INJECTION AND STORAGE OF CO_2 – EFFICIENT METHOD FOR INCREASING OIL RECOVERY

Nicolae TRAŞCĂ-CHIRIŢĂ[1], Iolanda ALEXE[2], Mihai CHIRAN[2] , Amuliu PROCA[1], Constantin Ştefan SAVA[3], Alexandra Constanţa DUDU[3], Sorin ANGHEL[3], Andreea BURLACU[1], Corneliu DINU[1]

[1]CO_2 Club Romania, 23-25 D. Onciul St., Bucharest,
e-mail: trascatitus@gmail.com, andreea@co2clubromania.com, codinu@gmail.com
[2]PicOil Infoconsult S.R.L., 21 Ion Campineanu Street, Campina, Prahova, Romania,
e-mail: iolanda.alexe@pic-oil.ro, mchiran@pic-oil.ro
[3]National Institute of Marine Geology and Geo-Ecology (GeoEcoMar), 23-25 Dimitrie Onciul St., 024053 Bucharest, Romania
e-mail: savac@geoecomar.ro, alexandra.dudu@geoecomar.ro, soanghel@geoecomar.ro

Abstract. The paper shows the advantages of technological CO_2 injection in Romanian oil deposits, the main ones being the increase of oil production and gathering the necessary data for optimal geological storage of CO_2. Several Romanian oil fields where geological storage of CO_2 may be applied after technological injection of CO_2 are also presented.

Key words: CO_2 storage, enhanced oil recovery, CO_2 utilization

1. GENERAL DATA

The oil fields exploitation using their own energy, known as "primary exploitation", is characterized in general by intense extraction rates in the first phase followed by quick production decline and by a small recovery factor – in general of 2 – 20 %. Once the deposit's energy is reduced it is necessary to supplement the remaining energy by various methods. From the time when such methods are applied, the field enters the phase of "secondary exploitation" or "enhanced oil recovery – EOR", whose characteristics vary according to physical parameters of each field and the recovery methods applied (Cârcoană , Aldea, 1976; Goran, Ionescu, 2003; Traşcă-Chiriţă *et al.*, 2008). The application of enhanced oil recovery methods is a safe solution to increase the oil reserves and to intensify oil extraction. This explains why in Romania extensive laboratory research and field experiments have been carried out on enhanced recovery methods, like chemical methods, thermal methods (underground combustion, steam or hot water injection), CO_2 injection, petro mining methods, microbiological methods, nitrogen injection, horizontal drilling, etc. The best results were obtained by underground combustion that has been applied on 26 Romanian oil fields. In the final chapter of this paper several Romanian oil fields are presented, where technological injection of CO_2 might be applied, possibly followed by geological storage of CO_2.

2. CLASSIFICATION OF ENHANCED OIL RECOVERY METHODS

There are two large groups of enhanced recovery methods: conventional and unconventional, which will be briefly presented here.

- Conventional methods: technological water injection; gaseous hydrocarbon injection; thickening the exploitation grid.
- Unconventional methods: chemical methods; CO_2 technological injection; thermal methods; petro mining methods; microbiological methods; flue gas injection; nitrogen injection; horizontal drilling (drilling horizontal or very inclined drains); acoustic stimulation.

Depending on the working agent used and on the acting principle, there are chemical and thermal methods.

Chemical methods include:

- Water with polymers injection;
- Tensioactive - alkaline solutions injection;
- Micellar solutions injection;
- Solvents injection.

Thermal methods include:

- Underground combustion;
- Cyclic or continuous steam injection
- Hot water injection.

Out of conventional methods, thickening of exploitation grid and water injection are widespread in the world and are over 100 years old, but the final recovery is reduced, in general to between 15 and 30 %. The best results are obtained by application of thermal methods, especially the underground combustion that ensures the increase of recovery factor up to 40 – 60 %. On the other side, underground combustion and steam injection have many disadvantages that make them prohibitive on the majority of oil fields, the most important being:

- relatively narrow application domain: only to fields with heavy or viscous oil;
- large volume investment needed for equipping the derricks with necessary surface equipment (air compressors or steam generators, pipes, water and flue gas separators, etc.) and the time to install all these (3.5 years in average);
- big inertia of such a method (3.5 years between starting of such a project until the first favorable results).

