FIELD EXPERIMENT OF ECBM-CO$_2$ IN THE UPPER SILESIAN BASIN OF POLAND (RECOPOL)

Henk Pagnier$^{1,4}$, Frank van Bergen$^{1,4}$, Pawel Krzystolik$^{2}$, Jacek Skiba$^{2}$, Bartłomiej Jura$^{2}$, Jerzy Hadro$^{2}$, Paul Wentink$^{3}$, Guillaume De-Smedt$^{3}$, Hans-Jürgen Kretzschmar$^{4}$, Jörg Fröbel$^{4}$, Gert Müller-Syring$^{5}$, Bernd Krooss$^{6}$, Andreas Busch$^{7}$, Karl-Heinz Wolf$^{8}$, Saikat Mazumder$^{9}$, Dan Bossie-Codreanu$^{10}$, Xavier Choi$^{10}$, David Grabowski$^{10}$, Daniel Hurtevent$^{10}$, John Gale$^{11}$, Pascal Winthaegen$^{11}$, Bert van der Meer$^{11}$, Zbigniew Kobiela$^{12}$, Hans Bruining$^{6}$, Scott Reeves$^{12}$, and Scott Stevens$^{12}$

$^1$Netherlands Applied Institute of Applied Geoscience TNO, P.O. Box 80015, 3508 TA Utrecht, The Netherlands
$^2$Central Mining Institute (Poland), $^3$Air Liquide (France), $^4$DBI-GUT (Germany), $^5$Aachen University of Technology (Germany), $^6$Delft University of Technology (the Netherlands), $^7$Institut Français du Pétrole (France), $^8$CSIRO (Australia), $^9$Gaz de France (France), $^{10}$Gazonor (France), $^{11}$International Energy Agency Greenhouse Gas R&D Programme, $^{12}$Advanced Resources international (USA)

ABSTRACT

The RECOPOL project is an EC-funded research and demonstration project to investigate the technical and economic feasibility of storing CO$_2$ permanently in subsurface coal seams. The main aim is to demonstrate that CO$_2$ injection in coal under European conditions is feasible and that CO$_2$ storage is a safe and permanent solution before it can be applied on a larger scale in a socially acceptable way. An international consortium of research institutes, universities and industrial partners is carrying out the project activities. This is the first field demonstration experiment of its kind in Europe. The development of the pilot site in the Upper Silesian Basin in Poland began in summer 2003. One of the existing coalbed methane wells was cleaned up, repaired and put back into production. As RECOPOL is a research project it was possible to optimize the pilot in order to maximize the understanding of the sequestration process to be gained from the tests. A new injection well was drilled at 150 m from the production well. After completion of the well with casing, cementing and perforations, the perforated zones were tested. A baseline cross borehole seismic survey was carried out for monitoring purposes in September 2003. Activities in autumn 2003 included the finalization of the injection facilities. Production has started in the first half of June 2004, to establish a baseline production. First injection tests took place in the first week of July. Once the injection is stabilized, both injection and production will continue until the end of 2004. During the injection period the process will be monitored directly and indirectly to assess any potential, although unlikely, leakage of CO$_2$ to the surface. Along with the field tests, an extensive laboratory programme is carried out, and a socio-economic evaluation of the project is performed.

INTRODUCTION

One option to reduce carbon dioxide emissions in order to control the overall levels of CO$_2$ in the atmosphere is permanent storage in subsurface coal seams, while simultaneously producing methane (ECBM-CO$_2$). This option has gained increasing interest world-wide during the last couple of years, as can be observed by growing interest for ECBM in the latest GHGT conferences. Although several desk studies illustrated the potential of the process, only a few experimental field sites have been realized in the world. In November 2001, the EC-funded RECOPOL project started, which targets the development of the first European demonstration plant of CO$_2$ storage in coal seams while enhancing coalbed methane (CBM) production. An international consortium was formed to execute the research, design, construction and operation of the RECOPOL project. This consortium is formed by research institutes, universities and companies from the Netherlands, Poland, Germany, France, Australia, U.S.A. and by the IEA Greenhouse Gas R&D Programme. Feedback to the project from industry and governmental organisations is realised through the participation of Shell International, Jcoal (Japan) and the Federal Region of Wallonie (Belgium) in an end-user group. Overall co-ordination of the project is in the hands of TNO-NITG.

