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GEO ENeRGY

Promoting *R&D capability* in the service of European Industry

Enhanced Oil Recovery through CO_2 Injection in Hungary

Hungarian geoscientific literature reveals that carbon dioxide injection has achieved a wide range of field applications within Hungary. CO_2 injection has been applied to several types of reservoirs: e.g. sandstone, karstic limestones and metamorphic. The type of flooding technology applied at various sites depends on oil properties, reservoir morphology and follows laboratory measurements and pilot tests with practical results.

Hydrocarbon exploitation by CO_2 flooding has been tested in some of the major oil fields in Hungary shown in Figure 1. *Budafa* and *Lovászi*, the two oldest oil (and gas) fields discovered in 1937 and 1940, respectively, are sandstone reservoirs. The production was started in both fields using natural depletion. Already in 1939 and 1944, re-injection of hydrocarbon gas was used as a secondary recovery method. Later edge, and subsequent areal, water flooding was used as additional recovery mechanism.

The bulk of the oil in the *Nagylengyel* oil field, discovered in 1951, is accumulated in karstic Cretaceous rudistic limestone and Triassic dolomite. During primary recovery, natural water drive was dominant. Water encroachment became more and more intensive by the end of the seventies.

The *Szank* Field reservoir is a very special reservoir. The reservoir rock consists of heavily faulted Precambrian metamorphics. The exploitation started by natural depletion in 1969. The predominant displacement mechanism has been natural edge water drive. By 1990 production wells located at the edge of the reservoir watered out and the production rate decreased dramatically.

Laboratory and pilot plant tests demonstrated the possibilities of practical use of the substantial reserves of natural carbon dioxide for EOR in Hungary. Several field-scale applications have been realized. Applications have varied over a wide range from immiscible displacement in sandstone and karstic reservoirs to miscible displacement in metamorphic and mixed rock type reservoirs. Results (summarized in Table 1) show that CO_2 gas injection can be used successfully in various lithology types. The additional oil recovery varies between 5 to 14% depending on the type of reservoir and the technology applied.

Sandstone reservoir

Natural carbon dioxide from a nearby resource was injected into a depleted sandstone reservoir to increase oil recovery. The aim of flooding was to increase the depleted reservoir pressure to its initial value. The basic precondition for the successful operation was to ensure fixed CO_2 concentration of the dissolved gas in oil. In order to achieve this stable concentration and to increase sweep efficiency, cyclic gas/water injection was carried out, followed by reservoir depletion. The process is immiscible. The additional recovery factor of oil in the reservoir is 6 to 14%.

Karstic reservoir

After primary recovery substantial oil was left behind in the karstic reservoir. CO_2 gas was injected to establish an artificial gas cap. As a consequence of the gravitational segregation, induced by the gas injection, part of the oil left behind becomes mobile. Below the gas-oil contact moving downward, an oil belt is formed. A fraction of this oil can be recovered through the production wells until the gas breakthrough. During the blow down of the gas cap the oil moves upward and can be recovered by water drive. In this case reservoirs are produced with active karstic water drive at the original reservoir pressure. The process is immiscible and the additional recovery factor in the reservoir is 7 to 13%.

Metamorphic reservoir

The predominant displacement mechanism in the reservoir before CO_2 injection has been the water inflow from the edges. The wells located at the edge of the reservoir watered out and the production rate dramatically decreased. Afterwards, a CO_2 injection project has been started. The primary goal of the injection was to ensure the disposal of carbon dioxide-rich waste gas coming from neighbouring gas fields. The secondary goals were enhanced oil recovery and the protection of the environment from CO_2 pollution. Consequently, watered out wells, located at the edge of the reservoir, became oil producers again, resulting in higher recovery rate than expected.

