WO

CCUS

Will EOR become the unsung hero of oil and gas decarbonization strategies?

The oil and gas industry has used CO_2 for enhanced oil recovery (EOR) in mature reservoirs for 50 years. Now, as CCUS becomes a critical part of the industry's decarbonization strategy, lessons learned from EOR can help solve CO_2-related subsurface challenges.

STEVEN KNABE, Halliburton

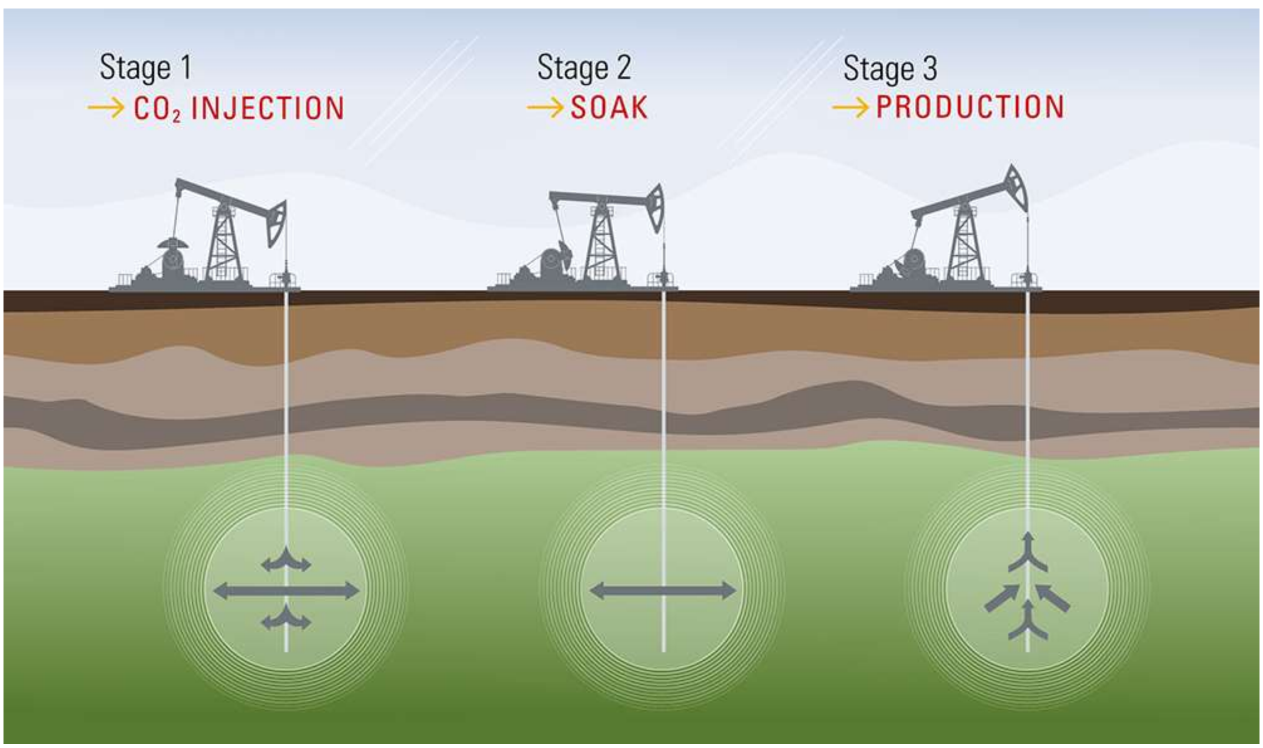

Fig. 1. Example of cyclic forced imbibition with CO_2.

Long before government entities offered incentives for decarbonization initiatives in the private sector, operators discovered the value of CO_2 in the oil field. In the mid-1970s, the oil and gas industry began to use CO_2 for enhanced oil recovery (EOR) in mature reservoirs. This helped operators extract the highest amounts of hydrocarbons from wells and maximize their companies' investments in their assets.

Today, carbon capture, utilization, and storage (CCUS) emerges as a critical component in the industry's overall decarbonization strategy. Many of the lessons learned from EOR in the past can help provide a path forward, as oil and gas and many other hard-to-abate industries decarbonize their operations, while they provide critical energy and materials to the world.