The general aim of the project is the investigation of the technical and economic feasibility of storing CO$_2$ permanently in subsurface coal seams, while simultaneously producing methane gas, under European conditions. The results of this project should help in the discussion on whether this type of storage is a safe and permanent solution. In addition, the experience gained in this project should help to evaluate the economic feasibility and social acceptance of ECBM-CO$_2$ in Europe. In order to get a firm understanding of the process itself, there was a clear goal in the development phase to construct the pilot in such a way that as much could be learned from the pilot as possible. For this understanding, it was recognised in an early stage that it was required to have breakthrough of the injected CO$_2$, thus pushing concentration of CO$_2$ in the production gas above natural concentrations.

This paper gives an overview of the project and status of the activities within the project.

CHARACTERISTICS OF THE PILOT SITE

The Upper Silesian Basin (Fig. 1) was selected as the most suitable coal basin in Europe for the application of ECBM [1, 2]. This basin has (relatively) favorable coalbed properties (depth, permeability, gas content, etc.), was subjected to CBM production before, and drilling costs in Poland are relatively low compared to many other European countries. The location of the pilot site in the village Kaniow, about 40 km south of Katowice, was selected at an early stage of the project. There are two wells, 375 m apart, which were formerly used for a short period to produce CBM. The selected site is located within the concession of the Silesia mine, which has been in operation for decades. The characteristics of the site have been documented from these activities and from the activities in the nineties by the owner of the existing wells MS-1 and MS-4. As many data as possible were collected and evaluated, in order to get a good background for the development plan of the site. All available documents of former drilling and CBM-production were analyzed.
Geological setting

The Upper Silesian Coal Basin is structurally complex compared to commercial coalbed methane basins in the U.S.A. [3]. The area of interest is located on a large block that was upthrust during the Alpine orogeny. The intra-Carboniferous steep-dipping normal faults have mainly a broad N-S trend. The site itself is bounded by a NE-SW and a NW-SE fault (Fig. 1). Smaller (sub-seismic) faults can be expected. These faults are pre-Miocene and already active in the Carboniferous. Experience from the coal mines suggests a sealing character of these intra-Carboniferous faults. Activity of these faults probably ceased before the Miocene. The major E-W fault zone to the south, bordering the upthrust block, is still active. The principal targets for CO$_2$ injection are coal seams of Carboniferous age in the depth interval between 900-1250 m. The Carboniferous deposits are discordantly covered by circa 200 m thick Miocene shales. The Carboniferous deposits, which are more than 1000 m thick in the study area, consist of an alternation of sandstones, shales and coal seams. The Carboniferous deposits dip 12° to the north. The majority of the 10 to 20 metres thick sandstone bodies, with low permeability and porosity, show fault induced syn-sedimentary characteristics. Some sandstones cut into underlying coal seams, thereby destroying the lateral continuity of the coal. Therefore, some lateral variation and anisotropy is expected in the permeability and porosity distribution of the sediments due to depositional differences. The three selected coal layers for the test are deposited in sand-poor sequences. The coal seams of interest are of high volatile bituminous rank (0.8 - 0.85 %Rr) and vary in thickness between 1.3 and 3.3 meter (Figure 2). Main component of the coal is vitrinite (48-72%), with lesser amounts of inertinite (15-32%) and exinite (6-14%). Mineral matter ranges between 5 and 19%.

DESIGN AND CONSTRUCTION OF THE PRODUCTION FACILITIES

Due to budgetary constraints it was not possible to put both existing wells back into production. It was therefore decided to clean up and repair the up-dip well (MS-4). The intervals with the six major coal seams penetrated by this well were perforated in the 1990’s. However, only the seams 364 and 405 (Figure 2) were fractured. The CBM-production tests from these wells, which took place during 1996/1997, were considered unsuccessful because of low gas content in undersaturated coal. This is caused by a phase of degassing in the geological past [3]. However, the storage capacity for CO$_2$ sequestration still exists.

The development of the pilot site began in the summer of 2003 with the workover of the MS-4 well. Fortunately, the well perforations were still open after five years of inactivity. The pump was installed after a seismic tomographic survey (see below) at the end of September 2003. Due to permitting it was impossible to start continuous production before mid-June 2004. Therefore the (base line) production from MS-4, before the start of the injection of CO$_2$, is limited to a relatively short period (several weeks). The gas that is produced is burned on the site via a flare. The produced water (saline, up to 160 g/l) water is transported to the disposal site of the nearby mine. The fluid level in the production well will be regularly monitored, to check the performance of the production pump and to regulate the pump operation.
DESIGN AND CONSTRUCTION OF THE INJECTION FACILITIES

