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Review of developing of CO_2 sequestration technology in coal seams

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Abstract

Considering the global race against the increase of CO_2 emissions in the atmosphere, mitigation has been strongly advised and several technologies have been tested. In this context, research on CO_2 sequestration in coal seams using ECBM technology is emerging.

This work is a review that aimed to critically show the feasibility of using coal as a repository of CO_2, given its unique properties, especially the ability to perform CO_2 / CH_4 exchange sorption.

In order to meet the international protocols of climate changing up to 2050, technology of ECBM must advance progressively, since there is still immaturity for effective implementation of it.

Keywords: Climate changing, CO_2 sequestration, Enhanced Coal Bed Methane Recovery, CO_2/CH_4 exchange sorption

Introduction

The technology of CO_2 sequestration in deep coal seams have been research from decades [Fulton et al., 1980; Reznik et al., 1982], and it is still being developed.

In recent years, researchers at The Strata Mechanics Research Institute of the Polish Academy of Sciences have been carrying out studies connected with the issue concerning CO_2/CH_4 exchange sorption [Skoczylas and Kudasik, 2017; Kudasik et al., 2017; Dutka et al., 2013; Topolnicki et al., 2013; Dutka et al., 2012a; 2012b]. For the purposes of the studies many original measurement equipment were constructed which was used to carry out a series of experiments.

The detailed analysis of the literature on the subject showed that CO_2/CH_4 exchange sorption is well recognised. However, carry out exchange sorption in coal material under confining pressure (as in situ conditions) is a completely uninvestigated subject. Combining these two research directions is the subject of the present work that is being developed in The Strata Mechanics Research Institute of the PAS and financed from the resources of the National Science Centre in Poland, as part of the project entitled "CO_2/CH_4 exchange sorption in coal material under confining pressure".

The purpose of this work was review about methodology of CO_2 storage in geological formation, especially coalbeds, in the context of the international climate change agreements.

The carbon cycle and global warming

Most of Earth's carbon – about 65,5000 Gt is stored in rocks, however, it can also be found in the ocean, atmosphere, terrestrial and marine biosphere, as reservoirs. Through the geosphere, chemical reactions and tectonic activity, an average of 0.01-0.1 Gt of carbon move in the slow carbon cycle every year; and between 1-100 Gt of carbon move through the biosphere in the fast carbon cycle every year [Riebeek, 2011].

In recent decades, the CO_2 concentration in the atmosphere has increased by about 43%, from 280 ppm in the pre-industrial period, through 315 ppm in 1958 [Keeling, 1960] to over 400 ppm in 2015 [Dugug-kencky and Tans, 2016]. The Earth that spent 10,000 years to warm up from the glacial to the interglacial phase (Holocene), since the last two decades has been heating almost 0.2°C per decade. This is a rate 50 times faster than the natural glacial-interglacial cycle [Nobre et al., 2012].

According to BP energy statistics, in the year 2017, there were 33 Gt of CO_2 emission worldwide. According to Nobre et al. [2012], the increase in carbon observed in the atmosphere is the organic origin CO_2, not the inorganic origin CO_2 released when a volcano erupts. Evaluation of isotopic carbon signatures lead to fossil sources and forest burning as responsible for the increase the concentration of this gas in the atmosphere, as a results of burning of coal, oil and natural gas by human activities.

Approaching climate change is a large-scale global challenge to reduce and avoid the release of enormous amounts of greenhouse gases (GHGs) over the course of this century. CO_2 is recognized as one of the principal greenhouse gases, which may be sequestrated underground [Metz et al., 2005]. An assessment conducted by The Intergovernmental Panel of Climate Change [IPCC, 2014], concluded that the CO_2 emissions should be decreased by at least 50%, from the currently annual rate, to limit the escalation of the global average temperature to 2°C by 2050. This is a limit agreed by 125 nations that signed the Paris Agreement in 2015 – United Nations Framework Convention on Climate Change – UNFCCC – that would stabilize CO_2 concentration in the atmosphere “at a level that would prevent dangerous anthropogenic interference with the climate system”.

For IPCC assessment report, Smith et al. [2009], the calculation of climate change risk involves the process of integrated assessment, taking theoretical climate model-based projections of future climate change, using appropriate approaches to assess the likely environmental, societal, and economic impacts.

