOR) or tertiary production methods evolved.

These make use of chemicals. For example, chemical surfactants lower the 'interfacial tension' between oil and water — allowing them to form an emulsion. (This is a mixture of two substances that usually don't mix, where one exists as tiny droplets within the other; oil and vinegar salad dressing is an example.) Like a detergent removing grease from plates, surfactants act to 'wash' the oil into the water, thus enabling it to move more freely from the sand and rock grains, between which it is held, into the well.

The water cut (the percentage of water from underground in the product extracted) from oil wells increases as they age. This is because water, being less viscous than oil, moves more easily through the rock and into the bottom of the well. A solution to this is thickening the water, which we can do by adding soluble polymers.

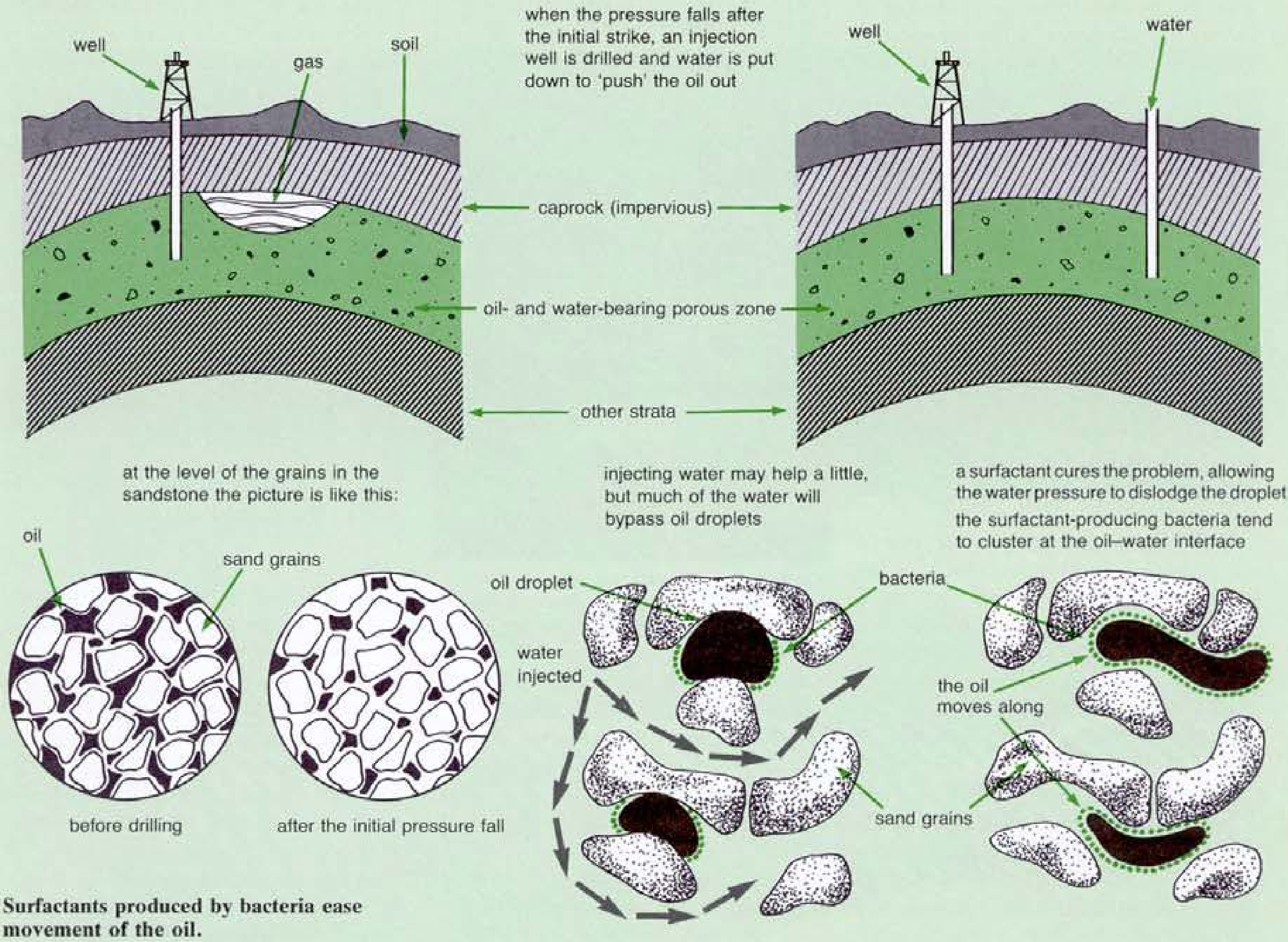
Another problem concerns water deliberately injected from the surface to provide pressure to move the oil. Some layers of rock may be more permeable than others; the water may push through these, creating easily flowing channels and essentially by-passing the zones containing the oil. Here, polymers may help again, if they can be induced to form 'insoluble plugs' at the right places to stop the water passing through the high-permeability channels, thus ensuring that it only moves through the oil-bearing strata.