The location of the injection well was determined by the results of the reservoir modelling and the local terrain conditions. A distance of 150 m between the production well and an injection well would give the best chance of a CO$_2$ breakthrough within the test period. The injection well was placed down-dip of the production well, and nearly rectangular to the strike of the coal bearing beds. Permits for drilling were arranged and agreement with the landowner was settled. Site construction, mobilisation and rig up took place between mid July and August 2003, followed by drilling of the well to a depth of 1,120 m in August and September. Cuttings of the entire interval and core samples of the most important coal seams were taken for various laboratory experiments. Extensive wireline logging was done before running the 7" casing to determine petrophysical properties, lithology, porosity, saturation, dip, well deviation, etc. The well was completed with casing, cement and perforations. The cement integrity was checked with a Cement Bond log. The perforated zones (seams 364, 401, and 405; Fig. 3) were tested. A crosswell seismic tomography survey was carried out in September 2003. This seismic method was selected in an earlier phase of the project as the one with the highest chance of success of imaging the target subsurface structures in which CO$_2$ will be injected [4]. After the survey a 2 7/8" tubing and packer were installed for CO$_2$ injection (Fig.3).

Activities in autumn 2003 comprised the construction of the CO$_2$ storage and injection facilities (Fig. 4). The CO$_2$ for injection will be supplied by trucks in liquid form, where it is stored at -20º C and 20 bar in two 35 t containers, in order to assure continuous operation. A pump-SKID with installed pump capacity of 800 kg/h allows a maximum daily injection rate of about 20 tonnes. The hydrostatic pressure of the formation at 1000 m is circa 80 bar. The SKID allows wellhead pressure of up to 110 bar, resulting in downhole pressure of up to circa 200 bar (depending on the weight of the column of pressurised CO$_2$). If the injection rates are too low, adjustments of the SKID to reach pressure in the fracture range of the coal seams are considered. The total amount of CO$_2$ to be injected in the coal depends on injectivity and project lifetime, but is estimated to be more than 1000 tonnes. It is intended to inject the CO$_2$ downhole at approximate reservoir temperature (40 ºC). It is expected that heating at the surface above 5ºC will not be required since the maximum injection rate is relatively low, allowing the CO$_2$ in the tubing to adjust to the temperature of the surrounding rock. A heater was installed to heat the CO$_2$ to circa 5ºC before injection to prevent thermal stress and freezing of the CO$_2$ line and wellhead during pressurizing of the well at start-up.

LABORATORY EXPERIMENTS

Along with the field activities laboratory work was carried out since the beginning of the project. Initially, analyses were performed on coal samples from nearby mines. After drilling, samples from the well were used in the experiments. In total 9 core and 29 cutting samples were collected for desorption tests. The samples show slow desorption rates, indicating that the diffusivity of the coal is low. After the desorption test, the samples were integrated in the ongoing advanced laboratory experiments. These experiments involve coal characterization (maceral and rank analysis, CT scan on cores, NMR pore size distribution, Hg capillary pressure), adsorption/desorption (sorption capacity & kinetics, diffusion µ-balance) and flow-throughflushing tests for CO$_2$, CH$_4$ and mixtures. These experiments deliver fundamental knowledge about, for example, the permeability, cleat orientation and swelling behavior, which will help in the evaluation and interpretation of the field results.

PRELIMINARY RESULTS

Injection tests

The project has experienced several delays, merely due to legal and administrative issues. All these issues were solved in the course of 2004 and in the last week of June/first week of July 2004 the initial testing at the site started. Wireline retrievable memory gauges were installed downhole to measure the pressure and temperature during the initial testing. The results of this downhole monitoring will be used to investigate the CO$_2$ phase behavior in the well. During this first week, several operational and technical problems appeared and were solved. Despite these problems, several injection tests were performed. These tests, similar to fall-off tests, were performed by pressurizing the well followed by closing-in the well. The tubing pressure, tubing temperature, annulus pressure and pump activity were continuously registered digitally.
Monitoring

Local mining experience showed that the Miocene shales are sealing and are not in hydrological contact with the Carboniferous. No leakage is expected through the Miocene seal. Monitoring is undertaken for health and safety issues and to gain public confidence in CO₂ storage. It is important to know that the CO₂ is injected at the intended location and that it migrates towards the intended direction. CO₂ is not a toxic gas, but can be suffocating at elevated concentrations. CO₂ is denser than air and thus will collect in depressions or in the basements of building. Additionally, monitoring could become important for accounting of credits in a future international CO₂ market.

As mentioned, a time-lapse cross borehole seismic survey was performed. The results of the tomography were not yet fully processed at the moment of publication (July 2004).