Carbon Capture and Storage in geological formations

Considering the global populations and standards of living for the four different future socio-economic scenarios by IPCC, this challenge implies a significant change in the way that energy is produced and consumed around the globe. Although the energy scenarios predict an increase in the share of the renewables, in absolute numbers the fossil fuels will continue to provide most of our energy needs in the foreseeable future. This is simply because is not likely the growth in renewable energy will be able to keep up with our increasing energy demand associated with a growing world population in such a short period [Smith et al., 2014]. Thus it is necessary to deal with this global challenge, more than ever, on different fronts. Therefore, new technologies are needed to be developed as one of the critical methods to mitigate the global warming issue [Norhasyima and Mahlia, 2018].

Even the most positive scenario, still points to the need for negative emissions [Shepherd, 2009]. Considering these tendencies, is growing the need of technologies to activity mitigate the effects of climate change. It involves land management practices, accelerated weathering, albedo modification, and also technologies to reduce carbon levels from the atmosphere, as through large-scale carbon dioxide removal – CDR [Boysen, 2017; Kreidenweis et al., 2016; Smith et al., 2014; Caldeira et al., 2013; Lackner et al., 2012; Vaughan and Lenton, 2011; Keith, 2009; Shepherd, 2009].

Thence, it is rising the development of carbon capture and storage – CCS – technologies has been oriented, as well as is included the reuse of CO_2 in the process, thus carbon capture utilization and storage – CCUS. Technology for CO2 sequestration is still being developed, although some industrial-scale carbon sequestration projects are already operating around the world [Brennan et al., 2010; Sundquist et al., 2008].

CCUS is a methodology in which a relatively pure stream of CO_2 from industrial and energy-related sources is separated (captured), conditioned, compressed and transported to a storage location for long-term isolation from the atmosphere, but also produce valuable products, making this process more profitable and thus more viable. Due to the high cost and uncertainties in long-term geological storage, there is a growing inclination to include utilization, which re-use the CO_2, hence CCUS [Norhasyima and Mahlia, 2018].

In the context of flue gases, CO_2 is seen as a waste product. However, there are many applications, where CO_2 is utilized or considered as a valuable commodity [Smith et al., 2014]. IPCC [2014] stated that without CCUS implementation, the overall cost required to mitigate global climate change may increase up to 138% and there is a great challenge to achieve the 2°C targeted.

Given the enormous amounts of CO_2 that are emitting the geological sequestration emerges as a possible solution. Appropriate geological formations such as deep saline aquifers, depleted oil and gas fields, unmineable coal seams, and silicate formations can accommodate up to 11,000 Gt of CO_2 [Dooley et al., 2006]. For Dooley et al. [2006] this potential capacity should be more than enough to address global CO_2 storage needs for at least this century.

Many researches demonstrated that potential deep geologic CO_2 storage sites exist around the world. Although they are highly heterogeneous in quantity, quality and distribution, in many places, these candidates are near large groupings of power plants and other industrial facilities, which should lower the cost of deploying CCS systems [Dooley et al., 2006].

The concept of geological storage has been known for a long time. Similar deep geological formations have been used for oil and gas production and for fluid storage for over a century. But only recently the researchers related the potential of these formations and the climate change issue.

Dooley et al., [2006] explains the general conception of CO_2 storage reservoirs candidates. The reservoirs are normally at depths greater than 800 meters, sufficiently distant from water resources. CO_2 is injected as a supercritical fluid (dense as a liquid, but viscous like a gas), which allows it to flow easily through pipelines and into the geological formation. The layers of rocks that receive the CO_2 are more porous, facilitating the injection and storage of this. The surrounding rock layers are much more impermeable, working as reservoir seals, to keep CO_2 injected in place.

Many of the technologies needed to safely inject CO_2 into these deep geological formations already exist and are drawn from technologies, techniques and best industrial practices that are routinely used in the oil and gas industries. While CO_2 injection can be considered an established technology, large-scale deployment of CCS systems is potentially so great that it requires continuous development and demonstration in the field of more advanced techniques drilling and CO_2 injection [Dooley et al., 2006].