The main disadvantage with these ideas is their cost. The majority of surfactants are oil-derived and expensive; so too are most polymers. Typically, one-quarter of a barrel of oil is used to produce the surfactant necessary to extract one extra barrel. All in all, these extraction techniques add about an extra $10–15 to the price of a barrel of oil (currently about $23). Furthermore, the surfactants used are minimally biodegradable, and hence may pose serious environmental problems. Quite simply, in most reservoirs these chemical techniques are scarcely worth it at the moment.

Bacteria help out

Back in 1926, Dr J. Beckman, an American scientist, suggested that bacteria could provide products that would be of use in oil recovery. The first research on this took

Moving oil



Surfactants produced by bacteria ease movement of the oil.

Attacking toxic wastes

The biochemical versatility of micro-organisms means that, as well as producing useful substances, they can metabolise unwanted ones.

In the case of an accidental oil spill, oil-digesting bacteria can be seeded onto the contaminated area (the chances are that some would already be present). This method has been used for many years. The bacteria will oxidise the oil — a compound rich in carbon — to satisfy their energy requirements. However, like all living things they also need nitrogen, phosphorus, and other elements for growth, so it may be necessary to add certain nutrients to maintain the correct carbon:nitrogen ratio to ensure the greatest level of reproduction by the bacteria.

Mr Sheehy and his team at the Microbiology Research Unit are studying ways to use microbes to break down unwanted waste — which includes toxic industrial compounds as well as oil. Currently, polluted land sites are often excavated and the contaminated material is either buried as land-fill — which merely transfers the pollution to a second site — or incinerated, which, although generally effective, is costly and may produce toxic ash and fumes.

Other possibilities include chemical treatment, itself possibly polluting, or the unattractive option of leaving the problem where it is and trying to contain any spread or contamination of groundwater. The use of microbes to improve the situation — a process termed bioremediation — offers the prospect of a relatively inexpensive, efficient, and environmentally friendly way of removing toxic chemicals.

Selection of the microbes, and the mode of application, will depend on the type and concentration of the contaminant and the soil characterisitics. The rate of biological degradation can be limited by unfavourable pH or temperature, or by the availability of oxygen, water, and nutrients, so scientists must monitor the situation.

The Microbiology Research Unit at the University of Canberra has developed a novel bioreactor system. It provides for changes to the suite of microbe species throughout the breakdown process, leading to more rapid and complete destruction of the contaminant.

Currently, Mr Sheehy and his team are involved in the bioremediation of a number of contaminated sites in Melbourne. Early results indicate successful breakdown of a range of toxic organic compounds such as TNT as well as oil-derived hydrocarbons.

Mr Sheehy believes that bioremediation is the only really effective solution to many of our worst pollution problems. The greater efficiency and precision that his work has given the process is likely to lead to its wider use in the future. He is currently involved in a proposal to set up a soil biological remediation unit in each State.

place in the 1940s and '50s. In the 1970s in Australia the Baas-Becking Geobiological Laboratory — an organisation then jointly funded by CSIRO, the Bureau of Mineral Resources, and the Australian Mining Industry Research Association — started studying this microbiologically enhanced oil recovery (MEOR). (See *Ecos* 47.)