In the present conditions**, the most efficient method of enhanced recovery** that can be applied in Romanian oil fields is technological injection of CO_2, named also CO_2-EOR. Injection of CO_2 into oil reservoirs to enhance oil recovery has been commercially used for almost 50 years in the oil industry (IEA, 2015). The main concentration of CO_2-EOR projects is in North America, mostly in the Permian Basin of United States (IEA, 2015).

CO_2-EOR technology has the following advantages:

- Ensures an important increase of oil production and reserve, being able to increase recovery by 5% to 15% of the original oil in place, as shown by United States projects experience (IEA, 2013);
- Has the largest application domain that is to all types of oils and fields, as it has many application modes and displacement - recovery mechanisms that act depending on the characteristics of each field. However**, to have an increased economic efficiency it is necessary that natural or industrial sources of CO_2 be close to the oil field**.
- The operation mode is relatively simple: a stopping of CO_2 is injected in the injection wells and it is pushed toward production wells by water injection in the injection wells (that is if the water-alternating-gas injection scheme is used);
- There are many industrial sources of CO_2, some of them being situated close to oil fields where CO_2 injection might be applied;
- It can be applied even after other EOR methods had been tried/used, but with somewhat different results;
- It can be followed or associated with a process of CO_2 geological storage which significantly increases the overall efficiency of technological injection due to the additional economic benefits in the future permanent storage phase;
- Supplementary useful data can be obtained on injection pressure and CO_2 underground behavior. Also a partial CO_2 storage is done, the so called "technological storage – TS, that is 10 – 30 % from the total capacity storage is depending on properties of oil and physical – geological model of the field. We are speaking of the CO_2 that is dissolved in oil or saline water of the field aquifer and the one that accumulates in primary or secondary gas caps;
- It can attract important European funds through ECO-BASE or ALIGN projects;
- The efficiency of geological storage of CO_2 is increased in the respective oil fields - it benefits from existing injection installations and equipment, as well as experienced personnel trained during the technological injection phase.

The applicability of CO_2 injection in EOR is estimated in accordance to its specific properties, the most important being:

- High solubility in oil, 2 – 10 times higher than the solubility in water (soda);
- Increasing the volume of oil up to 1,6 – 1,7;
- Reducing oil viscosity by 3 – 100 times;
- Total or partial miscibility with oil;
- Acid effect on carbonate host rock with increased permeability;
- Substantial reduction of interfacial tensions in the oil field.

Depending on temperature and pressure conditions in the oil field, the possible mechanisms of displacement – recovery are as follows:

- CO_2 détente as it came out of solution;
- Miscible displacement of oil;
- Immiscible displacement of oil ("piston" type).

Out of these mechanisms , CO_2 détente as it came out of solution is met at most of the fields, at the other end being the miscible displacement as it needs a higher pressure up to miscibility pressure.

3. ENHANCED RECOVERY METHODS APPLIED IN ROMANIA

Both conventional and unconventional methods have been applied on Romanian oil fields with various physical – geological parameters. Out of conventional methods, thickening the exploitation grid has been applied on all the oil fields, conventional water injection on more than half of the commercial fields, while gas injection has been applied less, mostly experimentally, because of no availability of gases. Technological water injection, although it was practiced in many fields, did not offer the expected results except in very few cases because of operational errors.