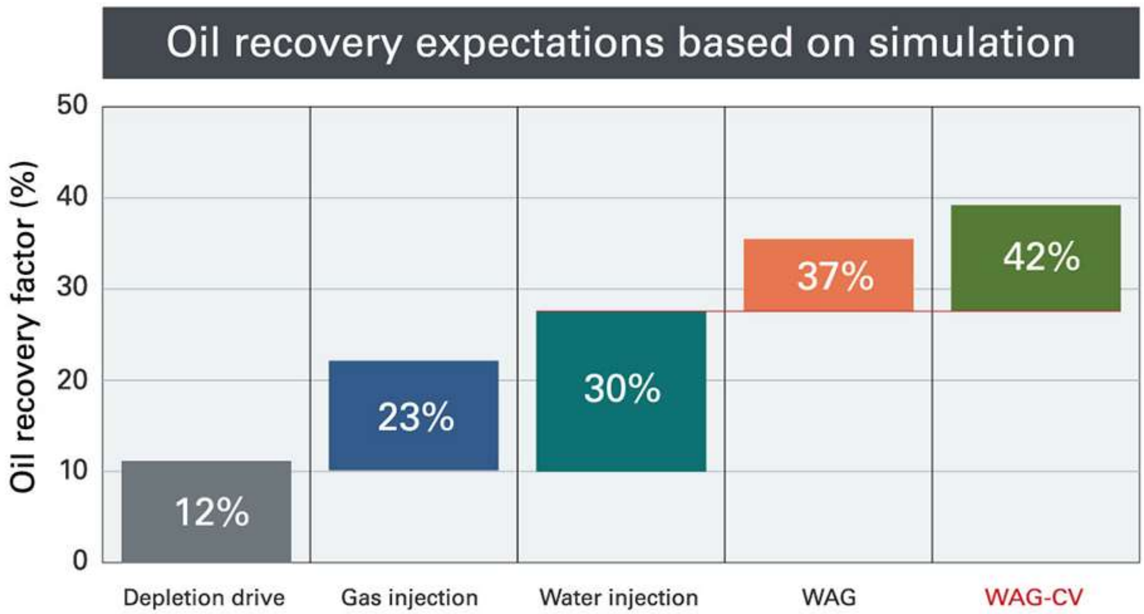

Fig. 2. Oil recovery expectations, based on type of stimulation.

EOR TECHNIQUES HONED FOR MORE THAN FOUR DECADES IN THE PERMIAN BASIN

Drilling and cementing oil wells began in the oil-rich Permian basin of Texas in the 1950s, decades before CO_2 injection became a possibility for EOR operations. At that time, corrosion-resistant materials were not always used. However, when operators discovered the potential benefits of CO_2 to help maximize reservoir output, they found safe ways to work with existing well materials or make small modifications.

For example, conventional legacy well tubulars often consisted of carbon steel which increased the risk of corrosion in CO_2 environments. Operators developed ways to use existing tubing for EOR, such as the addition of fiberglass to the tubing, which helped to avoid well integrity issues.

EOR can occur in reservoirs as shallow as 5,000 ft (1,500 m), since CO_2 is miscible with light oils at low pressures (~2,000 psi). Permian basin operators obtained inexpensive CO_2 from natural reservoirs via pipelines from nearby states. Two main techniques were developed, as operators looked to extract the maximum amount of hydrocarbons from mature fields: huff-and puff and water alternating with gas (WAG).

Operators first employed a technique known as huff-and-puff to conduct EOR operations. This involves cyclic stimulation or forced imbibition of CO_2 in conventional or hydraulicly fractured tight formations. Huff-and-puff provides an on-ramp to EOR pilot projects for many operators, as they can have industrial gas suppliers deliver liquid CO_2 in 25-ton tankers to well sites for their programs.

Pilot programs help operators determine the feasibility of CO_2 EOR at their well sites before they commit to pipeline projects. In these huff-and-puff programs, reservoir simulations are used to evaluate CO_2 behavior in the reservoir, to determine efficacy of the process within each local geological formation.

The second common EOR method, WAG, alternates slugs of water and CO_2 into the well. The use of water helps delay CO_2 breakthroughs in projects. Corrosion does pose a concern, but corrosion-resistant packers and fiberglass-lined tubing help to mitigate CO_2's effects, so it can be recovered and not seep outside the reservoir. The oil and gas industry also developed specialized cement mixtures, such as non-Portland and resin-based compounds, as well as custom metallurgy for packers and logging tools that detect casing leaks. These innovations help mitigate potential corrosion issues.

The success of huff-and-puff and WAG methods could broaden the commercial use of CO_2 for EOR into CCUS applications. Much of the CO_2 remains in the reservoir after years of EOR operations, which reduces atmospheric emissions. Once CO_2-facilitated EOR is no longer viable, the remaining CO_2 can either be utilized in other applications or stay sequestered in the geological formation.