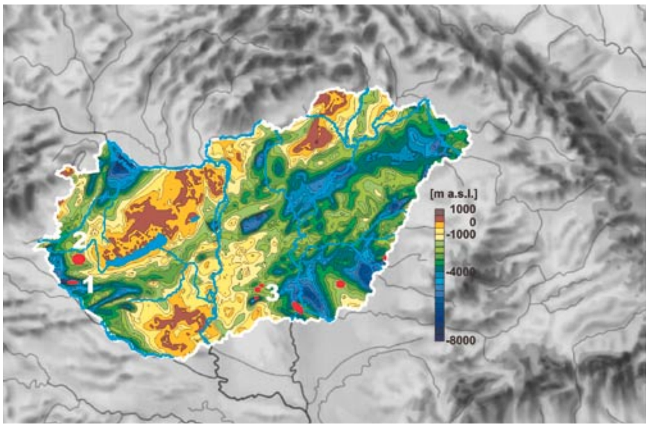

Fig. 1: Pre-Tertiary basement contour map of Hungary (in color) with the topographic map of the Pannonian Basin and its surroundings (in gray). Some of the major oil fields in Hungary are indicated by red. Those ones involved in EOR activity are numbered: 1 – Budafa & Lovászi Fields; 2 – Nagylengyel Field; 3 – Szank Field

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Table 1: Main parameters of extended hydrocarbon production of certain oil and gas reservoirs in Hungary as a result of CO_2 injection

	Oil and gas reservoirs			
	Sandstone (oil)	Karstic (oil)	Metamorphite (oil)	Sandstone (gas)
Mean porosity (%)	21	1.2	13	20
Mean permeability (darcy)	0.1	3.8	0.08	0.04
Primary recovery efficiency (%, OOIP*)	22.5	42	28	75
Start date of CO_2 injection	1972	1988	1992	1985
Injected CO_2 gas (Mm^3, up to 1996)	719	1852	142	15
Additional recovery (%, OOIP*)	7	10	5	12

*OOIP original oil in place

The recovery factor of the whole reservoir in this case is now expected to be 5 to 6% at the end of the project.

Gas recovery by CO_2 injection

A depleted sandstone gas reservoir at *Budafa Field* was used to test the applicability of CO_2 injection for gas recovery. The plant experiment was prepared using laboratory experiments, numerical simulations and modeling. The excess recovery (11.6%) proves the efficiency of the injection method. Started in 1985, it was one of the first successful examples of EGR in Europe. The injected CO_2 rich gas has good exchange capacity with gas of high methane content. Excess recovery of the gas exceeded 11% with respect to original gas content and was about 50% of the residual gas in the resource. Low capacity gas production of the wells enables continuous gas production without the damping effect of condensed water in the pipelines.

These practical results prove the success and efficiency of carbon dioxide injection in hydrocarbon production in Hungary.

Endre Hegedüs, György Falus

European Commission Funds CO_2 Capture and Storage Projects (Part I)

In response to the call for proposals launched by the European Commission on 17 December 2002, five projects have been selected for funding – three integrated projects (IP) – "CO_2 SINK", "CASTOR" and "ENCAP", one network of excellence (NoE) – "CO_2 Geonet" and one specific targeted research project (STREP) – "ISCC".

In-situ R&D Laboratory for Geological Storage of CO_2 – CO_2 SINK

Coordinator – GeoForschungsZentrum Potsdam (GFZ – Germany)
European funding: 8.7 million Euro

The project will be carried out by a consortium of 14 organisations from 8 European countries which include universities, research institutes and industrial companies. The main objective of the project is to advance understanding of the science and practical processes involved in underground storage of CO_2 to reduce emissions of greenhouse gases to the atmosphere.

The site selected (an abandoned gas storage near Ketzin, Germany) includes industrial land and some infrastructure, which makes it suitable as a testing ground for small scale demonstration of CO_2 capture processes.

The first steps will be to prepare a baseline survey of the site and the target reservoir and to carry out a detailed risk assessment to ensure that the experiment can be conducted safely. The necessary approvals and consent of local authorities and residents will also be sought. This is expected to take 12–18 months.

The CO_2 SINK project will use the existing site infrastructure. The plan is to inject some 10,000 tons per year of pure CO_2 into the reservoir for a period of approximately 3 years. The source of CO_2 is still under discussion and negotiation with the intent, if at all feasible, to make use of a renewable primary fuel source.

To characterise the underground and understand the processes which happen there, an array of activities is planned. Detailed analysis of samples of rocks, fluids and micro-organisms collected from the underground, measurements and experiments in boreholes, geophysical surveys at the surface and borehole seismic imaging, novel monitoring instruments at the surface and downhole and numerical predictive models will all help to prepare for the injection of CO_2 underground, follow its fate over long periods of time and evaluate reservoir stability and integrity.