The EOR unconventional methods have been applied in Romania both experimentally as well as industrial projects. The following methods are singled out:

- Chemical methods, that is injection of micellar or alkaline – tensioactive solutions, injection of polymers. These methods have been applied mostly experimentally and sometimes industrially, like polymers injection on Meotian - Drăgăneşti and alkaline solutions at Dacian - Băicoi fields.
- Thermal methods as underground combustion, cyclic or continuous steam injection, and hot water injection. Out of them, steam injection and underground combustion have been applied both experimentally and industrially (70 field experiments and 11 industrial processes have been carried out on 26 oil fields with different physical – geological parameters) and hot water injection has been applied experimentally only at Meotian – Sotanga and Meotian – Oțeşti fields.
- Injection with microbiological solutions has been applied only experimentally.
- Petro mining methods have been applied both experimentally and industrial with good results at Sărata Monteoru, Matița, Solonț, Derna –Budoi and Suplacu de Barcău.
- Continuous CO_2 injection has been used experimentally only at Meotian Bradu – Albota, details have been presented in several papers (Trașcă-Chiriță *et al.*, 2008, 2010, 2017; Trașcă-Chiriță, Baciu, 2008, 2012); the results were favorable and an important operational experience was obtained.
- Horizontal drilling was applied experimentally and industrially on many fields with good results (Trașcă-Chiriță *et al.*, 2008, 2010; Trașcă-Chiriță, Baciu, 2008, 2012) especially when very inclined drains were drilled in old drillings (side –track).

The association of CO_2 storage during and after CO_2 technological injection is potentially very efficient because:

- An important surface infrastructure is already in place – pipes, electrical supply lines, separator batteries, storage tanks, pumps for liquids, access roads, etc. ; all these can partly be used both in the injection process and for its monitoring;
- There is already qualified operational personnel operating the nearby oil fields and it can be employed either for necessary works at injection or for monitoring the storage process;
- The CO_2 injection for geological storage can be carried out in any season with maximum flexibility and even discontinuously as the temporary halt of injection do not affects the storage process.

Another advantage of the association between geological storage and technological injection consists in the fact that it facilitates obtaining the necessary permits from the National Agency of Mineral Resources – NAMR.

4. THE FUTURE OF CO_2 TECHNOLOGICAL INJECTION AND GEOLOGICAL STORAGE IN ROMANIA

To implement the provisions of Paris Agreement on slowing the pace of climate change, the most efficient solution is the geological storage of CO_2, as it is the main component of human generated greenhouse gases. Expert bodies on climate change around the world agree that climate change targets cannot be achieved without CCS (Global CCS Institute, 2018). The latest assessment of IPCC (International Panel on Climate Change) on global warming (IPCC, 2018), a response to the request of UNFCC (United Nations Framework Convention on Climate Change) at COP21 in Paris (2015), acknowledge CCS (carbon capture and storage) to “play a major role in decarbonising the industry sector in the context of 1.5°C and 2°C pathways, especially in industries with higher process emissions, such as cement, iron and steel industries” (IPCC, 2018).

The geological storage of CO_2 can be mainly carried out in underground saline aquifers, in unminable deep coal seams and in depleted oil and gas fields (IPCC, 2005). The main advantage of the oil and gas fields as CO_2 storage reservoirs is that these are known structures that have sufficient reservoir data from exploration and exploitation of hydrocarbons, facilitating the appraisal of storage site and prediction of CO_2 behavior. In addition, enhanced oil recovery with CO_2 storage can be an attractive business, especially since today CO_2 storage lacks a business case in the absence of specific incentives.

Since many of the Romanian oil fields are currently in the tertiary exploitation phase, the technological injection of CO_2 could be an important tool to increase oil recovery. Moreover, the association with CO_2 storage is essential to prevent generation of additional CO_2 emissions from the oil fields. Selection of the Romanian oil fields that can be used for the implementation of CO_2-EOR technology must be based on several specific criteria, presented below.

The oil fields with more than 3-4 superimposed beds have been considered as to avoid the CO_2 migration in other strata within the storage site. Also, oil fields with wells drilled before 1950 have been avoided, as there are no reliable data on construction, cementing and abandonment of the wells that can become ways for CO_2 migration toward the surface. Nor have been considered the oil fields situated in areas of seismic risk: those in Buzău – Focşani – Galați area and in the vicinity of major faults (Pericarpatian Fault and others) and of other faults with high seismic potential, like the Vidraru – Snagov – Shabla (Bulgaria, where it extends under Black Sea). This fault was reactivated after more than 100 years of being a “closed”, inactive fault.

