Book of Abstracts

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Carbon Capture Utilization & Storage

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Symposium overview

Carbon capture, utilization and storage (CCUS) is vital for reducing emissions across the energy system in both the Energy Technology Perspectives (ETP) 2°C Scenario (2DS) and the Beyond 2°C Scenario (B2DS). With the theme “Advancing CCUS through global cooperation”, the Applied Energy Symposium and Forum, CCUS2018: Carbon Capture, Utilization and Storage, to which the present issue of Energy Procedia is dedicated, was held in Perth, on June 27–29, 2018 (http://applied-energy.org/ccus2018). More than 80 participants from 7 countries attended this conference with oral presentations of 56 papers. A selection of CCUS2018 symposium papers have be published in the journal *Energy Procedia*.

A diverse range of topics were covered including progress updates from operating and planned international and Australian CCS/CCUS projects, economics and legal frameworks, CO_2 enhanced shale gas recovery/enhanced oil recovery/enhanced water recovery projects, storage assessments, pipeline leakage and novel utilisation technologies, capture technologies, monitoring and sensor technologies, geochemistry, and leakage risks and faults.

Organisers

The CCUS2018 is organised *by The International Journal of Applied Energy*, Geoscience Australia, Applied Energy Innovation Institute (AEii), and The Administrative Centre of China's Agenda 21 (ACCA21), and co-organized by Future Energy Profile/Mälardalen University Sweden.

The event consists of two-day symposium for sharing the most recent progress of research in carbon capture, utilisation and storage, as well as a one-day field trip.

Sponsors

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Keynote speeches

CCUS: A retrospective and prospective view

Author

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Abstract

CCUS, under various titles and acronyms, has been around for almost 30 years and in that time much has been achieved. We know how to capture and store carbon dioxide at a range of scales. We have identified many geological locations where we can store CO_2 safely and securely, and how it can be monitored. We have demonstrated how CO_2 can be used beneficially, whether for EOR or for making mineral or chemical products. We have convinced the IEA, the IPCC, the UNFCCC and others that it will be impossible to meet the aspirations of the Paris Accord in the absence of CCS.

There are national CCS initiatives such as those in China, Japan, Norway, Australia and the USA that are providing important new information. But I would like to highlight International collaboration, because it has been such a key driver in taking CCUS R&D forward. Examples include many government -supported collaborative initiatives such as those within the European Union, the IEAGHG, the Regional Partnerships Program, CSLF, the GCCSI, and of course CAGS. We are also now seeing the development of Company — initiated programmes specifically around international collaboration. The Oil and Gas Climate Initiative (OGCI) involves a large number of major oil companies; the Carbon Capture Project, again involving a number of oil companies, has been supporting international collaboration for more than a decade. We are now seeing individual companies proactively working to encourage, financially support and steer international collaboration between research organisations. For example, BHP has recently developed the GeoCquest Programme involving Melbourne, Cambridge and Stanford Universities; it has established a major research initiative in CCS and steel and has co-developed the International CCS Knowledge Centre. A related but different example of international collaboration is provided by CO2CRC, which has an outstanding record of world-class collaborative research in many areas of CCS, but most notably through its research at the CO2CRC Otway site in Victoria. So, much has been achieved, with international collaboration.

And yet, CCS (or CCUS) is not proceeding at anything like the pace that is needed. Nowhere near what is needed! Some countries have banned onshore geological storage of CO_2 (though appear to have no problem with onshore geological storage of methane); many do not have an adequate regulatory or liability framework in place. The level of public support (and therefore political support) is low. Some communities are opposed to it; some NGOs are strongly opposed to it. There is a view that renewables can provide all the energy needed, despite the fact that globally, fossil fuel use continues to rise. Along with this is a view that CCUS is too expensive, it does not work and we don't need it! The reality is we do need CCS and we need it now and for a long time into the future. But we are currently failing, not scientifically, though there is more science to be done. We need to better understand trapping and learn how we can make less- than- perfect reservoirs (that happen to be in a convenient place) into suitable storage sites. We need to be smarter in more cost-effectively monitoring CO_2 behaviour in the subsurface. We need better solvents, membranes, adsorbents, the

whole gamut of options, and make them more benign, more effective. We need to be more creative with hybrid technologies that cost-effectively bring solar or wind or batteries into the CCS equation. We need to modularise capture plants.

Opportunities and risks for CCS

Author

Alex Zapantis

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Abstract

Carbon Capture and Storage (CCS) is a suite of technologies that capture carbon dioxide from anthropogenic sources and permanently stores it in appropriate geological structures. Authoritative analyses of least cost pathways to achieve ambitious climate change targets (i.e. limiting the rise in average global atmospheric temperature to less than two degrees Celsius above the pre-industrial period) conclude that CCS is an important part of the technology mix. However this fundamental need for CCS has not translated into deployment at the rate and scale required to achieve climate targets. The nascent state of the global CCS industry creates risks for potential investors. The well-established and familiar business models, structures and practices that exist in mature industries and play a significant role in reducing investment risk have generally not yet developed for CCS. In most cases, the market does not provide sufficient reward for CCS to achieve required rates of return on investment — and the required rate of return is often elevated due to the perceived risk associated with the investment making financing very difficult. Significant innovations in technology, in business models and in industrial efficiency are generally driven by the competitive powers of the market. Providers of goods or services compete to reduce costs, to improve the utility of their products and hence to win market share. Innovations can only be protected from competitors for a finite time; knowledge leakage inevitably occurs spreading developments throughout the entire industry. As a market grows, economies of scale and scope and learning-by-doing also deliver cost reductions, which increases demand for the product until market saturation occurs. The net result is the familiar pattern of reducing technology cost over time in real terms. This is certainly the pattern that has been observed with renewable energy technologies since the turn of this century. These cost reducing processes are only just beginning with respect to the global CCS industry. The market has not yet reached the point where competitive forces are driving sufficiently large investments by the private sector in CCS or where economies of scale and learning-by-doing are rapidly reducing cost. These circumstances create both risks and opportunities for CCS. Carbon dioxide utilisation has a role to play in maximizing opportunities.

Progress and innovation in CO_2 capture

Author

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Abstract

The global challenge to limit overall temperature increase to below 2 °C, in accordance with the Paris agreement, will require the introduction of CO_2-capture and storage (CCS) technologies at a hugely increased pace across the full range of industrial sectors (oil&gas, electricity, cement, steel, aluminium). For CO_2 capture technologies the challenge to reduce costs remains a significant one and is addressed by the two-pronged approach of learning by doing and conducting research. International collaboration is crucial for success through the sharing of experiences, transfer of methodologies and joint development of best practices. Against this background the presentation will address the following topics:

1. overview of capture technologies

2. capture technologies in large scale integrated projects

3. global technology development trends

4. CO_2-capture technology development in Australia

5. towards zero and negative emissions from CCS

CCS/CCUS projects

The China Australia Geological Storage of CO_2 (CAGS) Project: An example of bilateral cooperation and successful capacity building

Authors

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Abstract

The China Australia Geological Storage of CO_2 (CAGS) project was established in 2008 and is jointly managed by the Department of Industry, Science and Innovation (DIIS) through Geoscience Australia (GA) and China's Ministry of Science and Technology (MOST) through the Administrative Centre for China's Agenda 21 (ACCA21). The project aims to help accelerate the development and deployment of geological storage of carbon dioxide in both China and Australia.

CAGS is celebrating 10 years and is considered by both the Australian and Chinese governments, participating organisations, and international observers to be a highly successful demonstration of bilateral cooperation and has been suggested as a model to follow for other bilateral collaborations. Capacity building in geological storage has been achieved through researcher exchanges, study tours, research project support, and facilitating access to leading international experts for sharing their knowledge at workshops and training schools. CAGS has been both an instrumental and enabling program in bringing together research, government and commercial organisations within China itself to collaboratively address CCUS. Although largely focused on CCUS in China, the program is a true collaboration and has benefited both countries. A summary of the impact and benefit of these different programs is described in Table 1.

The nature of the capacity building activities has changed over the course of the project. In CAGS3 (January 2016 – December 2018), the focus in China changed from national level capacity building and supporting desktop/laboratory research projects to targeted capacity building activities in the western Xinjiang province, a region undergoing rapid industrial growth. This strategic area of China is home to a large coal chemical industry but is coming under increasing scrutiny for its rapid growth in carbon emissions. CCUS is considered to be a key technology by the provincial and Chinese Government to address these carbon emissions. The region appears to be prospective for large scale implementation of CCUS: it has a ready supply of higher purity and comparatively inexpensive CO_2 from industrial emissions; basin capacity assessments suggest the Junggar Basin has large-scale storage potential; it is a low population region; the CO_2 could be used for enhanced oil recovery (EOR) or enhanced water recovery (EWR); and there is typically good co-location of sources and storage sites. In Australia, there too has been a change in the nature of the capacity building activities. In the early stages of the CAGS project, Australia hosted virtually all scientific exchanges but this has changed in more recent times and increasing numbers of Australian researchers are undertaking scientific exchanges in China. Presentations at the early workshops were mostly by Australian and international speakers but there is now a greater sharing of Chinese CCUS research and industry experience and knowledge. This evolution from CAGS1 to the current program reflects the growth in

both knowledge of and confidence in CCUS among Chinese researchers, and allowed them to share their research in an open, international forum. Indeed, one of the early programs in CAGS supported Chinese researchers to participate in international CCUS conferences in order to accelerate their exposure to international research and to encourage them to share their own. Over the last decade there has been substantial progress in China in CCUS with a number of CCUS demonstrations constructed or in development. Over the same period, CCUS in Australia has been largely limited to regional/site storage capacity assessments, research advances (particularly in monitoring) and pilot scale/research demonstrations. The one exception is the Gorgon CO_2 Injection Project, due to start injecting CO_2 in 2018, which will be one of the world's largest geological storage facilities.