CO_2 from Capture to Storage – CASTOR

Coordinator – Institut Français du Pétrole (IFP – France)
European funding: 8.5 million Euro

The project will be carried out by a consortium of 30 organisations from 11 European countries which include universities, research institutes and industrial companies. The project's objective is to make possible the capture and geological storage of 10% of European CO_2 emissions, or 30% of the emissions of large industrial facilities (mainly conventional power stations). To accomplish this, two types of approach must be validated and developed: new technologies for the capture and separation of CO_2 from flue gases and its geological storage, and tools and methods to quantify and minimize the uncertainties and risks linked to the storage of CO_2. In this context, the Castor project program is aimed more specifically at reducing the costs of capture and separation of CO_2 (from 40–60 €/ton CO_2 to 20–30 €/ton), improving the performance, safety, and environmental impact of geological storage concepts, and, finally, validating the concept at actual sites.

The R&D work is performed into 3 sub-projects: Post-combustion capture (65% of the budget), Geological storage (25% of the budget) and Strategy for CO_2 reduction (10% of the budget).

Work on capture is aimed at developing new CO_2 post-combustion separation processes suited to the problems of capture of CO_2 at low concentrations in large volumes of gases at low pressure. The processes will be tested in a pilot unit capable of treating from 1 to 2 tons of CO_2 per hour, from real fumes. This pilot will be implemented in the Esbjerg power station, operated by ELSAM in Denmark.

The work on storage will provide the European industrial community with four new storage facility case studies representative of the geological variety of existing sites across Europe:

- storage in an abandoned reservoir in the Mediterranean (Casablanca Field, operated by Repsol, Spain)
- storage in a deep saline aquifer (Snohvit, North Sea, operated by Statoil, Norway)
- storage in two depleted gas reservoirs, one deep, at 2500 m depth (K12b, North Sea, Netherlands, operated by Gaz de France, injection in 2004), and the other closer to the surface and on land, at 500 m depth (Lindach, Austria, operated by Rohoel).

Risk and environmental impact studies will be conducted and methodologies for predicting the future of these sites and for monitoring them will be developed, thereby enriching current knowledge in these fields. During timeline of the CASTOR project, CO_2 injection will be performed in at least two sites – K12b and Snohvit.

The activity under "Strategy for CO_2 reduction" aims to define the overall strategies required to effect a 10% reduction of EU CO_2 emissions and to regularly monitor the effectiveness of the strategies (from capture to storage) from a techno-economical point of view. Research work is also focused on obtaining data on CO_2 sources and potential geological storage capacities from Eastern Europe (extension of the GESTCO European project).

Information sources: information provided by the projects leaders.

