MARCIN A. LUTYŃSKI, PIOTR SAKIEWICZ
Silesian University of Technology, Poland

FEASIBILITY STUDY OF CO_2 STORAGE IN CLOSED COAL MINES

The increase in energy demand causes greater greenhouse gases emission. The most dangerous greenhouse gas is the carbon dioxide which emission is going to double over the next 20 years. The paper presents a concept and feasibility study of a CO_2 storage in abandoned coal mines as one of the CO_2 sequestration methods. The main advantages of this method are: close location to the source of emission, low cost of storage, high storage capacity of closed workings as well as remaining coal seams. The main obstacles for the implementation of this method are: gas migration to the surface due to former mining operations and mine flooding, proper sealing of all the surface connections (shafts, adits, etc.), gas leakage within long period of time and material stability in aggressive medium. A concept of a CO_2 high pressure storage as well as storage mode of CO_2 in a coal mine are presented in the paper.

Рост энергопотребления приводит к увеличению выбросов парниковых газов. Наиболее опасный парниковый газ – это диоксид углерода, чьи выбросы по прогнозам увеличатся вдвое в течение 20 лет. Описываются концепция и технико-экономическое обоснование сооружения хранилища CO_2 в заброшенных шахтах в качестве одного из способов утилизации CO_2. Основные преимущества данного метода заключаются в близком расположении хранилища к месту выбросов CO_2. Основными препятствиями на пути внедрения метода являются миграция газа на поверхность вследствие проводившихся ранее горных работ и затопления шахт, изоляция всех выходов на поверхность (шахт, галерей и пр.), утечки газа в течение продолжительного времени и стабильность материалов в агрессивной среде.

Introduction

The demand for energy is growing worldwide - according to IEA the energy demand in 2030 will increase by almost 70 % over the next 30 years. Over 85 % of the energy needs is covered by burning fossil fuels which in consequence cause greenhouse gases emission. In computer-based models, rising concentrations of greenhouse gases generally produce an increase in the average temperature of the Earth. Rising temperatures may, in turn, produce changes in weather, sea levels, and land use patterns, commonly referred to as “climate change”. One of the most dangerous greenhouse gases is carbon dioxide whose emissions will increase, according to IEA Reference Scenario, by 63 % from today’s levels by 2030 – this is 90 % higher than 1990 levels. Stronger actions than those currently being considered by governments will be necessary to avoid substantial increases in CO_2 emissions. The development and deployment of technology options that have the potential to significantly cut emissions will be essential.

One of such option is CO_2 capture and storage securely for hundreds or thousands of years. Major reservoirs, suitable for storage, have been identified under the earth's surface and in the oceans (fig.1). When describing CO_2 in geological formations and oceans, the term “CO_2 storage” is used. It is now commonly accepted that the term sequestration refers only to the terrestrial storage of CO_2.

So far, only one project of underground CO_2 storage in deep saline aquifiers has been implemented on an industrial scale. It is located in Norway, offshore at Sleipner facility operated by Statoil. Located beneath the Norwegian sector of the North Sea, the extensive Sleipner West natural gas field is characterized by a high (9 percent) concentration of CO_2, well above the 2.5-percent limit imposed by European export specifications. Statoil strips excess CO_2 from the recovered gas in a