The collaborative project has facilitated the individual exchange of some 30 researchers between the two countries and supported over 10 training schools and workshops. The CAGS alumni now extends to over 900 researchers, industry representatives and government officials. The project has had a measureable positive impact on advancing CCUS in China through its capacity building activities. The paper describes the history of the collaboration, the administrative arrangements and outcomes of this successful project.

Tomakomai CCS demonstration project of Japan — CO_2 injection in progress

Authors

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Abstract

A large-scale CCS demonstration project is being undertaken by the Japanese government in the Tomakomai area, Hokkaido Prefecture, Japan. The objective is to demonstrate the viability of a full CCS system, from CO_2 capture to injection and storage. One hundred thousand tonnes/year or more of CO_2 is being injected and stored in offshore saline aquifers in the Tomakomai port area. The implementation of this project has been commissioned to Japan CCS Co., Ltd. (JCCS) by the Ministry of Economy, Trade and Industry (METI).

At the annual meeting of the Carbon Sequestration Leadership Forum (CSLF), a ministerial-level international climate change initiative with 26 member governments for the development of improved cost-effective technologies for CCS, in Tokyo in October 2016, the Tomakomai Project was formally certified as a CSLF-recognized project.

The CO_2 source is a pressure swing adsorption offgas from a hydrogen production unit (HPU) of an oil refinery located in the coastal area of Tomakomai Port. The HPU provides CO_2 rich offgas to the Tomakomai demonstration project CO_2 capture facility via a 1.4 km pipeline. In the capture facility, gaseous CO_2 of 99% or higher purity is recovered from the offgas by a commercially proven amine scrubbing process with a design capacity of 200,000 tonnes per year.

At the injection facility, the gaseous CO_2 is compressed and injected into two different offshore reservoirs (Moebetsu Formation/sandstone layers and Takinoue Formation/volcanic rocks layers) by two dedicated deviated injection wells. The storage points are located at 3 to 4 km offshore.

The project is scheduled to run between the period of JFY 2012 - 2020 (JFY is from April of calendar year to following March). The injection of CO_2 began in April 2016. The injection of CO_2 will be conducted for three years and monitoring for five years. The injection target is 300,000 tonnes in total over three years.

The main features of this project are: 1) Extensive monitoring system in seismically active country, 2) Deviated CO_2 injection wells drilled from onshore to offshore, 3) Application of law reflecting London Protocol, 4) Low energy CO_2 capture process utilizing high CO_2 partial pressure gas, 5) Injection of CO_2 near urban area.

To confirm the safety and stability of CO_2 injection, it is necessary to monitor the CO_2 behavior in the reservoirs and conduct observation continuously to detect any CO_2 leakage. This is particularly important in a seismically active country like Japan. Thus, the most important objective of the Tomakomai CCS Demonstration Project is to verify that:

・natural earthquakes have no influence on the CO_2 stored

・no perceptible earth tremors are induced by the CO_2 injected

thereby removing concerns about CCS regarding earthquakes. To this end, an extensive monitoring system has been installed. The monitoring system is comprised of three observation wells equipped with pressure and temperature sensors, seismic sensors, comprehensive seismic instrumentation of one onshore seismic station, four ocean bottom seismometers and an ocean bottom cable with a total of 72 seismic sensors. Baseline data acquisition of the monitoring system started from February 2015. A baseline 3D seismic survey was conducted in 2009 during the investigation period prior to the project, and a 2D seismic survey was conducted in 2013. The first time-lapse 2D seismic survey after the start of CO_2 injection was conducted from January to February 2017 when the cumulative injection was at 7,200 tonnes, and did not show any anomaly. The first time-lapse 3D seismic survey was conducted from July to August 2017 at cumulative injection of 61,000 to 69,000 tonnes and a clear anomaly was detected along the injection interval. Further data processing is currently underway.

The injection well for the Moebetsu Formation is an extended reach drilling (ERD) well with a maximum inclination of 83 degrees, a drill depth of 3,650 m, a vertical depth of 1,188 m and a horizontal reach of 3,058 m. The injection well for the Takinoue Formation has a maximum inclination of 72 degrees, a drill depth of 5,800 m, a vertical depth of 2,753 m and a horizontal reach of 4,346 m. The injection intervals of both injection wells exceed 1,100 m, and are completed with slotted or perforated liners. The injection wells were drilled from onshore to offshore, resulting in significant reduction of drilling, operation and maintenance costs, and the long injection interval length is intended to enhance injection efficiency.

Japan amended a domestic law, “Act on Prevention of Marine Pollution and Maritime Disaster”, and a permit system was created conforming to the London Protocol. The obligations of the operator of offshore CO_2 storage include:

・Receiving permit from Minister of Environment

・Implementing environmental impact assessment

・Monitoring surrounding sea environment (ex. concentration of CO_2 in seawater)

An activated amine process with a two-stage absorption system and a low pressure flash tower reduces the amine reboiler duty in the capture system, and the energy consumption of approximately 1.16 GJ/tonne CO_2 for CO_2 capture, which includes required energy for reboiler steam generation and electricity generation for amine solution circulation, is achieved at almost maximum actual operation load This process utilizes the high pressure of the feed gas to the CO_2 absorption tower and the high partial pressure of the CO_2 in the feed gas.

The CO_2 injection area is very close to the urban area and the public outreach activities are very important. JCCS’s main approach to public outreach activities was first, sharing correct information based on current CCS technology; second, maintaining constant, thorough cooperation with the local government and various local stakeholders; third, avoiding a one-way flow of information by encouraging conversation with all parties; fourth, designing its activities to create a personal connection with the audience; fifth and last, planning all of the above mentioned approaches in consideration of the benefits to the local communities.

Full-scale CCS in Norway

Author

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Abstract

Gassnova is working to establish what could become the first industrial CCS project in Europe based on onshore capture. The project will demonstrate that carbon capture, transport and storage (CCS) is possible and safe to implement.

The feasibility study from July 2016 shows that CO_2 capture is technically possible at three industrial emission sources in Norway: At Norcem's cement factory in Brevik, at the Yaras ammonia factory in Porsgrunn, and at the energy recovery plant at Klemetsrud in Oslo. All three of these sites delivered their concept studies for CO_2 capture in the autumn of 2017. In May 2018, the Norwegian Government proposed that Norcem should be given the opportunity to carry out FEED studies, while Yara ends its project. It has not yet been decided whether Fortum Oslo Varme will continue with the FEED studies.

It is planned that CO_2 will be transported by ship from the point of emission in the Eastern part of Norway, to an onshore facility at the Norwegian West Coast for intermediate storage. Gassco delivered a concept study for transport by ship in the autumn of 2017. Equinor (Statoil) and its partners Shell and Total (the Norhtern Light consortium), have taken over responsibility for the transport part of the project during the FEED phase.

The CO_2 will then be piped to a specially-developed field on the Norwegian continental shelf for permanent storage. The Norhtern Light consortium is responsible for the planning of the storage facility. The concept study for storage will be completed during 2018.

Learning for others

A full-scale CCS project can provide lessons and experiences that new CCS projects can take advantage of. The technology is currently considered as being ready, but with significant potential for improvement. However it is the commercial barriers that have proved especially difficult to overcome.

If Norway is successful in realising a full-scale CCS chain, this will demonstrate that CO_2 management is possible and safe within the current European regulations. The International Energy Agency (IEA) has repeatedly pointed out that Norway can play an important role as a pioneer, and that this may encourage other countries to follow their lead.

Real-world experiences also provide more targeted research, which in turn can provide better and more affordable technical solutions. Efforts to actively share and disseminate such lessons are systematised through the work on benefits realisation.

Plenty of storage capacity

The infrastructure that is established in connection with the full-scale project will have excess capacity. This means that the storage site can store more CO_2 than the amount that the first project generates. Sharing the infrastructure that has already been established can help to ensure that the next projects can be considerably more affordable.

The Norwegian full-scale project for CCS will help to ensure significant reductions in Norwegian CO_2

emissions. Both Norcem and Fortum Oslo Varme plan to capture around 400,000 tons of CO_2 each per year.

