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CO_2 STORING CAPACITY IN GEOLOGIC FORMATIONS IN THE CZECH REPUBLIC*****

1. INTRODUCTION

One of causes of global warming is carbon dioxide emission and its concentration in the atmosphere. The reduction of anthropogenic CO_2 emission to the atmosphere may stop this process.

The emissions can be reduced with the carbon dioxide sequestration, i.e. its capturing or separation followed by storing. This process is called Carbon Capture and Storage (CCS).

One of the applied solutions related to CO_2 storage is deposition underground. Geological sequestration of CO_2 lies in its deposition in deep geological structures. The basic condition deciding about the possibility of deposition of CO_2 underground is the presence of sedimentary rocks of considerable thickness and extent, having good collecting properties and covered with an insulating caprock. Such conditions are met by depleted deposits of hydrocarbons.

The CO_2 injection into reservoir rocks is a known practice applied for reservoir rocks to improve the degree of oil recovery (EOR – Enhanced Oil Recovery) in the oil industry for tens of years. Therefore, CO_2 can be freely injected into deep geological layers to limit its emissions to the atmosphere.

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A project dedicated to the use of depleted oil deposits as carbon dioxide storages was worked out in the Czech Republic.

This pilot project will focus on the use of already depleted oil deposit LBr-1 located in the south-east part of Moravia.

For the realization of the pilot project, which will help evaluate the storing capacity of geologic horizons in the Czech Republic for the planned CO_2 deposition, representatives of research units from the Czech Republic and Europe were invited.

The team working out the project consists of the following research units:

- International Research Institute of Stavanger – IRIS (Norway),
- NRI – *Nuclear Research Institute* – Research Center REZ Sp. z o.o.,
- Institute of Physics of the Earth – Masaryk University,
- Miligal Company.

The project is practically supported by MND Hodonin S.A., a company which imparted geological data (geological samples in the form of drilling cores, results of geophysical profilings) from the region of the planned CO_2 deposition.

The membership of the Czech Geological Survey and International Research Institute of Stavanger in the European research organization CO2GeoNet Network of Excellence will be used on behalf of the project realization.

This project will be used for the realization of objectives from the climate-energy package, approved during the summit of EU leaders in Brussels at the end of October 2014. The realization of the assumptions is planned by the year 2030 and the basic objectives of the package are to:

- lower CO_2 emission by 40% by the year 2030 as compared with the year 1990,
- increase the participation of energy from renewable sources (in Europe to 27%),
- continue the existing EU NER 300 program of the system of capture and environmentally safe deposition of carbon dioxide (CCS), and also innovative renewable energy technology (RES) in the EU territory, and its scope will be broadened by low-emission innovative programs for industry. Its range will increase (to 400 mln concessions (NER 400) for the co-financing commercial projects),
- increase the energy efficiency (target – from 27% to 30%),
- increase the share of connected transmission networks (from 10% to 15%),
- increase the prices of concessions for greenhouse gases emission and stabilization of the EU ETS system (prices are expected to gradually increase from about 11.5 EUR/ton of CO_2 in 2018 to 26 EUR/ton of CO_2 in 2030).

The realized project contributes to the activities aimed at lowering CO_2 emissions to the atmosphere.

The pilot project of making CO_2 storage in old depleted oil deposit LBr-1 was divided into 10 tasks. Each task was allotted various meritoric scopes of work to be done.

Tasks 1–5 concentrate on the description and evaluation of geological complex planned for CO_2 storage and the adjacent areas, in compliance with the respective Czech Republic law, i.e. act about carbon dioxide deposition in deep geological structures (§26 of the Act no. 85/2012Sb) and annexes to the act (no. 62/1988Sb) about geological works. These activities are directly connected with working out a pilot project evaluating the possibilities of CO_2 deposition in the collector horizons of the depleted oil deposit LBr-1.

In the framework of task no. 1 all available data which can be used for evaluating the selected site for CO_2 deposition, i.e. LBr-1 deposit, are collected and analyzed. The data will be used as entry data for creating a spatial, statistical geological model of geological layers in which the planned CO_2 storage will be organized, and a model of the whole storing complex, i.e. injection layers and the adjacent zones (task no. 2). Data and models will be used for preparing dynamic models of the storage (task no. 3) and the analysis of risk of CO_2 deposition in selected geological strata (task no. 4). The last task will lie in selecting an appropriate method of monitoring CO_2 storage (task no. 5).