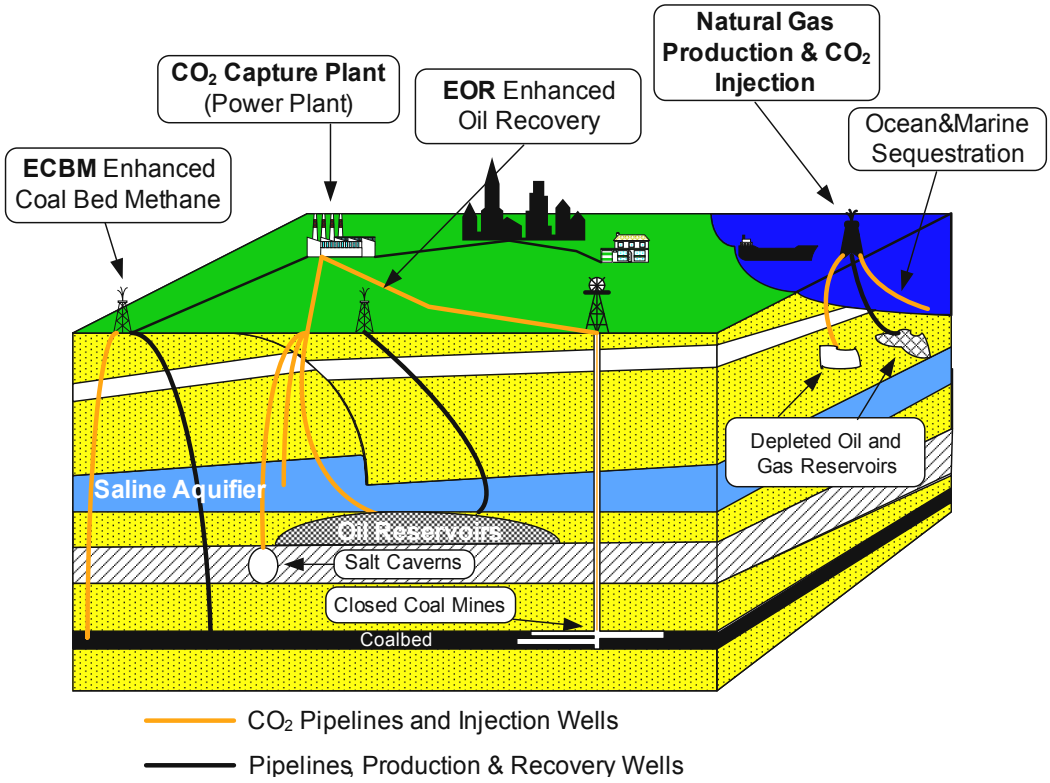


Fig.1. Concepts of CO_2 storage

tower on its offshore production platform before exporting the gas to the European community. Injecting the captured CO_2 into a confined aquifer-800 meters below the seabed and 2,500 meters above the Sleipner West hydrocarbon reservoir – results in no tax on Statoil for its atmospheric emissions. The storage capacity of a facility is over 250 t of CO_2 daily. It is assumed that Utsira formation where the CO_2 is injected is capable of storing 600 mld t.

Concept of CO_2 storage in closed mines

One of the storage places where CO_2 can be safely injected are mines. The main advantage of this method is close location to the source of emissions. Usually, power plants are located close to coal mines. Moreover, old workings form a large reservoir suitable for gas storage and CO_2 is absorbed on remaining coal seams ensuring high storage capacity.

The idea of storing gas in closed mines appeared in the late 50'ties in USA where the former coal mine Leyden near Denver in Colorado was converted into natural gas storage facility. The purpose of this facility was to optimize natural gas supply for the city of Denver during peak demands. Coal was extracted from two horizontal seams located at depths of 210 m and 225 m. The cap rocks consist of 20 m of claystones but the leak-off pressure of the reservoir is determined by shafts which can withstand 1.8 MPa or about 75 % of the hydrostatic pressure. Other examples of natural gas reservoirs are the abandoned mines of Anderlus and Peronnes located in Hainaut coalfield in southern Belgium. Both are characterized by a very low reservoir pressure of 0.35 which is determined by overburden consist of clay, marl and chalk. Exploitation levels were located between 660 m and 1100 m depth, but exist connections with flooded shallow workings where locally overburden is 10 m thick.

In case of CO_2 storage where gas is stored for hundreds or thousands of years the problem of mine flooding is essential. Uprising of water level in a mine due to infiltration of formation water will compress the CO_2 at the top seal and cause uncontrol-

lable leakage. Keeping reservoir dry by pumping is economically unjustified having in mind the duration of the targeted storage term. It is therefore crucial to a sequestration project that a leak-off pressure of sealed shafts can be estimated prior to the start of the project and be well above hydrostatic. Apart from that, the following issues need to be considered in case of CO_2 storage in closed mines:

– **Impermeability** of overburden, seals and all surface connections – a slow leakage of CO_2 do not pose a direct threat to humans or nature but may violate the concept of CO_2 sequestration,

– **High storage capacity of a reservoir** – only in this case the sequestration project may contribute to the reduction of CO_2 emission,

– **Low cost of CO_2 storage facility** – the cost of capture and storage must be lower than the price of CO_2 at the market or excess emissions fines (current price on the EU market, date 24.04.06:26.90 €/tCO_2),

– **Storage safety** – CO_2 reservoir must be well isolated from the biosphere and monitored.

All of the abovementioned requirements need to be fulfilled when considering CO_2 storage project in an abandoned coal mine. However, the main problems in implementation of this method are:

– Faults, fissures or cracks in the overburden caused by former mine operation and in consequence of mine flooding – gas migration to the surface,

– Proper sealing of former surface connections (shafts, adits, wells, etc.) and plug installation in underground parts of the mine– materials used for sealing must be cheap, commonly available and impermeable. Mixtures of Coal Combustion Products with bindings and sealing additives seem to be a good solution.