CO_2 sequestration-EOR in Wuqi oil reservoir, Yanchang Field, China: Estimation of CO_2 storage capacity

Authors

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Abstract

Depleted hydrocarbon reservoirs, deep saline aquifers, deep coal seams and shales are considered as potential CO_2 geological storage sites. However, depleted (mature) oil fields are often considered as first targets for geo-sequestration where the cost can be offset by enhancing oil recovery as well as utilising the existing infrastructure and facilities. However, evaluation of CO_2 injectivity/dynamic storage capacity and ultimate CO_2 enhanced oil recovery (EOR) are key elements for site selection and a successful CO_2 storage – EOR project.

The Yanchang Petroleum Company's Yanchang oil field is located at Ordos Basin in north western China and it is the second largest low permeability oil field in China with a very short and inefficient primary oil depletion and secondary water-flooding recovery. Thus, CO_2 EOR was considered an appropriate tertiary oil recovery approach. In this work, the Wuqi reservoir in the Yanchang field was selected to study the feasibility of full-field CO_2 sequestration – EOR. The Wuqi reservoir has been in production for over a decade using both primary and secondary oil recovery methods and has historical data that can be history matched to reduce the uncertainty for a CO_2-EOR field development plan. To acquire essential dynamic data to evaluate CO_2 injectivity/dynamic storage capacity, a specific well testing design is proposed to inject both water and CO_2. It provides accurate effective permeability estimates for the water (test phase 1) and CO_2 (test phase 2) at the injecting well and estimates of the water and CO_2 fronts in the reservoir. Using two monitoring wells significantly increase the radius of investigation (ROI) and also describes the reservoir heterogeneity.

An introduction to China Dunhua Oil Company's Karamay CCUS project

Author

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Abstract

China is making serious efforts in transforming its energy to a low-carbon mix; however, coal is still expected to remain a dominant position in the nation's primary energy structure in a foreseeable future. CO_2 abatement from coal-based power sector and industrial processes is not only crucial for China to achieve its deep CO_2 reduction, but also essential for the world to meet the 2-degree climate goal. Over the last decade, Chinese government has made a significant investment in CCUS research, development, and demonstration as well as issuing a series of policy guidance. Now China has almost demonstrated all primary technical paths of CO_2 capture, storage, and utilisation at the pilot scale. Almost all China's major CCUS scientific and engineering advancements have been driven by the state-owned energy companies and top public research universities. However, a small Chinese private company, called Dunhua Oil Company, has recently received a great deal of attention by building an integrated CCUS project in the northwest of the country in 2015. This project includes capturing approximately 100,000 tonnes CO_2, per annum, from a methanol plant located in Karamay City, and transporting the captured CO_2 by tanker truck for enhanced-oil-recovery (EOR) in the Junggar Basin. Dunhua is also planning to its expand its CCUS portfolio to several other China's major oil fields by working with domestic and international partners. This presentation will introduce Dunhua's Karamay project, and will also provide some thoughts on early opportunities for private companies to do CCUS in China.

The South West Hub project — Do you need a conventional seal for safe containment?

Author

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Abstract

The South West Hub (SW Hub) project led by the Department of Mines, Industry Regulation and Safety (DMIRS) in Western Australia has been investigating and characterising the Lesueur sandstone as a potential target for injection and storage of CO_2 since 2007. The area of interest (AOI) is located in the onshore part of the southern Perth Basin, geologically known as the Harvey Ridge, between the Mandurah Terrace in the North and the Bunbury Trough in the South. The Harvey structure is a N-S elongated fault bounded anticline. It covers an area of 332 km^2 and is located approximately 13km northwest of the town of Harvey, south of Perth. The AOI has a unique structure compared to the rest of southern Perth Basin, wherein, the formations have been up-lifted and the major Yarragadee aquifer (potable water supply) eroded out, thereby removing a potential conflict of CO_2 storage with fresh water resources.

The Lesueur sandstone was deposited in a fluvial environment in the late Triassic period. The target storage complex consists of the Lower Lesueur (Wonnerup Member), which has no regional shale layer, as the injection reservoir; and the Upper Lesueur (Yalgorup Member) with its numerous paleosol baffles as the lower confining layer; and the basal shale part of the Eneabba Formation as the upper confining layer. The injection reservoir is heterogeneous and over 1500 m thick with varying permeability layers that should support residual and solubility trapping as the primary containment mechanism.

As is the norm in non-prolific oil and gas regions, the project started with limited data. Progressing judiciously, the project has acquired data on a stage-gated decision basis. Starting with a deep well to 2,945 metres in 2011, and a 2D seismic over 110 line-kms, the project was able to move through various modelling stages and uncertainty tabulations. A complex 3D seismic over 115 km^2 was undertaken in 2014 before drilling three “shallow to intermediate depth wells” (1,350 m, 1550 m and 1,800 m) in 2015. The combination activities provided good areal coverage and significant core and logging data in the targeted sub-surface formations. Reservoir models have been built at each stage, and their sophistication has increased as more data and new interpretations became available.

The SW Hub project is in a pre-competitive data assessment phase aiming at an appropriate level of characterisation to support acreage release. The success criteria, against which the model results are tested, has been developed by the Petroleum Division of the DMIRS considering impending Greenhouse Gas Legislation in Western Australia and requirements for future acreage release for storage. These criteria call for a greater than P50 level of confidence to be able to inject a minimum of 800,000 tonnes of CO_2 per annum through less than nine wells and ensure safe containment for one thousand years.

The most recent set of models has considered fourteen scenarios varying the uncertainty parameters within ranges of geological plausibility to map the plume profile. Stress cases have been considered in which combinations of uncertainties are applied together to try and force the plume up and outwards

to see if the storage complex is breached. In all the modelled cases the injected plume remains within the storage complex. The results have been peer reviewed and while uncertainties remain, there is a high confidence that the success criteria can be met. Additional work is planned to further reduce the identified uncertainties.

The SW Hub is unique insofar as it relies on proving primary containment through “Migration Assisted Trapping” (MAT - sometimes referred to as Migration Assisted Storage or MAS) in the approximately 1500 m thick Wonnerup Member of the Lesueur Formation. Security of secondary containment is considered through the overlying paleosol packages in the Yalgorup Member, a 800M thick sequence of sand and paleosol deposits. There is no regional shale layer acting as a traditional seal. It would appear, that given the appropriate reservoir conditions, safe containment can be assured without the necessity of having such a seal.

CarbonNet project update — new data and new momentum

Author

Nick Hoffman

The CarbonNet Project, Australia

Abstract

CCS in Australia is entering a new era with major projects gaining momentum.

Chevron's Gorgon LNG project in Western Australia is on track to become Australia's first and the world's largest commercial carbon capture and storage (CCS) project (at a scale of 3.4 MTpa). The CarbonNet Project (CarbonNet) in Victoria aims even higher – at a scale of 5 MTpa. Both projects are based on established oilfield technology with structural storage of CO_2 in large proven structures, located in well-understood and data-rich petroleum basins. New data acquisition has commenced for CarbonNet and the Project is developing strong momentum.

The CarbonNet Project is investigating the potential for establishing a commercial-scale CCS network. The network would bring together multiple carbon dioxide (CO_2) capture projects in Victoria's Latrobe Valley, transporting CO_2 via a shared pipeline hub and injecting it into deep underground, offshore storage sites in Gippsland.

Industrial source options have undergone major change in recent years with early electricity plant closures more than offset by new source technologies which have been announced in recent months and a number of significant steps have recently been announced by the Australian Federal and Victorian State Governments that support and provide context for CarbonNet. The project has concluded feasibility assessment and is now progressing through Stage 3 – Project Development and Commercial Establishment:

1) The Victorian Government Coal Policy Statement – July 2017

- consistent with the Climate Change Act and the target of net zero emissions by 2050
- sets initial emission intensity at 0.45 t CO_2 e/MWh which precludes unabated coal
- acknowledges strong interest in new industries – for low emission, high value products for domestic and international markets e.g. hydrogen and fertilisers
- identifies opportunities for new projects to mitigate emissions with CCS or offsets
- commits to completing the CarbonNet Project

2) The Victorian Government Climate Change Commitment 2017 defines 4 pillars of emissions reduction:

- energy efficiency
- clean electricity supply
- electrify/Switch to clean fuels
- reduce non-energy emissions and increase CCS deployment

3) The Hydrogen Energy Supply Chain (HESC) was launched in April 2018 with joint Federal and State support for the pilot project. A future commercial-scale HESC project will involve an innovative

new fleet of liquid hydrogen tanker ships supplying the Japanese energy economy, with hydrogen production from Victorian brown coal and intrinsic CCS in Gippsland to ensure that the hydrogen fuel is fully “green” from source to user.

Hydrogen will also be available to the Victorian economy to commence new energy systems and support the four pillars of the Climate Change Commitment.

The CarbonNet Project:

The Project is jointly funded by the Australian and Victorian Governments to 2020. CarbonNet is working collaboratively with industry to secure customers and investors in a commercial fee-for-service full-chain CCS Hub.