Task no. 6 is concentrated on a broader context of carbon dioxide deposition and applicability of experience from the pilot project to further research works on the use of deep geological structures to lower CO_2 emissions [8]. This task encompasses the analysis of potential sources of CO_2 in the neighborhood of the potential storages, techniques of CO_2 transport to the storage sites and an analysis of the capacity of underground gas storages in deep geological structures. This task concentrates on the broader possibility of developing CCS technology in the Czech Republic.

Task no. 7 covers the description and methodological analyses of characteristic and evaluation of injection layers to be used as CO_2 storages. Tasks nos. 8 and 9 are dedicated to the promotion, dissemination of information and education related with carbon dioxide sequestration and storing.

Task no. 10 is connected with directing, organizing and managing the project, including administrative support.

2. AIMS AND RESEARCH TASKS OF THE PROJECT

The main research objective of this project in which participate the authors of this paper lies in working out and improving the methodics of laboratory experiments, modeling, simulation procedures and techniques, which are needed for the evaluation of the possibility of CO_2 storing in preselected geological structures. Another research objective is preparing static and dynamic modeling of CO_2 storing, risk analysis of CO_2 storing in deep geological structures, monitoring of the storage and its close vicinity etc.

The realization of these objectives and research tasks is important from the point of view of the pilot project and further monitoring in a long time perspective. The realization of the project is relatively short to fully analyze and investigate the long-term consequences of CO_2 storing in depleted horizons of LBR-1 deposit. Modeling and various analyses will be of key importance for the realization of the pilot project and also for further works relating to new CO_2 storage projects in deep geological strata in the Czech Republic and their evaluation.

The VŠB-TU laboratories in Ostrava will be used for the analyses of rock samples from drilling cores from the reservoir horizons of the depleted oil deposit LBR-1. The analyses will be performed with the use of multiphase Permeameters BRP 350 and FDS 350. The research connected with the simulation of CO_2 to laboratory samples will be performed with the simulation of *in situ* conditions, i.e. at similar pressure and temperature as in the reservoir LBR-1. The volume of liquid phase (oil) displaced from the analyzed samples and the possibility of practical optimization of oil displacement with CO_2 will be observed to obtain the synergy effect – CO_2 deposition and simultaneous increase of volume of displaced oil, leading to the improvement of the depletion coefficient in natural conditions. The evaluation of the residual saturation of samples before the analysis will rely on the available basic data obtained from the MND Hodonin S.A.

Further methodological research will be focused on the influence of injected CO_2 on the equipment of the injection wells. The main purpose of these research works is minimization of risk of CO_2 escaped from injection layers through the casing and through the annular flow. Carbon dioxide in reservoir conditions in the presence of reservoir waters may have a degrading impact on the near-well zone and also on the durability of cement sheath sealing the casing, casing, production pipes, packers, etc. Therefore, it is necessary to conduct detailed laboratory experiments on the influence of carbon dioxide on the strength of cements used in drilling, effect of CO_2 on the corrosion of casing, equipment of injection wells and its impact on the rock mass – cement – casing system. The obtained results of the laboratory experiments can be worked out in the form of recommendations how to use materials to injection wells of particular properties. Thanks to these research works and also the prepared material specifications, the risk of CO_2 escapes through the near-well zone or through the casing can be considerably reduced. In this way the operational safety of the CO_2 storage and its immediate neighborhood will be increased [2, 3, 9, 11].

A pressure-temperature reaction chamber RK-1 (Fig. 1) will be used for analyzing reactions with CO_2 on a laboratory scale.

