Improved oil recovery using carbon dioxide

Economic and environmental benefits

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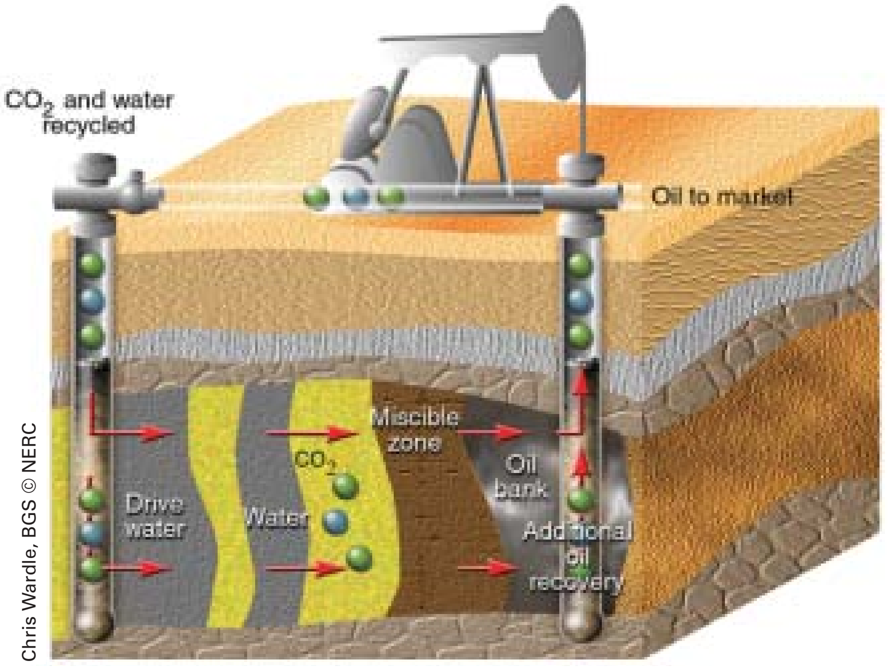
Improved oil recovery (IOR) is attempted in oilfields where the natural flow and pressure of oil has significantly diminished and further commercial production must be stimulated. Various different techniques can be used in IOR operations, but a key method is the injection of carbon dioxide which has been used in some IOR projects for around 40 years. If a mature underground oilfield satisfies certain physico-chemical parameters,



Cartoon of the carbon dioxide (CO_2) enhanced oil recovery process. 5000 tonnes of carbon dioxide are delivered to the Weyburn oilfield each day from a coal gasification plant. The carbon dioxide is injected into the oil reservoir. The extra oil produced will increase the life of the field by 25 years as well as reducing life-cycle emissions of carbon dioxide by 30 per cent compared with conventional oil.

Fieldwork being carried out by the BGS's research partners in the Weyburn project. On the left, a geologist from the Istituto Nazionale di Geofisica e Vulcanologia, Rome, measures carbon dioxide flux. On the right a geologist from the University of Rome collects soil gases for gas chromatography measurement in the laboratory.

the injection of carbon dioxide can give additional oil production; carbon dioxide-IOR can typically recover 10–15% of the original oil within the reservoir. This incremental production is achieved by the carbon dioxide, which is an excellent solvent, dissolving into the oil and thereby simultaneously reducing viscosity and increasing volume. The reduced viscosity makes the oil flow through the reservoir rock more easily. Furthermore, the swelling of the carbon dioxide-rich oil enhances reservoir pressure and both these factors will cause more oil to be produced. Water can also be used in this process in order to push the carbon dioxide and oil to the producing wells. Typically, a pulse of carbon dioxide is injected first, followed by a phase of water injection and this is termed a water-alternating-gas (WAG) strategy. Upon production, the oil is separated from the oil/water/carbon dioxide mixture, and the carbon dioxide and water are recycled back into the reservoir. Many ageing oilfields have been traditionally injected with water alone to sweep out the last barrels of producible oil. However, reservoir waterfloods are not as effective as carbon dioxide injection because oil and water are immiscible, and much oil remains underground.