Significant research investment supports CarbonNet, including the Australian National Low Emissions Coal (ANLEC) Research and Development programme which currently supports eight project-specific ongoing scientific research themes, some using Commonwealth Education Investment Fund assets. The CO2CRC is CarbonNet’s lead research organisation, but support is also drawn from The Peter Cook Centre at Melbourne University and other key national and international expert centres. Knowledge sharing and publication of technical reports has been enabled through the Global Carbon Capture and Storage Institute.

Geological storage site selection has been independently certified by Det Norske Veritas (now DNVGL) for the portfolio of three sites including the prioritised site.

A state-wide screening process has been completed and certified. The portfolio of available sites was quickly reduced to three key prospective storage sites, with one site in the offshore Gippsland Basin – ‘Pelican’ – prioritised due to its proximity to the mainland and other factors.

- CarbonNet has applied for and secured five offshore greenhouse gas assessment permits: legal access and established regulations under the OPGGS Act.
- Feasibility studies have been completed across the full CCS chain: capture, transport and storage.
- A whole-of-project environmental risk assessment was completed, including air and groundwater potential impacts.
- Whole of life costings were risk-adjusted for carbon dioxide transport and storage, and service fees addressed.
- The regulatory framework was reviewed and market soundings were carried out with industry. This provided CarbonNet with an understanding of investment preconditions.

The Pelican Site is a giant structural storage equivalent in scale to a billion barrel oilfield like the Kingfish field, with thick and simple high-quality reservoirs and excellent topseals proven nearby to contain oil and gas for millions of years. Extensive oil industry data (1,500 wells and “wall-to-wall” 3D seismic) define the basin architecture, stratigraphy, and all details of the CO_2 storage system.

Extensive modelling of injection scenarios has been completed, based on a conceptual offshore development plan and accounting for statistical uncertainties & sensitivities in the subsurface. Probabilistic capacity assessment is 125MT @ P90 probability level, which satisfies the project requirements of capacity, injection rate, and longevity. Under the SPE CO_2 Storage Resources Management System, a Contingent Storage Resource has been established:

- 1C (proven) of 125 MT
- 2C (probable) of 250 MT
- 3C (possible) of 500 MT

CarbonNet has already prepared a draft Declaration of Storage – the next regulatory approval step, pending final details of site appraisal and regulatory fine-tuning. Once the Declaration is approved and commercialisation is demonstrated, the C1/C2/C3 Contingent Resource will progress to a P1/P2/P3 CO_2 Storage Capacity (equivalent to Petroleum Reserves).

Storage Site appraisal activities are ongoing:

- Marine seismic survey acquisition is now successfully completed over a core area around the Pelican site where the CO_2 plume will migrate and be securely contained:
  - stakeholder engagement conducted during 2017
  - regulatory permitting completed
  - environment plan approved
  - acquisition completed in February 2018
  - data processing and analysis underway
  - a unique nearshore multi-streamer conventional survey into 15 m water depth
  - establishes high quality, high-resolution baseline for future 4D time-lapse plume imaging
  - an offshore appraisal well is planned for 2019
  - The well is to provide further evidence of the storage site capacity (both effective storage volume & injection rate) and overall site integrity characteristics.
  - rock and fluid samples will prove key physical properties for storage and permanent trapping in the local geological formations

Stakeholder and community engagement is crucial to CarbonNet, as with all CCS projects. There is a strong need to raise awareness of and confidence in CCS as a viable and effective technology for emissions reduction and climate management.

The suite of GipNet research projects (EIF/ANLEC) is validating environmental monitoring technologies in the unique local shallow marine environment:

- multiple research organisations – CO2CRC/CSIRO/UoM/ANLEC R&D
- onshore and offshore elements
- atmospheric, marine, and subsurface elements
- containment, conformance, and assurance monitoring

The future CarbonNet Commercialisation Pathway is clear:

- supportive policies and enabling legislation exist
- business case is complete
- pre-commercial business structure is being established
- storage site appraisal and certification is ongoing:
  - declaration of storage
  - injection licence
  - investment facilitation by targeted industry sector
  - ultimate commercialisation

CO_2 capture and transportation

Enhanced Oil Recovery (EOR) at the Moonie oil field

Author

Bruce Danny

New Hope Group, Australia

Abstract

Bridgeport Energy Limited, a subsidiary of the New Hope Group, is developing an EOR Project at its Moonie Oil Field in the Surat Basin of Queensland. A staged project, utilising CO_2 from the post combustion capture (PCC) plant at an adjacent coal fired power station, is currently under development. A pilot EOR phase is now in planning with detailed modelling and simulation being completed. Subject to the necessary approvals, CO_2 supply and a successful pilot phase, full field commercial operation could begin as early as 2022.

This project will not only increase the oil recovery from the Moonie Field by over 10% but also enable the storage of up to 1 million tonnes per annum of CO_2 during the operation phase. On completion of commercial oil extraction, the site can then be used as a Carbon Capture and Storage (CCS) site.

The Moonie EOR Project will be the first commercial CO_2-EOR project in Australia. It can also potentially link with a larger CO_2 hub now being considered for the Surat Basin.

Surat Basin CCUS Hub — securing a low carbon future

Author

Stephen Malss

COAL21, Australia

Abstract

The Surat Basin is well positioned to enable a low emissions future for Queensland's industry as a CO_2 Storage Hub. The region has three of Australia's four supercritical black coal power plants and a natural gas combined cycle power plant within 250 km. Other potential CO_2 sources also exist in the region. While many CCUS applications currently do not have a strong commercial incentive, CCUS is not a new technology and has the capability to provide a competitive carbon reduction option for reliable high volume, 24/7 power from coal and gas fired power plants. In addition, CCUS is able to decarbonise a number of existing and prospective emissions-intensive industries.

The Surat Basin Region of Queensland is an industrial hub for the mining of coal, gas and oil together with a manufacturing industry including ethanol production, LNG processing and electricity generation. Carbon Capture Utilisation and Storage (CCUS) is the only available option to mitigate the significant CO_2 emissions from these industries.

For the Surat region of Queensland, a Surat Basin CCUS Hub:

- Supports the continuation of these regional industries, the jobs associated with them, and the wealth they bring for the long term.
- Provides for environmentally responsible long-term use of abundant fossil fuels, guaranteeing energy supply and security.
- Can ensure the cost competitive production of reliable electricity from existing and new coal fired power stations in an environmentally acceptable manner.
- Can support the LNG industry through the removal of high concentrations of CO_2 from natural gas wells.

Can extend the life of depleting oil wells by supplying CO_2 for enhanced oil recovery.

Work to date on the Surat Basin is proving to show very good commercial prospects. The two key projects supported by COAL21 will implement a trial injection to prove that CO_2 storage can be done and de-risk the legislative processes (CTSCo), as well as determine the most commercial locations to implement storage (UQ-SDAAP). However a lot more work is required to enable the development of a hub involving all the potential users and the development of the necessary infrastructure.

Demonstrating geological carbon storage at the CO2CRC Otway research facility

Author

Matthias Raab

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Abstract

The CO2CRC Otway Research Facility is Australia's first demonstration of carbon capture and storage. The Otway Research Facility was established to demonstrate scientific, technical, legal, regulatory and social aspects of successfully operating a CCS project. The facility is also globally unique as it has its own source of CO_2 on site.

Experiments with strong national and international collaboration at the Otway Research Facility continue to progress through unique stages with each research experiment bringing with it a new set of challenges including the specific scientific, social, political and regulatory environments at the time of execution.

Over more than a decade of leading edge research the many projects undertaken at the facility have made a significant contribution to an emerging global CCS industry.

This presentation provides an overview of comprehensive demonstration of deep geological storage of CO_2.

CO_2GeoNet actions in Europe for advancing CCUS through global cooperation

Authors

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Abstract

To meet the ambitious target set out in the Paris Agreement to keep the temperature rise well below 2 °C, all the tools available for reducing CO_2 emissions, including CCUS, are needed to meet the challenge and global collaboration is key. CO_2GeoNet, a pan-European scientific body on CO_2 geological storage, has gained visibility and recognition in the European and global arenas, participating in research and providing scientific advice, training and capacity building, and information and communication. Two European research projects initiated by CO_2GeoNet are currently ongoing: the ENOS project and the ECOBASE project. Both projects use international collaboration to advance research into geological storage of CO_2.

Investigation of dynamic phase changes in high-pressure pipelines during flexible CO_2 transport

Authors

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Abstract

High-pressure CO_2 pipeline transport is an important component in the Carbon Capture and Storage (CCS) system, especially when a large amount of CO_2 is captured from power plants and other industrial sites and stored or utilized to reduce greenhouse gas emissions. With changes in market demand caused particularly by the growing utilization of renewable energy, variations in and intermittency of CO_2 supply from capture plants at large scale fossil fuel power plants are inevitable. This will require significant improvement in the operational flexibility during CO_2 transport in order to maintain proper control of the CO_2 flowing in the pipeline. During power plant load variations, the fluctuations in the CO_2 flow rate may subsequently cause pressure and temperature instabilities, and two-phase flow may occur when the pressure and temperature drop. In extreme cases, dry ice could even form increasing the potential risks of corrosion, hydrate formation and pipe failure.