To be continued in the next issue…

Georges Mosditchian

Introduction of New ENeRG Members

Eötvös Loránd Geophysical Institute (Hungary)
http://www.elgi.hu
The Eötvös Loránd Geophysical Institute (ELGI), as part of the Hungarian Geological Survey, is one of Hungary's most significant research centres in the field of geoscience.
Its activity includes research both in the pure and applied parts of geophysics as well as geophysical exploration and prospecting. It embraces the application of geophysical methods in investigations spreading from the shallowest engineering problems to the deepest Earth's crust and upper mantle studies, e.g. in structural studies, geological mapping or engineering and environmental investigations. ELGI handles the geophysical databases of Hungary, too.
One of the major running projects is the site characterisation for medium and high level nuclear waste repository.
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Greek Institute of Geology and Mineral Exploration (Greece)
http://www.igme.gr
The Institute of Geology and Mineral Exploration (IGME) is the national geological survey of Greece. It is a public corporate body supervised by the Minister of Development, and it is the State's advisor in all geoscientific matters.
Its fundamental aim includes geological research and mapping, mineral resources, energy resources, environment, natural hazards, water resources and management of geodata.
Geo-energy related activities of IGME embrace, among others, exploration, research and study of solid fuels, geothermal energy, CO_2 capture and storage, energy policy, environmental impacts assessment of energy raw material use. IGME has a staff of about 700 people, 300 of them are geoscientists.
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Institute of Geology at Tallinn University of Technology (Estonia)
http://www.gi.ee/new/
Institute of Geology at TUT is a former institute of Estonian Academy of Sciences. At present it is a governmental institution financed by Estonian Ministry of Education and Research. The institute consists of three departments (Bedrock Geology, Quaternary Geology and Collections), including four laboratories. Its scientists (44 of 75 employees) working in the frame of seven thematic groups have wide scientific interests and supervise (participate in) a number of scientific and applied projects. Their fields of study are lithology, palaeontology, stratigraphy, geochemistry, rock physics, petrology, mineralogy, geological modelling, hydrogeology and environment.
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PBG – Geophysical Exploration Company (Poland)
http://www.pbg.com.pl
PBG is a state-owned SME, founded in 1950. It has offered services on geophysical investigations to petroleum and structural geology, mineral and rocky raw material exploration, engineering geology, hydrogeology and environment protection in Poland and abroad. PBG's over 50-year activities contributed to geological recognition of Poland and findings of metal ores, oil and gas, rocky and chemical raw material deposits as well as groundwater (about 3500 reports and studies and over 3 million field and rock sample measurements stored in databases). PBG's research activities in geo-energy have been focused mainly on geological aspects of geothermal energy.
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PGI – Polish Geological Institute / Carpathian Branch (Poland)
http://www.pgi.gov.pl
PGI, founded in 1919, has headquarters in Warsaw and regional divisions in 6 other Polish cities (e.g. Carpathian Branch in Cracow). It is the country's leading institution on basic and applied geological research. PGI performs the function of state geological survey and has been a member of EuroGeoSurveys since 2001. Carpathian Branch of Polish Geological Institute has been committed to applied research for geological, mineral and energy resources and in hydrogeology, including investigations in the scope of geothermal resources, mainly in the Polish Carpathians and their Foreland. It has participated in many international scientific activities incl. two European FP5 projects.
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Estonian Oil Shales

Kukersite oil shales is Estonia's primary mineral resource and has been a major source of energy for many decades. The reserves amount to 7.6 Gt. With an annual production of around 14 Mt, Estonia accounts for about 70% of the world's oil shale production. The fields are located in the Baltic Oil Shale Basin, situated prevailingly in north-eastern Estonia and extending partly eastwards to Russia. Three well explored oil-shale deposits – "Estonia", "Leningrad" and "Tapa" – are situated within the basin.

"Estonia" is the largest commercially exploited oil shale deposit in the world with total reserves exceeding 5 Gt of oil shale. Kukersite oil shales forming the productive bed of the "Estonia" deposit occur in the Kukruse Stage of the Upper Ordovician (Llandeilian – early Caradocian). The area of the "Estonia" deposit is about 3000 sq.km. At the present time extraction takes place in 2 underground mines and 2 open-cast pits.

The Estonian oil-shale sector, which employs about 4700 workers, poses serious environmental concerns, and efforts to achieve increased efficiency of production and reduced environmental damage, and to minimise the social impact of reforms in this sector, ongoing as part of the „Restructuring plan for the Estonian oil-shale sector for the period 2001–2006".

Alla Shogenova (with the aid of materials published by V. Kattai and H. Bauert and at http://www.ep.ee)