In order to avoid the possibility of CO_2 contamination of phreatic water table, the oil fields within or close to inhabited areas have been avoided. It is possible that, after a very long period of time – hundreds or thousands years – the present seal of the beds to be lost by unforeseen phenomena.

Preference was given to oil or gas fields in advanced stages of exploitation and situated close to industrial sources of CO_2, as high capacity power stations, industrial plants (chemical, metallurgical, cement, etc.) that emit large quantities of CO_2 (*e.g.* C.E. Rovinari, Turceni, Mintia, Chimcomplex Borzeşti, etc.).

As the oil fields are hydrodynamically sealed, it is considered that even fields shallower than 800 m (the depth at which the CO_2 can be stored in supercritical - liquid state) can be used as storage sites for CO_2 in a gaseous state at a final pressure lower than the initial field pressure.

In Romania there are many oil and gas fields with high potential for geological storage of CO_2, but the majority of them are producing and can get permit for CO_2 storage from NAMR only after a preliminary phase of technological injection, although some of them are in the final stage of production. This phase – technological injection – can last 3 – 10 years, depending of oil properties, physical – geological model of the field, its present energetic potential and oil saturation of the field.

Table 1 shows the Romanian fields where, according to our present estimate, CO_2 technological injection (TI) with technological storage (TS) and /or geological storage (GS) can be applied. The difference between TS and GS is that the first refers to the inherent retention of CO_2 in the reservoir in the EOR phase while GS refers to permanent storage of CO_2. The table shows the producing geological strata, as well as their depth. It can be seen that at the majority of fields with possibilities of CO_2 geological storage, the technological injection – in the variant immiscible displacement – can be applied to enhance production and oil reserves. The CO_2 sources are flue gases from the nearby energy and industrial plants where carbon dioxide can be separated by various adequate physical and chemical processes, depending of the technology of these plants.

5. CONCLUSIONS

The application of oil enhanced recovery methods is a safe solution to increase oil production and exploitable reserves. In Romania, the best results were obtained by applying the thermal methods (underground combustion and steam injection), but the application domain is reduced and the required investments are very large.

Currently, the most efficient EOR method that is applied in Romanian oil fields is CO_2 technological injection that shows many advantages: it has the widest application domain, so it can be applied on all types of oil fields; ensures the increase of oil production and reserves with 20 – 30% and can be followed by a process of geological storage of CO_2 that ensures a sensible increase of technological injection efficien-

Table 1. Data on fields with possibilities of CO_2 storage and/or technological injection

Field	Depth, meters	Geological Age, Special Problems, Methods to be applied (*) and placement area
Suplacu de Barcău Sud	180-300	Pannonian, gas cap; TI+TS
Boldeşti	2000-2800	Helv., Sarmatian and Meotian; TI+TS
Brădeşti	2300-2500	Triassic, Dogger and Sarmatian; TI+GS; Craiova
Călacea	900-1100	Miocene and Pannonian; TI+GS; Banat
Independenţa	450-1050	Sarmatian and Meotian;TI+TS; Brăila
Călinesti-Oarja-Albota	900-1200	Meotian;TI+GS; Piteşti
Bâlteni	900-2300	Helv.,TI+GS; Tg. Jiu
Aninoasa	1100-1300	Meotian; TI+GS; Târgovişte
Turnu	900-1000	Basement, Miocene and Pannonian, very large gas cap; TI+GS; Arad
Băbeni - Tătărani	900-1200	Helv. ;TI+SG; Rm.Vâlcea
Bragadiru	650-850	Sarmatian TI+GS; Bucureşti
Jilava	500-620	Sarmatian 3 and Meotian TI+GS; Buc.
Berceni	400-500	Sarmatian 3 and Meotian TI+GS; Buc.
Dumitrana	500-650	Sarmatian and Meotian; TI+GS; Buc.
Nenciuleşti-Buzescu	600-800	Albian; GS; Alexandria
Abram	1800-2100	Badenian; TI+GS; Oradea

*) TI = CO_2 technological injection; GS/TS = CO_2 geological/technological storage.

cy; important data on injection pressure and CO_2 evolution in the field can be obtained; European funds can be obtained trough ECO – BASE and ALIGN projects.