Load variation is a complex problem because the transition between one- and two-phase flow is a dynamic process, and the effect of flow rate, pressure and temperature fluctuations on the phase transition is not clear. Moreover, facilities such as boosters and isolation valves need to be installed at specific locations along the pipeline. Selection of appropriate and optimal design locations will also require additional knowledge of the impact of load variation on operating behaviour.

Based on these considerations, this paper presents results from a small-scale experiment and large-scale simulations on dynamic phase changes in pipelines during flexible CO_2 transport under high-pressure. To obtain a better understanding of the phase transition process and the potential risks, a theoretical model was built in Olga to simulate CO_2 pipeline transport during load variation. Satisfactory agreement (validation) was obtained between the simulation and experimental data, with a maximum relative error of 13%. Simulations of large-scale CO_2 transport were completed using a pipeline length of 105 km and an inner diameter of 250 mm. The full-load mass flow rate of CO_2 coming from the capture plant was set at 1 Mt/a. The CO_2 was transported to a well with a depth of 2 km. The reservoir at the bottom hole was assumed to require a constant injection pressure of 17.2 MPa. Some conditions were varied to simulate seasonal effects e.g. the CO_2 inlet temperature was set to 35 ºC to represent summer conditions and 10 ºC to represent winter conditions. The temperature of the well was also changed.

Results from this research will be used to provide advice on the selection of operating parameters and the design of pipelines, including the mode of unloading, the achievable load variation range, the layout of boosters, compressors and valves, and the size of the pipe. These results will also provide better understanding of the dynamic phase behavior inside the pipeline. Such insights will be useful for developing and testing new ideas related to the practical implementation of large-scale commercial CCS projects.

Temperature evolutions near the release orifice and analysis of under-expanded jets and far-field diffusion process during the CO_2 release from the industrial-scale pipeline

Authors

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Abstract

Pressurized pipelines represent the most reliable and cost effective way of transporting captured CO_2 from fossil fuel-fired electricity generation plants for subsequent sequestration. Leakage of CO_2 through a small puncture is the most common form pipeline failure during normal operation; such failures could lead to fracture. The study of pipeline depressurization and inventory dispersion behavior is of paramount importance for assessing the possibility of fracture propagation and the impact of CO_2 pipeline releases on the surrounding environment. A large-scale fully instrumented pipeline (258 m long, 233 mm i.d.) was constructed to study the pressure response, phase transition and dispersion of gaseous, dense and supercritical phase CO_2 during vertical leakage through a 15 mm diameter orifice. The fluid pressures and temperatures in the pipeline were recorded to study the pressure response and phase transition inside the pipeline. Video cameras and CO_2 concentration sensors were used to monitor the formation of the visible cloud and the gas concentration distribution in the far-field. There was a “two cold, intermediate hot” phenomenon during the vertical release in the dense and supercritical release due to the dry ice particle accumulation near the orifice. The intersection of the jet flow and settling CO_2 mixture resulted in complex visible cloud forms in dense CO_2 release.

Enhancing vorticity magnitude of turbulent flow to promote photochemical efficiency and trichome helix pitch of Arthrospira platensis in a raceway pond with conic baffles

Authors

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Abstract

In order to clarify vortex mechanisms in turbulent flow field to explain the enhanced biomass productivity of Arthrospira platensis in a raceway pond (RWP) with alternatively permutated conic baffles (APCB), computational fluid dynamics and miniature Doppler velocimeter were employed to investigate the promoted vorticity magnitude and turbulent kinetic energy to support the increased actual photochemical efficiency (φPSII). Numerical simulation showed that vorticity magnitude and turbulent kinetic energy increased by 5.9 and 13.9 times, respectively. It was measured on pulse modulated fluorometer that average φPSII increased by 13% to 0.51 in a RWP with APCB. It was detected on Nikon inverted fluorescence microscope that average helix pitch of Arthrospira increased by 14% and trichome length increased by 10% to give a biomass productivity increased by 34.8%.

Intramembranous mass transfer under various anodic pH conditions of microbial fuel cells

Authors

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Abstract

Microbial fuel cells (MFCs) can convert the chemical energy of organic compounds into electric energy directly via microorganism and have dual effects on productivity and environmental restoration. A typical MFC unit is composed of an anode chamber, a cathode chamber, and a separator. MFCs using proton exchange membrane (PEM) as a separator have two main problems including the accumulation of protons in the anode chamber and the leakage of oxygen from the cathode chamber. These protons have two major sources which is composed of the decomposition of organic substrate and the dissolution of carbon dioxide (production of substrate decomposition process). Accumulation of protons leads to the deducing anodic solution pH, the reducing cathode potential and system output voltage, and the decreasing microorganism growth. On the other side, oxygen transfers to the anode chamber and further replaces anode electrode as the electron acceptor during the metabolic process. This process will lead the reaction become to the concurrent anaerobic and tremendously inhibit anaerobic bacteria growth. It significantly depreciates the Coulombic efficiency of MFCs. Therefore, it is important to find the methods to solve these two problems.

In this work, in order to study the effect of anodic solution pH on the mass transfer in Nafion membrane of MFCs, molecular dynamics (MD) models are established. Five groups of anodic solution pH decreasing with time at the initial stage of battery operation are chose as the independent variables. Diffusion coefficients of oxygen molecules and other structures in Nafion under different pH conditions are calculated respectively. Qualitative experiments are carried out to verify the law of diffusion deriving from MD simulation.

MD cell models are established based on the physical and chemical conditions deriving from the anodic interface of Nafion in MFCs by Materials Studio (MS) 8.0. A cell model contains 7 hydration Nafion molecules, several water molecules, hydronium ions and 19 oxygen molecules. The total number of water molecules and hydronium ions is assumed as 910. The numbers of hydronium ions in each model are 70, 80, 90, 100, 110 and the corresponding pH values are 7.00, 6.94, 6.89, 6.85, 6.80, respectively. MD model energy optimization steps are as follows (1) Smart algorithm and Fine quality are used in the Geometry Optimization. (2) Energy minimization process is Anneal achieved by Fine quality, Five Annealing cycles, 298K Initial temperature and 698K Mid-cycle temperature in MS Forcite module. Every 40K is a temperature interval of heating or cooling and dynamics steps per ramp is 100 with NVT ensemble and Andersen thermostat. The time step is 1 fs and the total number of steps is 10000. The diffusion coefficients are calculated according to formula (1):

(1) Where N is the number of diffusion particles, (2) is the mean square displacement (MSD). MS output trajectory document can record MSD with time and make an average of the number of particles. Hence, the self-diffusion coefficient D can be directly calculated based on the slope of the relation curve between MSD and time. A 50ps NVE dynamics simulation is performed to obtain the trajectory document mentioned above. The temperature is assumed as 298K. The time step is 1 fs. The total number of steps is 50000 and frames output every 50 steps. The change of dissolved oxygen (DO) and oxygen trans-membrane diffusion coefficients are measured as oxygen in the air transferring through Nafion117 into the acetic acid solution to verify the simulation results qualitatively.

In order to highlight pH difference and reduce unknown influence, three groups of an acetic acid solution with different pH (5.5, 6.0, 6.5) are prepared.

The MD results demonstrate that the diffusion coefficient of oxygen molecules increases sharply with the deduction of anodic solution pH of MFCs. It indicates that at the early stage of MFCs operation, the trans-membrane transfer of cathodic oxygen is very sensitive to the anodic solution pH. Proton accumulation in the anode chamber makes no contribution in suppressing the diffusion of oxygen other than making the process more facile. Therefore, the growth limitation of anodic microorganism and the change of electron acceptor caused by oxygen leakage from the cathode chamber is probably one of the main reasons to the delay of battery startup and the low MFCs efficiency. The experimental data suggests that the lower the solution pH value will lead more oxygen diffuses into the solution. This conclusion is corresponding to the simulation and it can be extended to other fuel cells. Furthermore, the effect of pH value on the trans-membrane diffusion of oxygen is nonlinear. It presents that the lower solution pH value leads more significant the effect.

The diffusion coefficient of hydronium ions is almost unchanged after the initial rise with the decrease of pH. The diffusion coefficient of hydronium ions is obviously smaller than oxygen molecules and water molecules. It indicates that the positive charge has a significant effect on the diffusion of hydronium ions. Moreover, to enlarge the mass transfer gradient may not promote hydronium ions diffusion.

The reason of the diffusion coefficients of oxygen molecules in Nafion membrane affected by anodic solution pH is analyzed from micro perspective. According to the free volume theory, the main factors affecting diffusion rate of gas molecules in the polymer membrane are temperature, size of gas molecules and free volume fraction. In this work, the temperature is 298K and the gas is only oxygen. Thus, the analyses are mainly focus on the free volume fraction including the distribution of free volume and the situation of polymer chain motion. The results show that free volume of water molecules is the main component of cell free volume, and the greater water molecular spacing enhances the cell free volume and the water molecular diffusion coefficient. The free volume of Nafion main chains is the fixed component. The main factors affecting the oxygen molecules trans-membrane transfer are the free volume and motion of Nafion side chains. The larger free volume of Nafion side chain makes their movement more intense, and the trans-membrane transfer of oxygen molecules is more facile to be occurred.