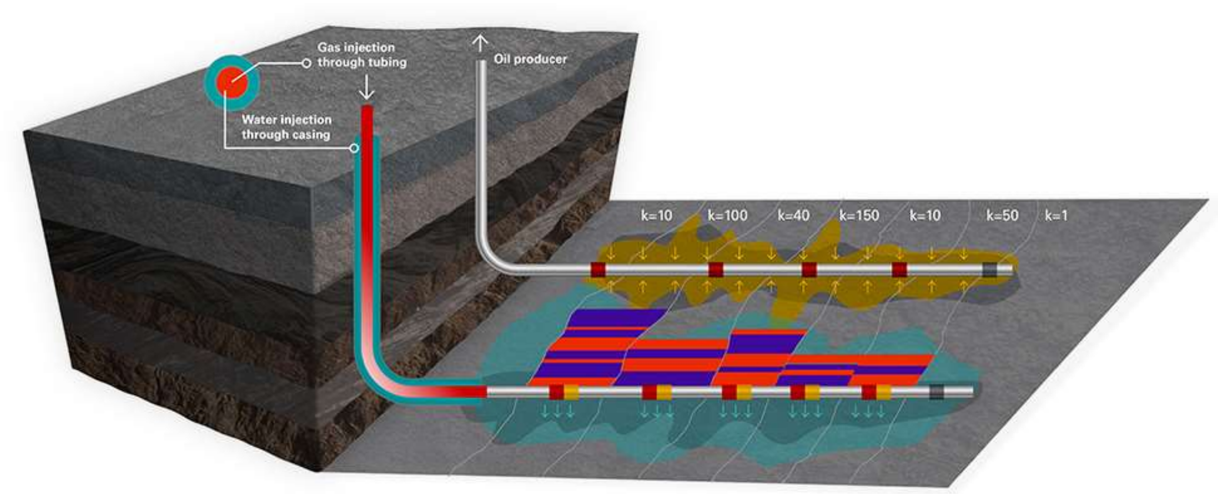

Fig. 3. The modified WAG-CV process is a proposed solution to maximize oil recovery.

DEPLETED FIELDS BECOME CO_2 SEQUESTRATION SITES AFTER EOR

After operators exhaust EOR potential, they can plan and prepare for CO_2 sequestration. As operators deplete oil from shale fields with EOR, the reservoirs can serve as repositories. However, effective CO_2 sequestration, even in fields used for EOR, requires models of how the CO_2 will behave in the formation and tools and technology to monitor the CO_2, to ensure it is sealed for the long-term.

Advanced completion tools help sequester CO_2 for long-term storage. Operators can manage injection and production locations with these tools. Valves placed within the well enable operators to shut off segments of injectors, producers, or both in case of rapid CO_2 breakthrough. Advanced completions may enhance CO_2 recovery in huff-and-puff operations.

Computerized reservoir simulations help to model underground CO_2 behavior, optimize water slugs for WAG, and test huff-and-puff operations. The integration of smart completions with reservoir simulation improves oil recovery and prepares shale reservoirs for effective EOR and sequestration. Reservoir preparation for CO_2 sequestration uses simulations to help identify potential CO_2 interactions or leak points with rock and fluid and help operators select appropriate tools for effective sequestration.

Regulatory bodies require measurement, monitoring and verification (MMV) plans before they grant permits. Fiber optic technology enables comprehensive monitoring of CO_2 behavior in the subsurface, a requirement for CCUS projects.

The combination of CO_2 injection in depleted shale reservoirs and government sustainability incentives presents numerous opportunities for profitable CO_2 sequestration and reduced atmospheric emissions. However, EOR has employed this technique for decades. Beyond CCUS applications, CO_2 adheres to shale and displaces methane. When reservoirs reach the end of their productive lives, the injection of CO_2 in depleted shale fields can allow operators to extract methane and sequester CO_2.

EOR serves as a critical bridge to CCUS projects, as mature oil fields near the end of their productive lives. Many methods and tools developed to help maximize oil extraction from reservoirs are also applicable to CO_2 sequestration projects. The ability to increase profitable and effective oil production through EOR builds a foundation for CO_2 sequestration. As mature fields near the end of their productive lives, CO_2 injection can help maximize asset value and support decarbonization strategies. **WO**

STEVE KNABE recently retired from his position as Global Director for Evaluation and Production at Halliburton Consulting, with more than 20 years of operator and service company experience. He has co-authored multiple technical papers and patent applications. Mr. Knabe holds a BS degree in petroleum engineering from Stanford University and an MBA from Harvard Business School. He also is an active member of the Society of Petroleum Engineers and a licensed professional engineer in the State of Texas.

Scroll down to read