Algerian Journal of Environmental Science and Technology
Avril edition. Vol.3. N°1. (2017)
ISSN : 2437-1114
www.aljest.webs.com

State of the art on enhanced oil recovery with CO_2 sequestration for low carbon industry

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ARTICLE INFO

Article History:

Received ***: 12/12/2016***
Accepted ***:03/03/2016***

Key Words:

CO_2;
Sequestration;
Enhanced oil recovery;
Global warming.

ABSTRACT/RESUME

Abstract: *The growing concerns over the global warming due to the increase in the global concentration of greenhouse gases in the atmosphere has increased the interest in examining various techniques to reduce the emission of these gases and for low carbon dioxide industry. A main component of greenhouse gases is carbon dioxide (CO2). A promising long term solution for mitigating global heating is to inject CO2 into geological formations; either for CO2 sequestration or enhanced oil recovery, or a combination between the two solutions. A suitable choice of geological formations for CO2 injection includes petroleum and gas reservoirs, water formation leg of the oil/gas reservoir or separate deep saline aquifers, deep-sea sediments and coal beds. This study aims to setup a state of the art on this problem.*

I. Introduction

The combustion and flaring of fossil fuels produces large quantities of CO2. The Intergovernmental Panel on Climate Change stresses the need to control anthropogenic greenhouse gases in order to mitigate the climate change that is adversely affecting the planet. Moreover, in some fields the hydrocarbon gases produced along with the oil are re-injected to the reservoir to enhance oil production. Nevertheless, in some fields the hydrocarbon gas is sold and the gas itself is considered as source of energy. An attractive option is the use of CO2 as one of the main components of the solvent mixture for EOR process.

Enhanced oil recovery using CO2 is an attractive oil recovery process that involves the injection of CO2 to oil reservoirs and produce petroleum substances that would otherwise remain unrecoverable . Typically only around one third of the oil is produced after primary and secondary oil recovery methods. Much of the remaining oil are trapped by capillary forces as disconnected drops, surrounded by water, or as a continuous phase at low saturation with gas occupying the larger fraction of the pore space. An efficiency EOR process must mobilise these dispersed oil and form an oil bank that can move towards the production wells. This needs to be accomplished both on the microscale, at the pore level, and also on the macro-scale affecting the largest possible volume of the reservoir. EOR operations using CO2 have been practiced for more than 50 years, the results revealed that $6-15\%$ of original oil in-place can be recovered by these kind of processes .

The low saturation pressure of CO2 compared to CH4 or N2, its low price compared with other hydrocarbon solvents are the incentives for the use of CO2 in the EOR process. Moreover, a mixture of hydrocarbon solvents with CO2 may be less likely to precipitate asphaltene, which is a great problem in enhanced oil recovery . Furthermore at high pressures, CO2 density has a density close to that of a liquid and is greater than that of either nitrogen (N2) or methane (CH4), which makes CO2 less prone to gravity segregation compared with N2 or CH4 .

II. CO_2 injection schemes for EOR projects

CO_2 is introduced in a reservoir through a number of injector wells perforated around a producer well.

As an injected phase, CO_2 can be injected into the oil zone through various schemes including miscible and immiscible continuous CO_2 injection, cyclic CO_2 injection, CO_2-flue gas mixture injection, water-alternating-CO_2 injection, carbonated water injection . Parameters such as the type of crude oil, thermodynamic conditions of the reservoir, petro-physical and geo-mechanical properties of the reservoir rock, and the extension of the oil zone have a significant effect on the performance of CO_2-EOR processes .

Under favourable reservoir temperature and pressure conditions and crude oil composition, carbon dioxide can become miscible with petroleum, i.e. the crude oil and CO_2 form a single homogenous phase (Figure 1). As a result of this interaction, the volume of oil swells, its viscosity is reduced, and surface tension effects diminish, improving the ability of the oil to flow out of the reservoir. When CO_2 is directly miscible with oil the interface between the two phases ceases to exist and theoretically the oil recovery factor reaches unity . However, Carbon dioxide can be not instantaneously miscible with oil at first contact, miscibility conditions develop dynamically in the reservoir through mass transfer of components as a result of repeated contacts between oil and injected carbon dioxide during the flow, via a process known as multiple contact miscibility (MCM), the pressure at which multiple contact miscibility takes place is called Minimum Miscibility Pressure (MMP). For a miscible CO_2 flood, the pressure should be above the MMP.