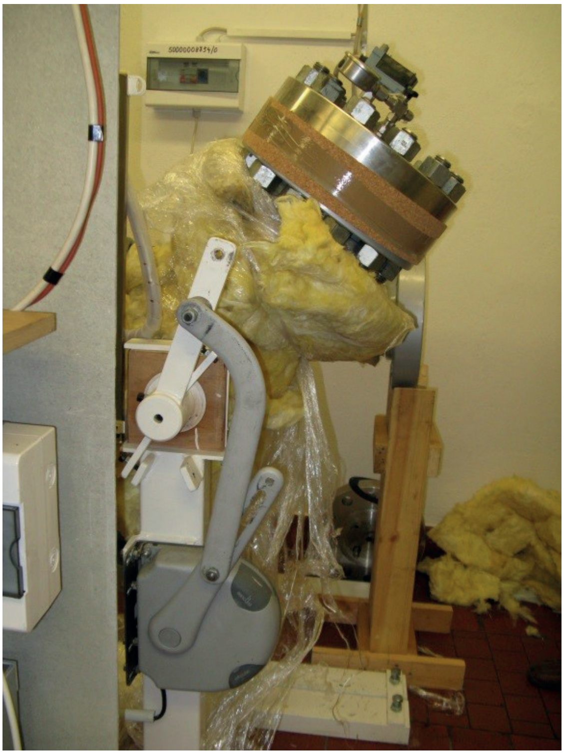

Fig. 1. Pressure-temperature chamber RK-1

During experiments the pressure and temperature conditions typical of the LBR-1 deposit will be simulated in the chamber. For the sake of creating quasi real conditions during laboratory tests, particular materials analyzed in the reaction chamber will be soaked in reservoir fluids. To provide the pseudo dynamic character of the system, the chamber will be put in a swinging motion during the experiment. In this way the natural conditions of CO_2 reaction with particular materials (cement sheath, casing etc.) will be simulated accounting for the chemistry of particular reservoir horizons. At the first stage the samples of materials used in LBr-1 deposit and commonly applied in the drilling industry, will be analyzed at the first stage. The analysis of the influence of CO_2 on the contact zone of rock mass – cement stone – casing will follow an identical scenario as described above, except that special reference samples will be used to evaluate processes taking place on the interface of particular materials.

3. MEASUREMENT OF PETROPHYSICAL PROPERTIES OF RESERVOIR HORIZONS

For the sake of identifying properties and evaluating the quality of geologic formations in view of their applicability to CO_2 storing as well as the evaluation of properties and quality of the sealing caprock, all available data should be analyzed and new measurements performed. New qualitative measurements for determining petrophysical properties of reservoir rocks should be performed in laboratory conditions simulating the actual conditions (pressure and temperature) in the reservoir horizons. Newly obtained data will be compared with archival ones and on this basis the change of physical parameters in the deposit can be assessed. The laboratory analyses will be conducted on drilling cores obtained from research wells and production wells during completion and production jobs on the LBr-1 deposit. The disposable cores from LBR-1 deposit are in a good condition and can be used for laboratory experiments. They are sufficiently numerous to make complex measurement for reservoir horizons and the sealing caprock.

Properly prepared laboratory samples from the drilling cores will be analyzed at the Laboratory of Stimulation of Wells and Deposits of Hydrocarbons VSB-TU in Ostrava. The automatic porosimeter and permeameter allowing for determining basic petrophysical properties of the samples will be used. A number of petrophysical properties of reservoir rock can be measured at high precision with this apparatus, e.g. porosity, permeability, volume of the skeleton, density of rock, etc. The measurements can be made with the concurrent simulation of real conditions *in situ*, i.e. by controlling temperature and pressure in the measurement chamber (Fig. 2). Multiphase permeameters BRP 350 and FDS 350 will be used for experiments (Fig. 3). The analyses and modeling of the injection process will be conducted for three phases flowing through the sample, i.e. oil, reservoir water and CO_2. The residual saturation of drilling cores (rock samples) with reservoir fluids from the LBR-1 deposit will be determined in a laboratory vacuum a tight retort furnace [5].

As a consequence of the performed laboratory experiments there will be obtained data determining the real pore conditions in reservoir horizons of the LBr-1 deposit, accounting for the side geostatic pressure and pressure at a given depth for particular wells. Moreover, we will receive the three-phase permeability values (oil – CO_2 – reservoir water) for samples from each analyzed horizon, accounting for the p-T conditions in a function of depth. The results will create bases for a 3D geological model of the Lbr-1 deposit, and then the modeling of the CO_2 injection (task 2).