In Romania, technological injection has been applied both as continuous injection (at a semi- industrial level at the Meotian – Bradu – Albota field) and as short time injection for stimulation of oil flow on various fields. The results were good and a useful practical experience has been gained (Trașcă-Chiriță, Baciu, 2008, 2012; Trașcă-Chiriță *et al.*, 2008, 2010, 2017).

The most important difficulties in applying the technological injection in Romanian oil fields include: poor attention given to this method in the last 20 years; it requires a small number of specialists in projecting, practical work in the field, and management of injection; lack of adequate infrastructure at the majority of commercial oil fields.

There are many oil fields in Romania where technological injection and geological storage of carbon dioxide can be applied, some of them presented in the Table 1. To unlock this potential, it is necessary that the Romanian Government grants fiscal facilities for the companies that apply EOR. So we suggest the reduction of royalties and other taxes to partially compensate the investments and current expenses needed for speeding up application of such methods.

REFERENCES

Cârcoană, A., Aldea, G. 1976. Mărirea factorului de recuperare la zăcămintele de hidrocarburi. Ed. Tehnica, Bucureşti.

Global CCS Institute. 2018. The Global Status of CCS 2018. Global Carbon Capture and Storage Institute Ltd 2018. Australia. https://adobeindd.com/view/publications/2dab1be7-edd0-447d-b020-06242ea2cf3b/qhqw/publication-web-resources/pdf/CCS_Global_Status_Report_2018_Interactive.pdf

Goran N., Ionescu Fl. 2003. Creşterea recuperarii petrolului. Editura U.P.G. Ploiesti, 2003, pag. 28-29.

IEA. 2013. Resources to Reserves 2013. Oil, Gas and Coal Technologies for the Energy Markets of the Future, OECD/IEA, Paris. https://www.iea.org/publications/freepublications/publication/Resources2013.pdf

IEA. 2015. Storing CO_2 through Enhanced Oil Recovery. Combining EOR with CO_2 storage (EOR+) for profit. https://www.iea.org/publications/insights/insightpublications/CO2EOR_3Nov2015.pdf

IPCC. 2005. Special Report on Carbon Capture and Storage. March 2005. https://www.ipcc.ch/site/assets/uploads/2018/03/srccs_wholereport-1.pdf

IPCC. 2018. Global Warming of 1.5°C. Summary for Policymakers. October2018. https://www.ipcc.ch/site/assets/uploads/sites/2/2018/07/SR15_SPM_High_Res.pdf

Trașcă-Chiriță, N., Baciu, C.M. 2008. Aplicarea metodelor de recuperare secundară în România - realizări şi perspective. Monitorul de Petrol şi Gaze (MPG), nr. 1/2008.

Trașcă-Chiriță, N., Baciu, C.M. 2012. Creşterea rezervelor de țiței la zăcămintele OMV PETROM prin aplicarea metodelor de recuperare neconvenționale. FOREN 2012, Neptun, iunie 2012, sectiunea 4, pp 1-9

Trașcă-Chiriță, N., Baciu, M. C., Crângașu, M. 2010. Creşterea rezervelor de țiței şi reducerea poluării prin injecție tehnologică şi stocare geologică de CO_2. FOREN, Neptun, 06. 2010

Trașcă-Chiriță, N., Popa, C., Baciu, M. 2008. Aplicarea metodelor de recuperare secundară a țițeiului în România. The International Conference Science and Tehnology in the Context of Sustainable Development. UPG Ploiesti, nov. 2008.

Trașcă-Chiriță, N., Sava, C., Turtă, A.2017. Stocarea bioxidului de carbon în zăcămintele de petrol. Revista Monitorul de Petrol si Gaze (M.P.G.), iunie 2017, pp 19-25