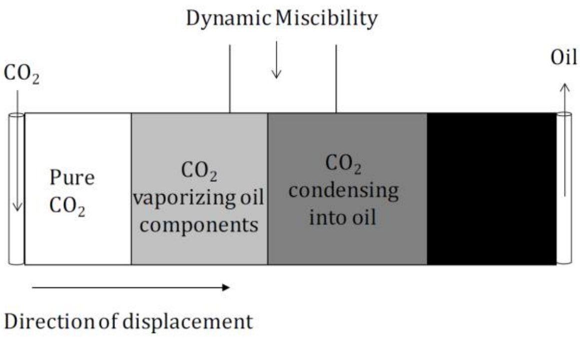

Figure 1. *One dimensional schematic showing how CO2 becomes miscible with crude oil*

If the reservoir pressure is lower than the MMP between the crude oil and CO2, the CO2 injection is classified as an immiscible solvent injection. In this case, the CO2 although not fully miscible with oil, it can still partially dissolve in it causing some swelling and reducing oil viscosity. More importantly, in immiscible displacement, the role of CO2 is similar to that of water in secondary oil recovery processes, i.e. to maintain reservoir pressure. The use of CO2 to maintain reservoir pressure has been considered in limited number of projects when the permeability of the reservoir formation is too low or geologic conditions do not favour the use of water.

Cyclic CO2 injection, which is also known as a CO2 huff-and-puff process, has been investigated through experimental and simulation studies as well as field tests as an EOR technique for more than 30 years . Cyclic CO2 injection was initially proposed as an alternative to cyclic steam stimulation for heavy crude oils. However, It is reported that the cyclic CO2 injection process has wider applications in light oil reservoirs . In this process, after the injection of CO2 into the reservoir, the well is close for a period of time called soaking period, depending on the pressure and temperature reservoir conditions and reservoir rock and fluid properties. Then, the oil production is initiated by converting the injection well to a production well. The injected carbon dioxide has the ability to change the reservoir rock and fluid properties in terms of rock wettability and relative mobility, leading to enhance the hydrocarbon production recovery. Several operating parameters including characteristics of reservoir rock, crude oil proprieties, pressure, soaking period, injection time and number of cycles influence the performance of this technique. Although a set of studies have been reported on this process, there remains a lack of experimental work to illustrate the influence of the aforementioned parameters on the recovery performance on CO2 injection process.

It is reported in the literature that there are also two types of CO2 injection in CO2-EOR processes: the water alternating gas (WAG) method and the gravity stable gas injection (GSGI) method. In WAG injection, CO2 is injected first to dissolve into oil through mass transfer for swelling the oil and improving its fluidity. Then, water is used to displace the oil bank towards the production well. A schematic of the process is shown in Figure 2.

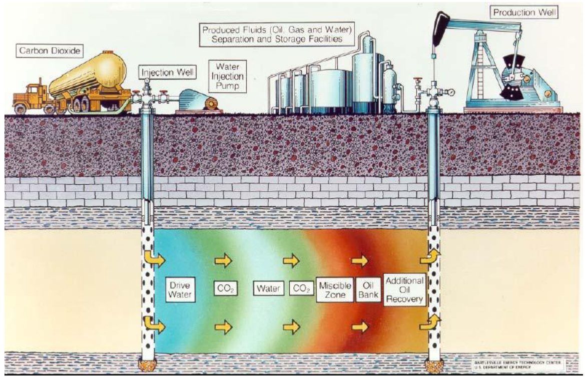

Figure 2. *A schematic of a WAG miscible CO2-EOR process*

Another method for introducing CO_2 in the reservoir is to inject it in the crest, called gravity stable gas injection (Figure 3). The injected carbon dioxide creates an artificial gas cap, pushing oil downwards and towards the rim of the reservoir where the producing wells are located. CO_2 (which can be miscible or immiscible to oil) is used for maintaining reservoir pressure and for stabilising displacements via gravity drainage to increase sweep. WAG has an advantage over GSGI in that it can be performed on a small field; while in general, GSGI is applied in the whole oil reservoir. Hence GSGI projects are likely to recover more oil and store larger CO_2 volumes