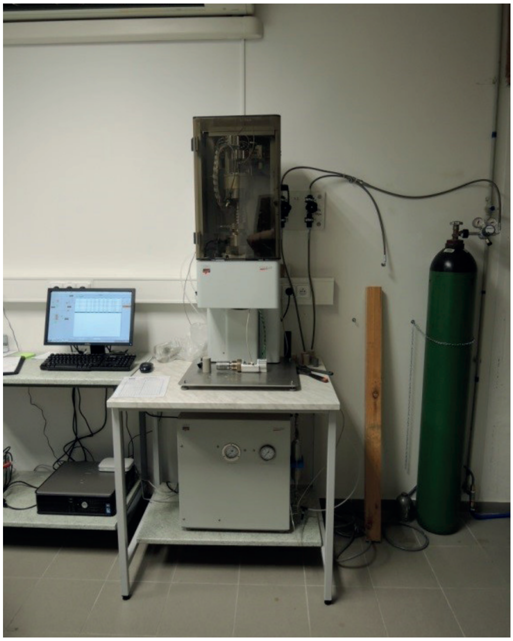

Fig. 2. View of fully automated porosimeter and permeameter

Fig. 3. Permeameter BRP 350

4. DETERMINING GEOCHEMICAL PARAMETERS OF LBR-1 DEPOSIT

Geochemical parameters of injection layers of the future storage are important for further evaluation of geological horizons in the context of the planned CO_2 storing. These parameters are basic input data for the geochemical modeling of porous layers to be injected, including simulation of dynamic changes in that horizon (subject of task 3).

At the moment CO_2 is injected to the geological medium we have an interaction of the following phases of the system: rock mass – reservoir water – oil – CO_2. It is assumed that in the course of the injection process CO_2 becomes a fluid in a supercritical phase. This, of course, depends on the pressure and temperature of the injection horizon, which in turn is conditioned by the depth of its deposition. In the majority of cases the absorptive strata are deposited at such depths that this requirement is met. The injected CO_2 totally changes the rock mass conditions. If we consider that the storage is made in deep sedimentary horizons, attention should be also paid to the presence of reservoir fluids, e.g. brine, oil or gas. A number of processes affecting the injection and then CO_2 storage may take place, e.g. the displacement of brine, CO_2 migration in the reservoir in the supercritical or gaseous phase or dissolution of CO_2 in the water phase. In the latter case the pH of water is lowered which may affect the environment or affect the dissolution of mineral compounds and the formation of new ones. The range of the reactions and consequently in aquifers is the key to describing geochemical properties of this horizons in definite reservoir conditions. This description will allow for the evaluation of safe CO_2 storing in a long time perspective [4]. The description of geochemical phenomena occurring in the course of CO_2 injection has been undertaken since the 1990s and is important from the point of view of changes taking place in the rock mass and their impact on the natural environment.

Since the middle of the 1990s many research works and experiments have been conducted in this field and the results created a bases for geochemical models focusing on the impact of CO_2 on the dissolution and precipitation of rock minerals and the chemical composition of brine. This knowledge will be used during the realization of task 1.

When injecting carbon dioxide in the supercritical state to the porous sedimentary rocks saturated with reservoir fluids, a few zones of impact of the injected fluid on the rock medium and the near-well zone should be distinguished. The processes taking place in the rock environment after the CO_2 injection has begun, have not been sufficiently described, especially as far as their practical aspect is concerned. The literature lacks descriptions of the laboratory experiments which would directly refer to dynamic flows of CO_2 in a supercritical state in the analyzed rock samples. A great advancement can be made in this respect by continuing research works originated in the last years. They should help develop the exact directions of the planned research works and increase the efficiency of laboratory experiments. The research works and searching for a description of a model should be mainly oriented to the recognition and description of types of interactions of CO_2 with natural environment, in that:

- interaction in a close proximity from the injection well – interaction of CO_2 and cement stone, interaction between CO_2, cement stone and the rock mass, concentration changes due to the dissolving of CO_2,
- long-lasting interaction of CO_2 with the rock mass and reservoir fluids in the injection horizon and the sealing caprock – improvement of large quantities of material in the porous environment at high pressure and high temperature gradient, the explanation of lowered permeability of a layer having a direct impact on the course of the injection,

– interaction of CO_2 with the rock mass along the CO_2 pathways – along the injection well, along tectonic disturbances and through the onlying horizons,
– CO_2 escapes from the storages and contaminates aquifers – CO_2 dissolved in shallow aquifers acidifies the environment and the metal and bitumen compounds start migrating,
– processes of reservoir fluids displacement to the upper horizons and the related geochemical processes.