Led by the late Dr Bohdan Bubela, the team started selecting bacteria that could produce surfactants, with the idea of deliberately injecting them into wells. Oil industry people at first felt a little suspicious of this approach, for they knew that some bacteria contaminating wells could cause problems through the chemical reduction of sulfate to produce corrosive compounds that 'sour' the oil, affecting its quality, and that sometimes even damage drilling equipment.

However, the scientists carefully selected surfactant-secreting bacteria that were not sulfate-reducers, and found that these preferentially grew exactly where they were needed — at the oil–water interface. Field trials carried out overseas — at temperatures of 45°C or less — confirmed that MEOR could indeed increase oil output.

This early MEOR work, in Australia and elsewhere, used a small number of bacteria and a supply of nutrients sufficient for them to grow and reproduce efficiently. But, in general, the bacterial strains employed had not originally come from within oil wells; therefore they were not tolerant of the extreme temperatures, pressures, and salinities pertaining in most wells.

Scientists watch mixing of the nutrient solution that both feeds the bacteria down the well and determines what compounds they will release.

Incredible as it may seem — especially to those whose school biology taught them that the processes of life cannot continue above 45°C — some microbes thrive deep underground, without oxygen, at pressures of 400 atmospheres and temperatures up to 110°C!

In 1986 Mr Alan Sheehy, senior lecturer in microbiology at the University of Canberra (formerly the Canberra College of Advanced Education) and a specialist in the microbiology of extreme conditions, took over the MEOR project. Funded through the CSIRO Division of Exploration Geoscience by an Australian company, BWN Live Oil Pty Ltd, he and a small team have taken the procedure forward in a unique fashion that makes Australia a world leader in oil recovery. They have done this by devising a process that uses the bacteria already existing in oil wells.

Mr Sheehy has taken microbes from oil wells and cultured them in the laboratory at high temperatures and pressures. Studying their nutritional physiology has enabled him, by changing the formula of the nutrient cocktail he feeds them, to alter their metabolism and thereby stimulate the production of a desired end-product. This is commonly a surfactant, but could also be gas — to increase the pressure within the reservoir and so help push the oil out — or 'sticky' biological polymers designed to plug permeable areas in the rock.

Bacteria are very versatile in their chemistry, and they can also produce enzymes to digest an array of organic compounds. For example, the bore hole of a well may sometimes become blocked with paraffin that has slowly been deposited from the extracted oil mixture. It may be possible to seed a well with the correct bacteria, which by paraffin digestion could solve the problem or prevent it occurring.

Two crucial differences distinguish this from the older approach to MEOR. Firstly, Mr Sheehy's process does not inject 'foreign' bacteria into a well — a procedure that could have unforeseen consequences (such as sulfate production) for the oil industry and the well's own ecology. All

An oil-well at the Alton Field site in Queensland where Mr Sheehy first tested his new process for improved oil extraction.

Hot springs, such as these near Rotorua, New Zealand, are among the places where thermophiles are found.

Basic biology teaches that the chemical processes of life only take place in a narrow temperature range, from a few degrees below freezing to about 50°C (individual creatures can have a far narrower range within this). But there are exceptions.

As the temperature increases, so does the speed of movement of atoms and molecules. High temperatures will literally pull apart the complex macromolecules — enzymes and nucleic acids — upon whose correct configuration the reactions of life depend. So how is it that those exceptions — some bacteria — can happily live in temperatures as high as 110°C?

First, we must distinguish between bacteria and their spores. Scientists have long known that the spore, or resting stage, of many bacteria is highly resistant to chemical disinfectants or heat. But this is because the spore is not metabolising — it is a dried-out piece of 'potential life', ready to turn into a bacterium only in more salubrious circumstances.