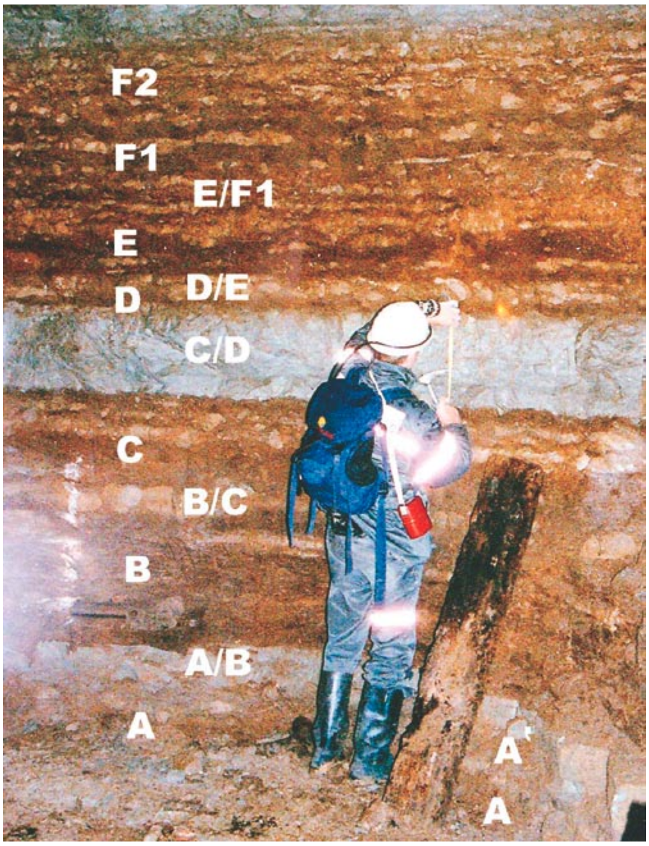

Fig. 1: Sampling of Upper Ordovician sequence including kukersite oil shale by scientists from Institute of Geology at Tallinn University of Technology in the operating Viru underground mine (north-eastern Estonia, Kohtla-Järve region). Estonian kukersite oil-shale commercial seam is represented by seams A to F1 (totalling about 3 m) with some limestone interbeds. Photo by Helje Pärnaste.

GEO ENeRGY Country Profile – Croatia

ENeRG member: University of Zagreb – Faculty of Mining, Geology and Petroleum Engineering
The Faculty of Mining, Geology and Petroleum Engineering is one of 29 Faculties of the Zagreb University, founded in 1669. Scientific activities at the faculty are performed within 25 research projects, fully or partly supported by the Ministry of Science & Education (http://www.mzos.hr/), related to the fields of mining & geotechnics, industrial minerals, petrography, structural geology, petroleum geology, engineering geology, hydrogeology, drilling, well fluids, reservoir engineering, production engineering, gas management, EOR studies, CO_2 capture and storage, geothermal energy, and waste disposal in oil industry. The research projects often include collaboration with the respective industry as well as government bodies and agencies.

Other institutions
On the state level, geo-energy issues, especially greenhouse gas management are coordinated by the Ministry of Environmental Protection and Physical Planning (http://www.mzopu.hr). Environmental pollution studies are performed and inventory of greenhouse gases emission made by state agencies and institutes dealing with national energy programmes: Energy Institute "Hrvoje Požar" (http://www.eihp.hr) and EKONERG Ltd. – Energy and Environmental Institute (http://www.ekonerg.open.hr). Strategic documents, e.g. *Environmental Strategy with Action Plan*, *Priority Action Plan* and *National Environmental Activity Plan* have been made public and can be found at the above web sites.
A lot of activities associated with specific environmental protection and management issues are carried out in the relevant energy sectors, e.g. Croatian Electricity Power Co. (www.hep.hr) and INA Oil Co. (http://www.ina.hr).

National geo-energy issues
Croatia has moderate hydrocarbon production (mature declining oilfields and natural gas/gas-condensate reservoirs inland, as well as gas fields off-shore), no coal production, some geothermal production potential and ample CO_2 underground storage potential.

Croatian territory is geologically complex, including both the Dinarides and the Pannonian Basin. Sedimentary rocks prevail by far – Palaeozoic sediments are found in Northern Croatia, and in the NW Dinarides, while Mesozoic to Palaeogene carbonates make most of the Dinaric region. The Croatian part of the Pannonian basin is filled with Neogene and Quaternary sediments. A total of over 50 small and medium-sized hydrocarbon reservoirs were discovered in the area. Production from the oilfields is in decline.

Croatia is among the European countries with the lowest total emission of greenhouse gases as well as per capita emissions of both greenhouse gases and acid gases. Total CO_2 emissions in Croatia in 2002 were 22,500 kt/yr, the major part of it being related to electricity production (4700 kt CO_2/yr) and oil industry activities (2800 kt CO_2/yr). The main point sources of CO_2 are 9 thermal power plants and large gas processing facility «CPS Molve», located close to Hungarian border, which presently releases approximately 600 kt of clean CO_2 per year into atmosphere.

Possibilities of decreasing CO_2 emissions in Croatia:
- Projects combining CO_2 capture with EOR are being developed for 3 mature tertiary oilfields and associated CO_2 storage aspects are being evaluated.
- Hydrodynamic CO_2 trapping in depleted gas or oil fields is being considered in terms of identification and selection of candidate reservoirs.
- Storage in deep saline formations is yet to be evaluated.

Bruno Saftic & Bogdan Goricnik

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