The composition of the produced gas is analyzed to monitor any significant increase of CO₂ in the produced gas, in order to establish if breakthrough occurs. Naturally up to 5% CO₂ occurs in the coalbed gas, which was confirmed by the first analyses of the production gas. These analyses showed a high methane concentration of more than 90% and a few percent of CO₂. These first measurements provide the baseline and natural compositional variation in the production gas, required to distinguish significant increases in CO₂ due to injection. In case of an early breakthrough, it is expected that only a slow and gradual CO₂ production increase will be observed.

The natural occurring CO₂ is likely to have a specific isotopic signal. Gas samples from the production well, from the CO₂ in the tanks and from the near-surface wells were taken for isotope analyses, but the results were not yet available at the time of publication. These results will provide the baseline of δ13 CO₂ on the produced formation gas. Until now it is unclear if the δ13 CO₂ signature from the CO₂ in the reservoir is distinctly different from the CO₂ that will be injected. The CO₂ that will be injected will carry the isotopic signature of the source gas from which it is produced in the production plant. Comparing the isotope signatures of the injected and produced gas might give an idea about the breakthrough of the CO₂.

In order to detect possible compositional changes in the production water, a baseline is established of the natural variation in the composition of the water. The analyses of the production water showed that the formation water is highly saline, with concentrations of Na⁺ of about 40 g/l and Cl⁻ of about 80 g/l. Ca²⁺ and Mg²⁺ have concentrations of about 6 and 2.5 g/l, respectively. It is expected that the concentration of these latter ions will increase as a result of CO₂ injection, because the formation water is expected to acidify when coming into contact with CO₂.

A surface monitoring system was put in place by installation of 5 sensors in 2 m deep tubes surrounding the injection well. The local soil thickness, where biogenic activity is expected, is less than 2 m. The CO₂ concentration of the tubes has been monitored from the 9th of April onwards. Continuous digital data registration resulted in baseline profiles for the area near the injection well. The profiles of the five sensors clearly show variation in concentration between the location and day and night. Neither observation is currently explained. A new calibration plan is currently set-up to assure that the measured absolute concentrations are real. At this moment it is not yet clear what causes the daily variation. The data will be compared to atmospheric pressure and temperature data and possibly weather conditions to see if there is any relation. It was observed that the CO₂ accumulated over time in the tubes. Opening of the tubes for a few hours did not ventilate the tubes; CO₂ concentrations remained high, indicating the higher density of CO₂ over air.

Monitoring of the baseline CO₂ concentration in the nearby Silesia mine, at a depth of 270 m and a horizontal distance of several hundreds of meters, and the site across the NW-SE boundary fault, started in May 2004. The fault is expected to be self-sealing. The actual CO₂ measurements show a large variation in the concentrations up to a maximum of circa 1 %.

FUTURE PLANNING

The second start-up is scheduled in the first half of August. Once continuous injection is established, local staff will take over the pilot site. Further activities in 2004 comprise continuation of field activities until the end of the year. A lot of uncertainties remain in the whole process. Further engineering solutions might be required to tackle these possible problems. History matching of the injection and production results will be done in the last phase of the project by numerical simulation of the process during and after injection of the CO₂. The results from the laboratory experiments will be introduced in these reservoir models, where possible. Upscaling of these results, core to inner-well and field scale is required. Laboratory experiments are due to run to the end of the project.

In principal, injection will continue until the end of the project life or when breakthrough is established. Anisotropy effects, with highest permeability perpendicular to the flow direction from the injection well to well MS-4, might hamper an early breakthrough. Therefore, continuation of the injection beyond the official end of the project (31st October 2004) is currently under consideration. The monitoring activities will also be continued along with the injection activities. The CO₂ concentration in the near-surface wells and the mine will be registered during and probably after injection. Gas and water samples will be taken and analyzed on a regular basis. Depending on the results of
the baseline survey, it will be decided if a second seismic cross borehole survey should be executed for time lapse monitoring. Along with the technical work, an economic evaluation and a future-technological assessment will be executed until the end of the project.

PRELIMINARY CONCLUSIONS – CONCLUDING REMARKS

Although it is currently impossible to draw any definitive conclusion, it is at this stage already clear that the laboratory results alone already allow major improvements in the dedicated numerical simulators. The consortium showed that with a limited budget it is possible to set-up an on-shore pilot, and the proven injectivity of the coal gives good hope for successful operation from August 2004 onwards.

The experience gained by a broad group of people is invaluable for the further development of CO\(_2\) sequestration in Europe. Besides the technological issues, it was, being the first sequestration pilot onshore in Europe, inevitable to deal with all "soft" issues (permits, contracts, opposition, etc.) related to this kind of innovative projects. The lessons learned in this operation can possibly help to overtake start-up barriers of future CO\(_2\) sequestration initiatives in Europe.

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