Coal as a CO_2 storage

For Mazumder and Wolf [2008] and Cui et al. [2003] coal, due to its properties, is a rock that under favourable geological conditions is the most promising CO_2 storage. Considering that the potential storage sites are any porous reservoir rocks with suitable impermeable cap rock, the coal seams that are not economically viable or too dangerous to mining can be considered to sequestrate CO_2 [Mukherjee and Misra, 2018]. Estimates [Metz et al., 2005] of CO_2 storage possible in global unminable coal seams lie in the range of 3-200 Gt of CO_2, for Dooley et al [2006] it can be considerate 140 Gt of CO_2.

As methane – CH_4 – is the main gas existent in the coal seams, it has been identified as an economical potential solution for the emerging world energy crisis. Because of the unique coal formation process compared to other reservoir rocks, the reservoir characteristics and gas storage and transfer mechanisms in coal reservoirs are quite different and therefore stand as important sources of natural gas [Sampath et al., 2017]. An additional advantage of this storage method is the recovery of methane (ECBM – enhanced coal bed methane recovery), thus it is characterized as an important method of carbon capture utilization and storage – CCUS. Norhasyima and Mahlia [2018] have methodically reviewed the patents for CO_2 utilization technologies for the application of CCUS, they have indicated the ECBM as one of the main technologies developed worldwide.

The CO_2 utilization potential should be of a scale proportionate with future CO_2 capture technology and requirements from large industrial sources and power generation. Potential CO_2 market demand and utilization method are presented in Table 1.

ECBM technology is a consequence of selective carbon sorption relative to CO_2. As was said, methane is found on the surfaces of the porous of coal. However, those surfaces have a chemical preference for CO_2 than CH_4. In case of low-pressure values, this relationship may stand at 8:1 [Krooss et al., 2002; Rodrigues and Lemos de Sousa, 2002]. When CO_2 is injected it induces the coal to release methane while adsorbing the injected CO_2 instead, it is called CO_2/CH_4 exchange sorption. The laboratory experiments are considered an effective approach in the characterization and quantification of the combined micro-processes that occur in ECBM and CO_2 sequestration [Norhasyima and Mahlia, 2018].

The analyses that phenomena in coal samples free of stress have been carried out since the 1980s. Fulton et al. [1980] presented the first laboratory tests of injecting CO_2 into coal samples to displace CH_4. Further analyses of the competitive adsorption/desorption process on coal were also presented by Reznik

Tab. 1. Potential CO_2 market demand. Comparison of ECBM with other technologies for carbon utilization [Norhasyima and Mahlia, 2018]

CO_2 utilization method	**Potential CO_2 demand (Gt of CO_2 / year)**
Enhanced oil recovery (EOR) & **Enhanced bed methane (ECBM)**	0.3-3
Mineralization	>3
Fuel & Chemical including urea yield boosting	>3
Biofuel from algae	>3
Enhanced geothermal system (EGS)	0.05-0.3
Beverage carbonation	(about) 0.14
Food processing, packaging	(about) 0.15
Horticulture	0.01-0.05
Water treatment	0.01-0.05
Power generation – CO2 as working fluid	<0.01

et al. [1982], in higher pressure. The majority of laboratory analyses of CO_2/CH_4 exchange sorption have described the specific interactions between coal, CH_4 and CO_2, as well as identified some features of coal as a potential container of CO_2 and the source of CH_4 [Merkel et al., 2015; Zhang et al., 2015; Yu et al., 2014; Lafortune et al., 2014; Dutka et al., 2012; 2013; Baran et al., 2010; Majewska et al., 2009; Busch et al., 2003; 2006; Krooss et al., 2002; Clarkson and Bustin, 2000]. Thus, CO_2-driven enhanced coalbed methane recovery – ECBM – with simultaneous CO_2 storage is an emerging technology [Mazumder and Wolf, 2008; Dooley et al 2006, Cui et al., 2003].

Extracting unrecoverable oil reserves is made by injecting, for example, polymers and surfactant into the reservoirs to remove the trapped oil in the rocks. Although there are currently several techniques for the application of ECBM, its productivity has been greatly impaired due to existing poor practice. Due to the associated significant environmental risks, economic problems and reduced commercial viability the conventional methods of gas extraction are no longer acceptable. This has boosted the development of gas and coal production improvement techniques [Mukherjee and Misra, 2018; Sampath et al., 2017].