– Material stability in corrosive medium – it is crucial to study the effect of CO_2 and brine on the integrity of materials used as a seal as well as corrosion of pipelines and other elements of infrastructure.

High pressure storage in abandoned

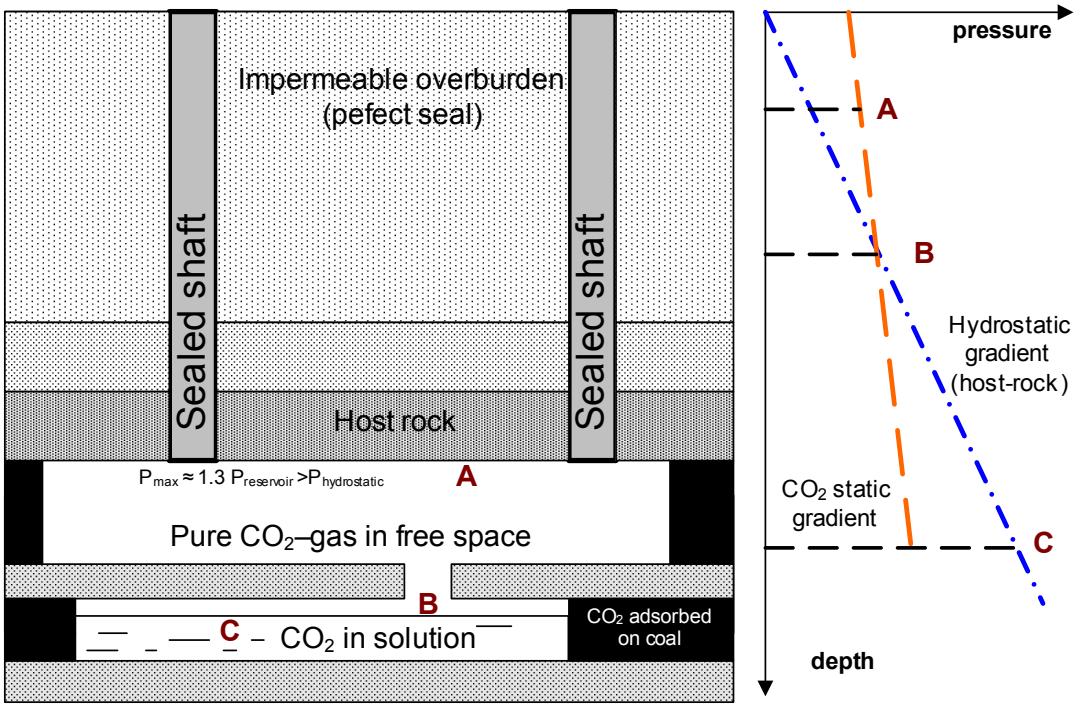


Fig.2. Concept of high pressure CO_2 storage in abandoned coal mine and diagram of pressure disequilibrium due to different densities of H_2O and CO_2

coal mine

Coal mine can be regarded as a reservoir with large height and irregular horizontal structures whereas classical reservoirs are usually flat. The permeability of such reservoir, even if completely collapsed is usually very high compared to the natural pre-mining state. The modes where CO_2 can be stored are as follows:

– Free space – workings, galleries, caverns and collapsed parts – where gas is stored as pure CO_2. The density depends on temperature and pressure and can be calculated from an equation of state. The volume of free space can be calculated on the basis of amount of extracted coal and the total dimension of workings.

– CO_2 adsorbed on coal – coal is a good adsorber of CO_2 due to high internal surface and micro-porous structure. The amount of CO_2 adsorbed can be estimated upon the results of laboratory testing and determination of adsorption isotherms.

– CO_2 in solution – CO_2 has a relatively high solubility in water and flooded parts of the mine can contribute to the total storage capacity.

Assuming that top and bottom seals are perfect and can withstand pressure approximately 30 % higher than hydrostatic and that permeability of reservoir is sufficiently high to allow considering mine as one continuous reservoir the concept of high pressure storage would be as presented in figure 2. The concept considers storage with no water pumping.

Conclusion

Reduction of greenhouse gas emissions seems to be a great challenge for the next years. New concepts of capture and underground storage of this gas need to be revised and implemented. One of them is CO_2 storage in closed mines. Few mines where natural gas was stored proved to be safe temporary reservoirs. However, some problems exists if we consider storing CO_2 for long periods of time such as gas migration to the surface through faults, fissures or cracks created due to former mining, proper sealing of surface connections that can withstand high pressure and be stable within long periods of time. If the abovementioned problems can be solved CO_2 storage in closed can be a promising alternative for other sequestration methods.

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