Economics and legal frameworks

Is it worth to invest? — An evaluation of CTL-CCS project in China based on real options

Authors

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Abstract

China's consumption of liquid fuels increased considerably, with the annual growth rates being 9.3% for gasoline and 5.6% for diesel over 2007-2015. Energy security has become a thorny problem for the Chinese government with rapidly growing dependence on foreign oil. China is short of domestic oil and gas resources but relatively rich in coal. So alternative liquid fuel technologies like coal to oil (CTL) are attracting attentions. Driven by energy security concerns, arbitrage opportunities between coal and oil markets, and local economic development especially in the less developed coal-rich western provinces, China has been actively supporting the CTL industry in recent decade.
Investment of CTL project encounters several uncertainties. First, energy prices are affected by various factors to fluctuate widely and bring significant uncertainties to energy project investors. These uncertainties are especially essential for evaluating CTL project, whose material and product are facing two energy markets both under frequent fluctuations of the prices (coal and oil prices). Second, China is committed to reduce its CO_2 emission with market-based policy instrument, the loss incurred by emission of CTL project is uncertain since the carbon price under emission trading scheme is not constant. This will add an extra degree of the difficulty in evaluating CTL project. Third, the government's attitude to CTL industry remains vague, and relevant fiscal taxation policies are unsettled. Such investment in CTL will be affected a lot when the policies have been adjusted. Fourth, latent opportunities for CO_2 utilisation will change the industry chain as well as the role of CO_2, which may contribute to the profitability of the project. With the above-mentioned uncertainties, traditional discounted cash flow (DCF) method is no longer applicable for investors to evaluate CTL project, neither a simple real option method is applicable due to the complexity of these uncertainties.
In this context, we develop a sequential investment real options decision model of a typical CTL-CCS project in China with flexibilities in investment timing and operation. The decision process is divided into 3 stages. In stage 1, the investors should decide whether to construct the CTL plant or deferred investment. In stage 2, if the CTL plant haven't reached its decommission time, the decision maker should first decide whether or not operate the CTL plant according to the market price of coal and oil, then decide whether or not to retrofit the CTL plant with CCS. Note that there are great differences of high CO_2 concentration carbon capture and low CO_2 concentration carbon capture in their capital cost and O&M cost. So the decision should be made separately according to the carbon price as well as the expectation of the operation situation of CTL plant in the future. In stage 3, if it haven't reached the decommission time, the decision maker should first decide whether or not operate the CTL plant according to the market price, then decide whether or not to operate the CCS facility.
As an application, the model is used to evaluate Shenhua direct coal liquefaction (DCL) project with CCS retrofits option. It is the world's first and largest DCL plant. The model is solved by an improved Least Square Monte Carlo simulation method.

Four scenarios and sensitivities of key parameters are discussed. The investment probability is only 26.42% in the base scenario simulations. Due to reasons of economic feasibility, CTL project should be strictly examined and approved. There will be a significant improvement in investment probability and CTL project value if a fuel tax exemption policy is implemented. As oil price is the main factor that affects the profitability of CTL project, a linkage mechanism between oil price fluctuation and fuel tax exemption might be good for healthy development of CTL industry.

Also, CCS is of an important and feasible technology that can not only drastically cut the emission level of CTL plant, but also make a profound significance in CCS technology itself. According to our simulations, CCS technology can only drastically cut the emission level on the premise that carbon price is above 150 yuan/ton CO_2. However, according to experience in China's pilot carbon markets, the carbon price is not able to support a massive emission reduction action in CTL industry. Therefore, it might be better to apply a carbon tax policy to CTL industry which provides a strong signal of emission reduction actions. Another way to effectively promote the emission reduction actions in CTL industry is better utilisations of captured CO_2. If CCS-EOR cooperation is established successfully with a relatively high level of CO_2 commodity price, the CCS technology adoption can also be greatly encouraged. The utilisation of CO_2 is even preferable to the emission trading scheme or carbon tax policy because it can increase revenue of CTL project while reducing carbon emission. Government should consider promoting such cooperation.

China is accelerating its emission reduction actions by energy transition and establishment of a unified national carbon trading market system. However, it is undeniable that China is still facing a serious challenge in energy security. CTL-CCS project is a feasible attempt that can both ensure energy security and support low-carbon transition. This paper gives insights of evaluations of such project and supporting policies related to those industries.

Outline of Korean integrated CCS Act draft and its implication

Authors

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Abstract

Worldwide interest is growing upon Carbon Dioxide Capture and Storage (CCS) as a realistic measure to mitigate the greenhouse gases. Korean government as well fully supports on advancement of CCS research and development. Yet technology is only one side of the pillar. To implement the technology in practice, nationwide policies are necessary, which should be grounded upon stable and systemic CCS legislation. On March of 2016, Integrated CCS Act has been drafted by the governmental task force. This paper delineates the outline of the draft and illustrates details on important issues to balance between the efficiency and safety of CCS.

Evaluating the effect of a subsidy policy on carbon capture and storage (CCS) investment decision-making in China — a perspective based on the 45Q tax credit

Authors

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Abstract

A trinomial tree model based on the delay real option is developed to evaluate the carbon capture and storage (CCS) retrofitting investment for existing coal-fired power plants in the context of the 45Q tax credit. The uncertainties regarding the carbon price, the CCS retrofitting investment cost, the operation and maintenance (O&M) cost, the CCS investment subsidy scenarios, and the allocation ratio of the carbon dioxide (CO_2) storage subsidy between the coal-fired power plants and CO_2 storage enterprises are taken into consideration. The results show that if the allocation ratio of the CO_2 storage subsidy for coal-fired power plants is zero, the full government subsidy for the initial CCS investment cost and clean electricity tariff (0.015 CNY/kWh) are not sufficiently attractive for the coal-fired power plants to invest in CCS and the critical allocation ratio is 17.8% in this case. The critical allocation ratio increases to 26.4% if the government subsidy for the initial CCS investment cost is zero. Moreover, if the government subsidy for the initial CCS investment cost and clean electricity tariff are both canceled, the coal-fired power plants need to receive at least 33.3% of the CO_2 storage subsidy to invest in CCS. The results provide theoretical support for the decision-making regarding CS retrofitting investment and CCS subsidy policy-making.

Study on LCOE of Chinese coal-fired power plants with CCS: based on comparison with natural gas power plants

Authors

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Abstract

China, whose energy consumption is dominated by coal, is seeking ways to reduce carbon emissions and air pollution, natural gas hence plays an important role in energy transformation. However, due to the limited resources of natural gas, China's natural gas production is difficult to meet consumer demand, making China's natural gas dependence on foreign supply increase year by year, posing a potential threat to China's energy security and increasing the uncertainty of natural power generation costs. At the same time, according to the current development speed and scale, natural gas power generation has a limited emission reduction potential.

Based on China's "rich coal" resource endowment and the current status of coal-fired power structures, the Carbon Capture, Utilisation and Storage (CCS) technology applied to coal-fired power plants has received more and more attention as a means of emission reduction with huge emission reduction potential. CCS technology is also the bridge connecting traditional electricity and renewable energy power supply. However, due to the fact that CCS technology is in the early stage of development, the high initial cost of its investment and high energy penalty have made it develop slowly.

On the one hand, the roles of the two technologies in the energy transition are similar and there is potential competition. On the other hand, the power generation cost of a coal-fired power plant with CCS (CPCCS) has been ambiguous in the current different power generation ways. In order to solve this problem, this paper constructs Levelized Cost of Electricity (LCOE) assessment models for CPCCS and natural gas power plants (NGPP) in China that contains carbon price factor. LCOE is often used as a metric to rank the competitiveness of power generation technologies and is widely adopted as a standard to compare different technologies. Two scenarios are set for the CPCCS, one is to reduce CO_2 emission to achieve natural gas power generation emission levels (capture rate of 41.5%), the other is to carry out deep emission reduction with capture rate of 90%. Finally, the LCOE of natural gas power plants and coal-fired power plants with CCS are compared from different perspectives of introducing in carbon trading mechanisms whether or not, changes in fuel and carbon prices, and the provincial differences of fuels in China. The results of the study are as follows:

(1) Under the current level of natural gas prices, thermal coal prices, and carbon prices, regardless of whether CPCCS and NGPP participate in the carbon trading mechanism, the LCOE for NGPP is higher than that of CPCCS. With neither of them involved in carbon trading, the LCOE of NGPP, CPCCS with a capture rate of 41.5% and 90% are 0.480 yuan/kWh, 0.382 yuan/kWh and 0.407 yuan/kWh respectively. When CPCCS exerts its deep emission reduction effect, although the increase of additional energy consumption will increase LCOE, it is still lower than the LCOE of NGPP. When participating in the carbon trading mechanism, the LCOE of NGPP, CPCCS with a capture rate of 41.5% and 90% are 0.466 yuan/kWh, 0.367 yuan/kWh and 0.375 yuan/kWh. It can be seen that the CPCCS has advantages over NGPP in the aspect of LCOE, and it has great emission reduction potential. The introduction of carbon trading mechanism can significantly reduce the LCOE, making the power generation enterprises have a competitive advantage in getting on power grid. At the same

time, the government subsidy to support the development of clean electricity can also be reduced, thereby reducing the financial burden on the government.