The use of carbon dioxide in IOR projects is relatively common practice in North America, where the majority of these operations have used relatively cheap carbon dioxide from natural underground accumulations. However, there is absolutely no reason why anthropogenic carbon dioxide cannot be utilised in this way. During the past few years, several commercial operations have started to use

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industrially-produced carbon dioxide for IOR purposes. At the end of an IOR operation, much of the injected carbon dioxide remains deep underground. The sequestration of this potent greenhouse gas underground has an environmental benefit, in that it is not simply vented to the atmosphere. As a consequence, incremental oil produced in this way effectively emits up to 30% less carbon dioxide than conventionally produced oil, when considering the overall carbon balance. Revenue gained from the increased oil production can also help to offset the costs of carbon dioxide recovery from the industrial source. Carbon dioxide-IOR could significantly extend the life of many ageing North Sea oilfields. However, the effective window of opportunity for this strategy is relatively narrow because many fields will start to be decommissioned in the relatively near future.

The capture of industrial carbon dioxide could be via the use of clean fuel technology, where either carbon is extracted from fuel before it is burnt, or the carbon dioxide is captured from the exhaust gases after combustion. If the source of carbon dioxide is sufficiently close to an IOR operation, the gas becomes a valuable by-product of the primary process and can be sold to the oilfield operators. The purity of the carbon dioxide is also an important factor: hydrogen sulphide improves miscibility but is corrosive to surface infrastructure such as pipework, whereas nitrogen and hydrogen inhibit flow properties.

As a method of carbon sequestration, deep underground storage has several distinct advantages over reforestation. Reforestation captures carbon dioxide already in the atmosphere, whereas underground sequestration can prevent the gas being vented in the first place. Also, injection of carbon dioxide underground is essentially permanent, providing the reservoir has good integrity. Although growing trees can sequester carbon for a limited time, when the trees die they release carbon as carbon dioxide or methane back to the atmosphere. Another advantage is that underground storage has minimal impact on land usage. The long-term sequestration of carbon dioxide using forests is extremely land intensive, with vast areas locked up for centuries.

In addition to working oilfields, there are vast volumes of oil-free porous sedimentary rock in the subsurface, which could safely store carbon dioxide. It has been established that, for example, rocks beneath the North Sea could store all the carbon dioxide produced within the European Union for electricity generation over hundreds of years. In the North Sea, saltwater-bearing strata, otherwise known as saline aquifers, offer the best storage potential. The geology of each storage operation must be carefully assessed to check that the reservoir will not leak carbon dioxide back to the surface via faults, fractures, joints or other migration pathways. During the injection operations, the carbon dioxide storage integrity of the reservoir should be monitored. For example, seismic methods can be used to visualise the carbon dioxide ‘bubble’ in the reservoir deep underground.

The BGS is currently involved with several projects monitoring carbon dioxide storage operations. For example, the Norwegian oil company Statoil commenced injecting carbon dioxide into a Neogene siliciclastic saline aquifer, the Utsira Formation, at its Sleipner Field, east of the Shetlands. Here, carbon dioxide is injected nearly one kilometre beneath the North Sea. It is expected that one million tonnes of carbon dioxide per year for at least 20 years will be injected, and the BGS and its partners are investigating how the carbon dioxide is behaving within the aquifer. The BGS is also leading a group of European-based researchers in another initiative, as part of Europe’s contribution to the International Energy Agency’s Weyburn carbon dioxide monitoring project. This is a study of carbon dioxide injection into the Weyburn oilfield, a commercial carbon dioxide-IOR operation in southern Saskatchewan, Canada. The carbon dioxide is produced as a by-product of synthetic natural gas from coal in North Dakota, USA and piped to the Weyburn oilfield. The field is operated by the EnCana Corporation (formerly PanCanadian Inc.), who commenced carbon dioxide-IOR operations in September 2000. The team of European scientists are working on geological, geochemical and hydrogeological investigations and modelling, soil gas monitoring and safety/risk analysis at Weyburn.

Storing carbon dioxide underground has the potential to extend the life of mature oilfields and, in so doing, sequester large amounts of this greenhouse gas. However, there are still uncertainties to be resolved. These include, for example, how the carbon dioxide moves underground, how long it will stay in the reservoir, how it will react with chemically susceptible lithologies, and its ultimate fate within the subsurface. Good quality scientific investigations and monitoring are therefore vital if governments, regulators and public are to accept deep underground storage of carbon dioxide as being safe and effective.

A BGS researcher operating in situ *soil gas measuring equipment. In the background is a service rig reaming a borehole.*

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