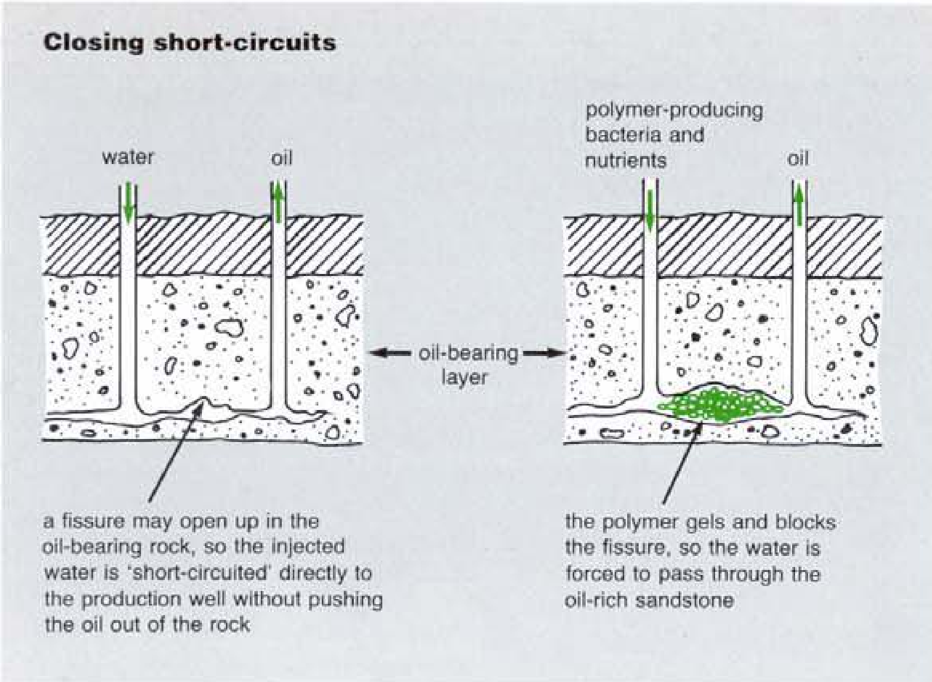
In contrast to this are bacterial cells that actually live and metabolise at high temperatures — the so-called thermophiles or heat-lovers. So well adjusted are they to boiling temperatures that they are often incapable of surviving, or at least growing, at more normal temperatures. Biochemical theory has yet to catch up with their amazing feats, but we do have a few ideas on how they protect their vital molecules.

Compared with mesophiles — that is, bacteria happy with temperatures up to about 40°C — thermophiles often contain large quantities of chemicals called polyamines. The high concentration of these appears to stabilise RNA (ribonucleic acid), perhaps by binding to it and preventing agitation caused by the heat from disrupting the molecule. Another mechanism for stability involves the interaction of small ions — of calcium, magnesium, and other elements — with charged areas on large molecules.

The cell membrane of micro-organisms also changes with variations in temperature. Thermophiles' membranes contain fatty acids and esters that have a relatively high melting point.

But perhaps the most basic reason is a direct modification of the macromolecules themselves. Various internal chemical bonds can be strengthened. The RNA of an extreme thermophile has one of its four bases replaced with a variant that helps to stabilise the molecule only at high temperatures.

Studying thermophiles is more than simply an intellectual challenge. Potentially, these organisms have immense practical importance — and not just down oil-wells. Almost all chemical reactions proceed more rapidly at high temperatures. Many processes in biotechnology involve extracting a product from bacteria grown at only 37°C. If the secrets of the thermophiles were unlocked and somehow coupled with those bacteria, then the temperature limitation on the many industrial processes that use microbes would be broken. Greatly increased productivity in these industries would result.