(2) Based on the fact that the price of natural gas is controlled by the government, at its average level of 1.723 yuan/m3, changes in the carbon price of 4-200 yuan/t and thermal coal price of 150-750 yuan/t are considered. In most cases, the LCOE of CPCCS is lower than that of NGPP. For CPCCS with capture rate of 41.5%, the LCOE of the NGPP is lower than that of the CPCCS only when the coal price is 750 yuan/t, and the trends of the LCOE of CPCCS and NGPP are consistent as the carbon price changing.

For CPCCS with a capture rate of 90%, the LCOE of the same coal price level is higher than CPCCS with a capture rate of 41.5%. With the gradual increase of carbon price, the LCOE of CPCCS with high capture rate decreased rapidly compared with CPCCS with low capture rate. At the thermal coal price of 650 yuan/t, when the carbon price is higher than 35 yuan/t, CPCCS has the advantage of LCOE over NGPP. Under the condition of the thermal coal price is 750 yuan/t, when the carbon price is higher than 160 yuan/t, the CPCCS will have the advantage of LCOE compared with NGPP. When the price of thermal coal is 150-550 yuan/t, whether the carbon price is at a low level or is expected to be higher in the future, CPCCS with a capture rate of 90% has a power generation cost advantage over NGPP. At the same time, it can also be seen that the thermal coal price has a greater impact on LCOE of CPCCS compared to carbon price.

(3) Under the average carbon price level of 48.11 yuan/t at present, considering the influence of natural gas prices and thermal coal prices in different provinces, CPCCS with different capture rates all have lower LCOE than NPGG. In the two scenarios, Shanxi has the largest LCOE gap between CPCCS and NGPP, both are 0.171 yuan/kWh higher than LCOE of CPCCS. However, the gap between LCOE of CPCCS and NGPP is smallest in Shaanxi because of the abundant production of natural gas and coal there, making both fuel prices are low and resulting in a narrow gap between them. But Hainan has the opposite situation, because lacks of fossil fuels, the prices of them are relatively high, making the LCOE of CPCCS and NGPP be similar.

Under the existing market and policy conditions, when CCS technology is used in coal-fired power plants to reduce carbon emissions, although the investment cost of CCS capture devices is relatively large, their LCOE is still relatively lower than NGPP whether to achieve the natural gas emission level or reduce carbon emissions by 90%. Combined with China's coal-based resource endowment conditions, the positioning of CCS technology for coal-fired power plants in the dual alternative process should be further clarified, at least to meet the constraints of low-carbon development under the current conditions, CPCCS have a significant LCOE advantage over NGPP. With the establishment of China's national carbon trading market, CCS projects for coal-fired power plants with greater emission reduction potential should be considered as the main trading entities. At the same time, the coal price in China is also affected by the region and the policy, to ensure the LCOE advantage of CPCCS, the relevant influencing factors should be comprehensively taken into account in the development of CPCCS so that changes in coal prices can be effectively judged. In addition, to promote the development of natural gas power generation projects, it is necessary to effectively regulate the price of natural gas.

Role of a general contractor in advancing CCUS projects

Authors

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XSIGHT by Saipem, Italy

Abstract

It is commonly acknowledged that large-scale Carbon Capture, Utilisation and Storage (CCUS) projects are important element of achieving targets of the Paris Agreement. Yet, with exception of using CO_2 for Enhanced Oil or Gas Recovery, such projects do not yet make pure economic sense and, therefore, progress of the sector is relatively slow. This hurdle can be addressed with two principal levers. On the one hand, governments need to widely incentivise CCUS deployment via public funding or tax rebates (e.g. Norwegian government support to full-scale CCUS project or US Q45 Tax Credit). On the other hand, and more importantly in the long-term, the industry needs to work hard on reducing costs and risks of large-scale CCUS projects. Success on the later front requires strong collaboration and integration along the entire value chain.

So far in the maturing CCUS industry we have observed active participation of academia, specific technology providers, and selected energy companies. We believe, that decisive entry of general contractors can create significant value, above all by stimulating cost and risk reduction through the following activities:

- Early engagement with project owners or developers, offering “constructability” knowledge and experience at the very beginning of the project life-cycle, thus anticipating and preventing issues during EPCI phase. For instance, Saipem has created a dedicated business division for this purpose: XSIGHT by Saipem.
- Bring critical experience from the design of Oil & Gas processes, where CO_2 had been traditionally managed either as a process component, or by-product.
- Integrate different phases of the project, from feasibility studies to EPCI phase, for precise estimation and optimisation of investment costs.
- Bring and keep multiple players together, coordinating the technical and commercialization design.
- Deep knowledge and objective selection of the most competitive technologies, mainly in the CO_2 capture field.
- Worldwide view on opportunities for utilisation, pro-actively suggesting to clients the best possible approach.
- Capability to find synergies between adjoining facilities, projects or industries.
- Act as a single point of responsibility and guarantor for multiple technologies and licences.
- Assure highest levels of quality as well as health, safety and environmental protection on CCUS projects.
- In selected geographies, general contractors may have considerable experience and capability for stakeholder management, permitting, and supply chain management.
- Finally, involvement of a recognised general contractor can increase attractiveness of CCUS project for financing, both by governments and by private investors.
- Using example of Saipem, a general contractor can accumulate under the remit of one organisation significant know-how related to CCUS, as described hereafter.

CO_2 capture technologies screening and validation. Saipem is closely following the development of novel CO_2 capture technologies, such as enzymatic absorption. When such technologies move beyond TRL5 we offer our involvement in further development, bringing in valuable constructability and scalability experience.

CO_2 capture technologies application. Of course, being a general contractor, we focus on application of mature technologies in real projects. Different technologies have been applied over years in various processes - natural gas sweetening, pre-combustion, post-combustion, oxy-combustion. Objective evidence thus has been collected and preserved in the internal lessons learned databases.

Furthermore, CO_2 capture process is often associated with purification and conditioning of CO_2 for further utilisation, transportation or storage. This part is an important link to be considered for cost-benefit estimation of the overall project.

CO_2 transportation. Having built in excess of 100’000 km of land and subsea pipelines, Saipem has accumulated vast experience, which can be successfully applied for CO_2 compression, pumping and transportation, specifically in supercritical phase. Efficient, low-cost transportation solutions can significantly increase success of CCUS project by exploring alternative possibilities in utilisation or accessing appropriate geological storage formations.

CO_2 utilisation. In the emerging circular economy CO_2 utilisation should be always considered first and be preferred to storage wherever feasible. Various possibilities exist, ranging from EOR/EGR, conversion to products (such as urea and methanol), and up to novel applications, such as bio-fixation by microalgae. Saipem has upmost knowledge and experience in this area and, paradoxically, can sometimes offer advantageous solutions initially not foreseen by owner or developer.

Finally, CO_2 injection, either for geological storage or for EOR/EGR. Few general contractors have reservoir modelling experience, but those who do can offer effective support to project owners or developers, thus closing the complete value chain. Furthermore, injection offshore requires specialised knowledge and skills.

Involvement of general contractors in the CCUS business comes with its own challenges. Firstly, due to slow progress of CCUS adoption observed so far, we continue sustaining expenses for R&D, experience accumulation and retention, internal and external promotion, all without significant revenues from actual projects. Secondly, our know-how described here above, has been collected in different parts of the value chain and from different projects. Therefore, considerable effort is required to consolidate our knowledge, skills and experiences in one place, creating a relevant business offer. Nonetheless, these challenges are known parts of doing normal business. We tackle them, and look forward with optimism to large-scale deployment of CCUS projects.

CO_2 storage capacity assessments

ETS-10 zeolite with enhanced performance for CO_2 capture from flue gas

Authors

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Abstract

Growing concerns for global warming and climate change in recent years have motivated research activities toward developing more efficient and improved processes for CO_2 reduction. Among the most widely investigated approaches, CO_2 capture and storage (CCS) represents a necessary technology to achieve the "no more than 2 ^oC target. One of the bottlenecks to hinder the wide deployment of CCS is the high cost of CO_2 capture, particularly post-combustion capture (PCC) from flue gas during power generation. Amine scrubbing, the current state-of-the-art PCC technology, suffers from a range of drawbacks such as high-cost, corrosion, etc., and thus CO_2 adsorption using solid materials was proposed as an alternative to lower the cost of CO_2 capture, and thus release the full potential of CCS in CO_2 reduction.