In this context, the use of CO_2 has become popular because it may potentially be then stored permanently in the same reservoir after production has completed, thus there would have been an environmental gain in reducing CO_2 emissions into the atmosphere [Mukherjee and Misra, 2018; Sampath et al., 2017]. Among the CO_2 based ECBM techniques, CO_2/CH_4 gas exchange and hydraulic fracturing using CO_2 are two popular techniques that give promising results [Sampath et al., 2017]. However, still uncertainties related to the underground behaviour of CO_2.

The challenge of ECBM

In ECBM, the injection of the CO_2 underground is reported to be a well-proven technology, achieved TRL-9, as petroleum industries have been injecting CO_2 in geological formations for many years. However, CO_2 utilization environmental and health impact is not yet well studied due to its immaturity of the technologies thus further studies are much needed. There are then some practical issues.

Firstly, ECBM is very much dependent on location-specific, whereby CO_2 sources and reservoir will determine its viability and economics. This means there isn't a universal viability [Mukherjee and Misra, 2018].

Secondly, according to Advanced Resources International [ARI, 2010], the CO_2 able to be used in ECBM is limited to only 60 million tons (0.06 Gt of CO_2), it is much less than the total emissions of CO_2, which implies that ECBM can only be a partial solution. Whereas ECBM should be considered only for mitigation purposes, would continue fulfilling its role.

The third point that could put the technology into questions is whether ECBM gives a negative balance of CO_2 in the atmosphere. The argument is that because of ECBM is produced more oil, and hence, further increase anthropogenic CO_2 emissions. The recovered CH_4, when burned will emit CO_2 in the atmosphere, thus this is exactly the opposite of what has been discussed to deal with the issues of climate change and CO_2 emission reduction. However it has been estimated that the burning of 1 ton CH_4 can yield 2.27 tons CO_2. The global survey indicates 3 Gt – 200 Gt of CO_2 can be sequestrated, while the recoverable volume of CH_4 is about 50 trillion cubic meter [Mukherjee and Misra, 2018]. Ottiger et al. [2006] suggested that if all recovered CH_4 is burned, there will be a net CO_2 storage, based on CO_2 balance and cycle.

The fourth potential issue would be related to the leakage. For Dooley et al. [2006], CO_2 leakage from deep geologic formations is not principally about human health and welfare today. In a properly designed and well-managed carbon capture utilization and storage facility – CCUS –, the chance of appreciable CO_2 leakage from the deep geologic storage formation is very small. The concern relates to slow, undetected leakage and how that might impact the climate for future generations. The scientific challenge is to ensure that CO_2 stays safe in these places for thousands of years. The development of monitoring, verification and evaluation technologies for all that CO_2 remains trapped in the soil is essential [Smith et al., 2014].

The principal task for the measurement, monitoring, and verification of stored CO_2 centers on how to demonstrate the long-term retention of stored CO_2 to regulators and the public. New and improved measurement and monitoring techniques and standards for their use need to be developed to provide proof of public and environmental safety and of each CCUS project's effectiveness in mitigating climate change [Dooley et al., 2006]. Ultimately, for Ramanov et al. [2009], the acceptance and implementation of any large-scale carbon sequestration methodology will be a social and political decision.

The expansion of this technology is needed at a fast pace to significantly contribute to the expectations of the century. This technology could play a significant role in society's efforts to stabilize atmospheric concentrations of greenhouse gases by the middle of the century. That means implanting thousands of carbon sequestration plants over the course of the century and as soon as possible. The implementation of this technology and effective implementation is not impossible, but definitely a challenge to reach the international protocol's targets.

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Rozwój technologii sekwestracji CO_2 w pokładach węgla – przegląd zagadnienia

Streszczenie

Biorąc pod uwagę globalny wyścig w redukcji emisji CO_2 w atmosferze, zalecona jest głównie ujemna emisja CO_2. W tym celu rozpoczęto na szeroką skalę badania nad sekwestracją CO_2 w pokładach węgla za pomocą technologii ECBM.

Praca jest przeglądem, który miał na celu pokazanie możliwości wykorzystania węgla jako składowiska CO_2, ze względu na jego wyjątkowe właściwości, w szczególności zdolność do procesu wymiany sorpcyjnej CO_2/CH_4.

Aby sprostać międzynarodowym standardom zmian klimatycznych do 2050 roku, technologia ECBM musi ciągle być rozwijana dla jej efektywnej implementacji.

Słowa kluczowe: zmiana klimatu, sekwestracja CO_2, technologia ECBM, sorpcja wymienna CO_2/CH_4