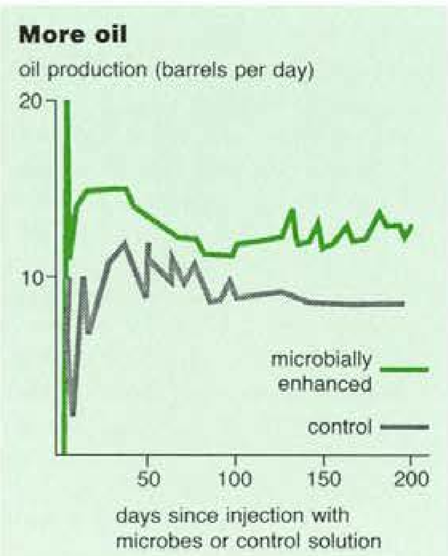
Polymer production by bacteria helps ensure water injection is effective.

the bacteria used are derived from the well under treatment.

Secondly, the nutrient solution added is compatible with the reservoir and its natural microbial population. When feeding ceases, the population will return to what it was originally, and so too will the microbes' metabolism, as they will only have the original substrates available. Therefore, the treatment produces no lasting effects such as could occur with the introduction of 'foreign' bacteria.

Also, much of the earlier work was carried out at temperatures up to only about 45°C and most major oil deposits are in wells hotter than this. Mr Sheehy has isolated bacteria that are tolerant of temperatures up to 105°C, although to date his process has only been used in the field at 75–80°C.

Microbe injection resulted in a sustained increase in oil production in this test at the Alton Field in Queensland.



The new BOS

The new process has a new name — biological oil stimulation (BOS). Unlike traditional MEOR techniques, it is aimed at the particular problem limiting production in a well — and every oil well is different. The key to its success is flexibility, as it can be tailored to the characteristics of each well. It has been patented, and BWN Live Oil has a licence from CSIRO to commercialise and market it.

Mr Sheehy's process currently takes about 1–3 months to put into effect. Firstly he and his team must visit the well, identify the factors restricting its full exploitation, and sample the bacterial population. They then determine the biological products that will help and establish which factors will cause the greatest synthesis of these products by the resident oil-well bacteria.

In the laboratory, the scientists grow the bacteria and carry out tests at the temperature, pressure, and salinity occurring in the oil-bearing region of the reservoir. The bacteria and the correct nutrient mixture for the desired end-product are then injected. A system for this process and the subsequent dispersion within the reservoir has also been patented.

With the assistance of AGL Petroleum Pty Ltd, Mr Sheehy has carried out an exhaustive series of tests on BOS in an oil-well at Alton Field in Queensland, with a reservoir temperature of 76°C. Production from this field began in 1966, but a slow and continual decline started in 1969, which, in recent years, has averaged 15% per annum. The tests included rigorous controls to ensure that any effect would not be attributable to the injection procedure itself. (Forcing anything into the reservoir naturally leads to an increase in pressure and a transient stimulation of oil output.)

Bacteria were added to the well on Australia Day (26 January) 1989 and, after being closed in for a time to allow microbial growth to occur, the well went back into production on 16 February 1989. Its rate of production immediately rose by 50%. But this increase was no transient effect; it has been maintained for 12 months and is still continuing as we go to press. The scientists had previously carried out a series of control injections on the same well, adding the nutrient medium without bacteria. The stimulation that this caused was subtracted from the final result, to give a true figure for the biological stimulation.

As well as measuring the increase in oil production, the scientists looked for more direct evidence of bacterial action. They found that the numbers of microbes in the water coming up from the well increased from less than 1000 per mL before the injection to 100 000 or more afterwards. Importantly, they did not detect the gas hydrogen sulfide, which is evidence of 'souring' of the oil by the action of sulfate-reducing bacteria. Furthermore, no changes occurred in the composition or physical characteristics of the oil.

It emerged from the field trial that BOS costs less than $1 per barrel on top of existing production costs — a far cry from the old chemical methods of enhanced recovery.

Mr Sheehy and his team are also studying the ability of bacteria to digest oil and other compounds from the petroleum and petrochemical industries (see the box on page 11). Of course, such microbes would not be handy down a well, but instead could be of great use in removing oil from places where it's not wanted. Bacterial treatment of oil contamination has the advantage of not using detergents, which can be damaging to the environment.

It looks as if the giant oil industry will, in the future, be making increasing use of armies of microscopic workers.

Roger Beckmann

More about the topic

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