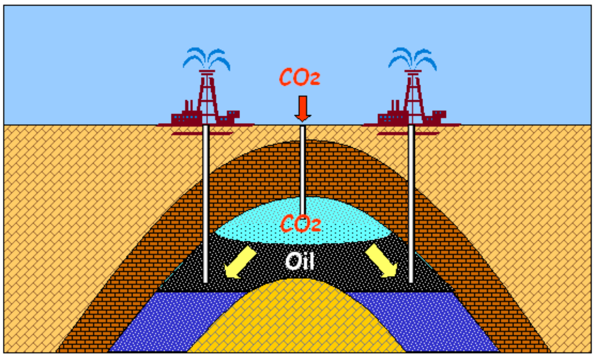

Figure 3. *A schematic of the GSGI immiscible displacement in CO2-EOR process*

III. On-going CO2-EOR projects

The first project of CO2 -EOR at industrial scale was started in 1972 in SACROC field in the USA . A large number of CO2 - EOR projects have started since then. Based on the 2014 EOR survey by the Oil and Gas Journal there are more than 140 of CO2-EOR projects worldwide. Nearly all of them are miscible CO2-EOR projects were implemented in the USA [30]. Table 1 shows the production of active CO2-EOR projects and their production rates in 2014 with the outlook of these projects in 2020 for United State by region . These projects produced cumulatively approximately 300000 barrels of oil per day at the start of year 2014 by injecting over than 68 million tonnes of CO2 per year. This rate of oil production has grown steadily for the past 30 years. Given the new volumes of CO2 supplies and the numerous announced CO2-EOR projects, A. Kuuskraa and M.Wallace envision strong growth in near-term oil production and CO2 utilization from CO2-EOR, their analysis shows that incremental oil production from CO2-EOR operations is likely to double to 638000 barrels of oil per day in 2020.

Table 1. *Projected CO2-EOR production*

Region	CO_2-EOR production rates (bbl/day) (1 bbl = 159 l)	
	2014	**2020**
Permian Basin	199000	323000
Gulf Coast	47000	152000
Rocky Mountains	39000	103000
Midcontinent	14000	59000
Other	1000	1000
Total	**300000**	**638000**

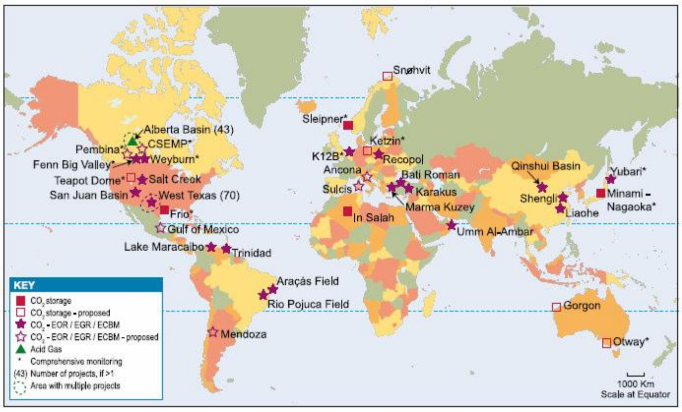

Figure 4. *Location of sites where activities relevant to CO2 storage are planned or under way*

The use of CO2 injection for oil recovery has been slow to catch some exception on outside of the US. One notable exception is Weyburn oil field, where in Canada and Apache have field-wide CO2-EOR projects. Additional exceptions include the injection of CO2 into Bati Raman heavy oil field in Turkey and the use of CO2 in a series of heavy oil fields in Trinidad. Recently, the interests have emerged several CO2 injection projects in Algeria (In Salah Gas), Abu Dhabi, Brazil, China, Malaysia, the North Sea, and other areas for purpose of enhanced oil recovery or CO2 storage, Fig 4.

In Salah Gas is a joint venture of Sonatrach, British Petroleum (BP), and Statoil, which started in July 2004, for producing natural gas to sale in Europe. The natural gas contains up to 10% of CO2 concentration, which has to be reduced to 0.3% before the gas is sold. Hence, 1 million tonnes/year of CO2 is produced and re-injected into the Krechba Carboniferous Sandstone reservoir via two horizontal wells at a depth of 1900 metres for combined between CO2 geological storage and enhanced gas recovery. The height of this geological formation is 20m, its porosity is 16% and its permeability is 10 md, fig 5. This joint venture is the first industrial-scale project in the world to store CO2 in the water leg of a gas reservoir .

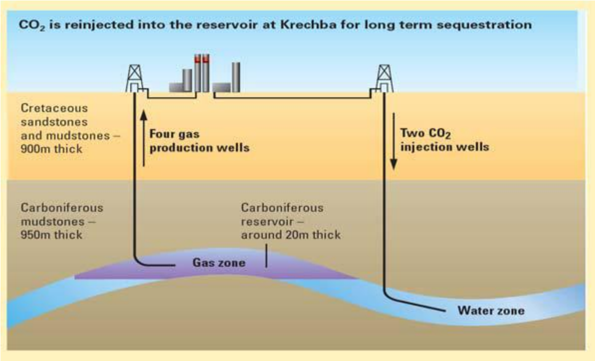

Figure 5. *Schematic of CO2 storage strategy at Krechba field (In Salah Gas project) .*

IV. Conclusion

With the decline of oil production and apparition of global warming problem caused by excessive emission of carbon dioxide during the last decades, it is believed that EOR-CO2 technologies will play a key role to meet the energy demand and better mitigation of climate change in years to come. If we look to the great number of studies interest by EOR-CO2 projects problem, we can conclude that this subject is being very important in Clean Technologies and Environmental Sciences.

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Please cite this Article as:

Atia A., Mohammedi K., *State of the art on enhanced oil recovery with CO_2 sequestration for low carbon industry*, ***Algerian J. Env. Sc. Technology***, **3:1 (2017) 05-08**