5. ANALYSIS AND MODELING OF GEOCHEMICAL REACTIONS, THE DECOMPOSITION AND FORMATION OF MINERALS IN THE P–T UNDERGROUND STORAGE CONDITIONS

The aim of these works is the preparation and testing of numerical software and then its use for the modeling of CO_2 flow and interactions in the rock mass. As already mentioned, the processes taking place in the rock mass at the stage of injection and then CO_2 storage have not been sufficiently well recognized and scientifically described, especially the experimental aspect. For this reason the reactions will be modeled on the level of minerals and pore surfaces, i.e. microscale. The mathematical modeling of processes taking place in hydrated collector horizons will be performed with the use of software "The Geochemist's Workbench 7" (GWB) [6, 1]. This simulator allows for conducting numerous calculations, determining quantitative relations between the consequences of the sequestration and hydrochemical, thermodynamical and kinetic characteristics, as well as geochemical and petrophysical properties of the geological medium which are connected with the on-going injection.

Modeling will be realized at two stages. The first stage will be devoted to the monitoring of changes in the rock mass at the beginning of the CO_2 injection, and the other one will be dedicated to the assessment of consequences and changes evoked by the CO_2 injection into porous strata. In the case of mineralogical differences among layers, the modeling will be performed separately for various combinations of mineral composition.

6. LABORATORY ANALYSES OF INTERACTIONS BETWEEN ROCK MASS, RESERVOIR FLUIDS AND SUPERCRITICAL PHASE OF CO_2

The reactions of CO_2 in a supercritical state with reservoir fluids will be modeled in a reaction chamber RK-1 at the laboratory of the Institute of Clean Technologies for Mining and Utilization of Raw Materials for Energy Use VSB-TU Ostrava. The experiments will be made on 20 samples collected from horizons in which CO_2 storage is planned. Samples will be placed in a chamber filled with reservoir fluids under pressure as in the target horizons, then CO_2 will be introduced to the chamber. During experiments the chamber will be heated up to a temperature as in the CO_2 storage. In this way a pseudostorage of CO_2 will be created in laboratory conditions. Changes which will take place inside the chamber will be measured constantly by pH probes. After finishing the testing, the samples will undergo analyses (spectrometry, RTG, electron microscopy). As a consequence a very detailed description of mineralogical, rheological and other changes taking place in the reservoir rocks will be made. Interactions between CO_2 and the sealing caprock will be analyzed in the same way [10].

After terminating extraction from a deposit reservoir fluids migrate in the reservoir horizon. Establishing whether or not the residual oil can migrate under the influence of the injected CO_2 is important from the point of view of dynamic models which describe CO_2 injection to the reservoir. The following oil migration scenarios will be evaluated within this research.

1. Migration of hydrocarbons and the risk of their escapes along damaged wells.
2. Reservoir fluids production – undertaken to maintain the equilibrium of pressure which is needed for proving a spatial distribution of the CO_2 'cloud' in the reservoir.
3. CCS when a permanent deposition of CO_2 makes its use for extended oil recovery impossible.

7. SUMMING UP

The workers of the Faculty of Mining and Geology VSB-TU Ostrava in co-operation with the Faculty of Chemistry VSB-TU, Faculty of Applied Geology of the Silesian University of Technology in Gliwice and the Faculty of Drilling, Oil and Gas of AGH-UST in Krakow have worked on these issues for years. Two projects devoted to this subject matter have been completed successfully, i.e. "Possibility of geosequestration of CO_2 in deep mine conditions" (no. 60–08 [ČBÚ 2008–2010]) and "Recognition of formations and structures for the safe geological deposition of CO_2 with the monitoring program".

The subjects relating to CO_2 have also been realized within co-operation and contracts with the MND Hodonin S.A. One of the projects was devoted to the use of CO_2 to increase the depletion of oil deposits in the Czech Republic area.

The membership of the Czech Geological Survey and International Research Institute of Stavanger in the research organization CO2GeoNet Network of Excellence will help integrate the Czech pilot project of CO_2 storage in LBR-1 deposit with the European research projects prepared within the Horizon 2020 Program, i.e. "Safe, clean and effective energy". This program is presently at the stage of preparations by CO2GeoNet, and in 2015 its realization will be planned. If the preparatory works succeed, its realization will allow for the continuation of the Czech Research Pilot Project on CO_2 (REPP-CO2) and its further development, which would significantly contribute to obtaining permanent results.

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