The past decade witnessed tremendous progress in the development of CO_2 adsorbents, most of which focused on PCC application. However, performances of these developed materials are still unsatisfactory when a holistic PCC picture was considered. For example, immobilized amines showed great promise for PCC due to their high CO_2 selectivity and low sensitivity to moisture, but these behaviours rely thermodynamically on their strong interaction with CO_2, as a result, their irreversible interaction with SO_x and NO_x (also acidic gases) might pose significant risk during practical operation. Consequently, the adsorbent-adsorbate interaction needs to be tuned judiciously to achieve more efficient PCC processes.

In this contribution, ETS-10 zeolite was synthesized by a template-free hydrothermal approach from cheap starting materials, the material was proved to have moderate CO_2 affinity, which balance both high adsorption capacity and stability for CO_2 capture from simulated flue gas. Effects of preparation parameters such as precursor composition, duration and temperature of hydrothermal treatment were investigated, which shed meaningful lights on the practical application of adsorption-based PCC.
For the synthesis of ETS-10, 23.0 g Na_2SiO_3 (>12.8 % Na_2O, and >29.2% SiO_2) and 2.9 g NaOH were mixed in 75 ml H_2O and stirred for 2 h, into this solution, another solution containing 6.8 g tetrabutyl titanate, 4.5 g concentrated H_2SO_4 in 45mL H_2O was added and stirred for 1 h. Afterwards, a KF solution (1.2 g KF in 15 mL H_2O) was added and stirred in ambient condition for 16 until hydrothermally treated at 180-220 ^oC for 12 h. The obtained precipitate was washed adequately and dried at 110 ^oC.

The prepared ETS-10 was characterized by SEM, XRD, N_2-adsorption, and FT-IR, the obtained results are showed in Figure 1. It can be observed from the SEM image (Figure 1a) that highly crystallized ETS-10 was obtained, and diffraction peaks at 6.1^o, 20.9^o, 24.8^o, 25.9^o, and 27.7^o in the XRD pattern (Figure 1b) can be associated with characteristics of the zeolite ETS-10. According to N_2 adsorption at 77 K, the BET surface area of the ETS-10 achieved a moderate value of 251 m2/g, and

in the FT-IR spectra (Figure 1d), bands at 1038 cm-1 (Si-O-Ti stretching), 735 cm-1(Ti-O stretching), 566 cm-1 (O-Ti-O bending) were observed. The above results demonstrated the successful synthesis and structural integrity of the prepared ETS-10.

CO_2 adsorption isotherm of ETS-10 was measured at 25 ^oC as showed in Figure 2a, clearly a rapid increase of CO_2 uptake was observed with the increase of pressure, particularly at low pressure region, this is in sharp contrast with traditional physical adsorbents such as activated carbons, indicating enhanced CO_2 affinity of ETS-10. CO_2 adsorption capacities of ca. 10.2 wt.% was obtained at 1 bar, which is considerably lower as compared with the most sophisticated activated carbons, probably due to low surface area of ETS-10. On the other hand, at pressures more relevant to PCC, e.g. 0.15 bar, a high CO_2 uptake of 8.8 wt.% was achieved. Next, CO_2 breakthrough in simulated flue gas of the ETS-10 material was measured in a fixed-bed adsorber at 40 oC, from Figure 2b, long retention time was observed for CO_2 as compared with that of N2, indicating the selective capture of CO_2. Figure 2c shows the equilibrium CO_2 uptake during 15 vol.% CO_2/N_2 breakthrough measurement, at such conditions, stable adsorption capacity of ca. 7 wt.% can be achieved when desorption was carried out at 115 ^oC in N_2. When moisture was involved in the flue gas, a sharp decrease of the CO_2 uptake was observed (Figure 2d), indicating the competitive adsorption between H_2O and CO_2 on the surface. Nevertheless, continuous decay of performance was not observed, and with the increasing of desorption temperature, more adsorption sites can be recovered for CO_2 adsorption. Consequently, at a desorption temperature of 180 ^oC, the adsorbent can be fully regenerated to achieve stable CO_2 uptake at 6-7 wt. %.

Physicochemical characterization of EDA-carbamate crystals generated in phase-changing solutions for efficient CO_2 capture

Authors

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Abstract

A new type solid-liquid phase-changing solution (ethylenediamine/ N,N-Dimethylformamide, EDA/DMF) was proposed to capture CO_2 efficiently from biohythane. In this EDA/DMF solution, only the precipitate product EDA–carbamate which was formed after CO_2 absorption needed to be regenerated, avoiding high energy consumption of amine aqueoues solution. The CO_2 absorption capacity of solid-liquid phase-changing solution EDA/DMF was 13.9 mg/g absorbent, which was 30% higher than that of the EDA/water solution. The CO_2 peak absorption rate of EDA/DMF solution (0.97 mg CO_2 g-1 absorbent min-1) was 67% higher than that of the EDA/water solution. The two type of precipitate products EDA–carbamates in EDA/DMF solution and ethylenediamine/ N,N-Dimethylacetamide (EDA/DMA) solution were characterized using X-ray diffraction (XRD). Although the molecular structures of the two EDA–carbamates were same, their molecular arrangements were different (their unit cell dimensions β=90° and β=95.8° respectively), resulting in the two EDA-carbamate crystals having different spatial groups and belonging to different crystal systems (monoclinic and orthorhombic). The reaction mechanism between EDA and CO_2 in solid-liquid phase-changing solution was revealed. The decomposition activation energies of monoclinic and orthorhombic EDA- carbamate crystals were 63.6 kJ/mol and 91.2 kJ/mol, respectively.

Regenerating CO_2 at high pressures for chemical absorption

Authors

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Abstract

Chemical absorption, which has been commercialized, is suitable to capture CO_2 with the low concentration at the large point source such as from the flue gas at large power plants. However, the large thermal energy requirement in solvent regeneration has hindered the wide application (Li et al., 2012; Tan et al., 2016). Operating the desorber at higher pressure can reduce the compression work after the desorption; therefore, there is a potential to reduce the energy penalty of CO_2 capture and storage. The objective of this work is to investigate the feasibility of operating desorber at high pressures up to 10 bar.

A model has been developed in Aspen Plus, which has been widely used for the simulation of chemical absorption and desorption of CO_2. After absorption, the pressure of the rich solvent is lifted by the solvent pump, and CO_2 is regenerated at a lifted pressure in the desorber. After condensation, the high pressure CO_2 is compressed to 110 bar by the two-stage compressor with inter-cooling to 313.15 K for transportation after dehydration. The input data were taken from (Abu-Zahra et al., 2007). Aspen rate-based model was applied to the simulation of absorber and desorber columns. For both columns, the V-plug, which simulates the vapor phase in plug flow and the liquid phase as ideally mixed at each stage was chosen as a stage flow option (Kucka et al., 2003; Nookuea et al., 2016).

By doing steady state simulations, results show a potential of reducing the energy penalty caused by chemical absorption for CO_2 capture. By increasing the desorber pressure, both the required thermal energy of solvent regeneration and the power consumption of compressors decrease, even though the power consumption of pumps and the temperature of solvent regeneration increase.

CO_2 absorber coupled with double pump CO_2 capture technology for coal-fired flue gas

Author

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Abstract

Amine absorption method which is used for removing CO_2 from coal-fired power plant flue gas has the high energy consumption and degradation rate, strong corrosion. In view of these defects and flue gas having low CO_2 partial pressure, a new organic amine absorbent whose saturated absorption capacity can reach to 47.447.4L CO_2/Lamine has been developed. Compared with MEA solution, its saturated absorption capacity has been increased by 29.1%, and the regeneration rate increased by more than 80%. The CO_2 capture process flow has been analyzed, and 'absorption heat pump +MVR heat pump double heat pump coupled low energy consumption CO_2 capture system has been developed. Compared with traditional MEA technology, this system can save 38.32% energy, and its water saving rate can reach to 63%. The new amine absorbent and new system has been used in Sheng-li 100t/d power plant for the plot test. The results of the study show that under the conditions of CO_2 capture rate ≥80%, CO_2 purity ≥99.5%, its regeneration energy consumption is 1.395 tsteam/t CO_2 (2.9GJ/t CO_2), and compared with MEA industrial measured value 2 tsteam/t CO_2 (4.2GJ/t CO_2), it reduced by 30.2%; integrated double pump device system regeneration energy consumption fell to 1.01t steam per ton of CO_2 (considering power consumption of total energy consumption of regeneration 2.3GJ/t CO_2). Compared to the previous system without applying double pump, the energy consumption (2.9GJ/t CO_2) reduced by 21%, and compared to the determination of MEA industrial value, it reduced by 45%.

Process and integration optimisation of post-combustion CO_2 capture system in a coal power plant

Authors

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Abstract

Post-combustion CO_2 capture (PCC) is commonly believed to be one of the major strategic means to reduce the CO_2 emission in coal power plant. However, the operation of PCC system will cause substantial increase of operation cost due to the energy consumption for regeneration of the capture solvent. The optimal integration schemes of large-scale PCC system with thermal power plant are studied in this work, based on a feasibility study of 1 million tpa PCC system conducted for a thermal power plant in northeast China. A power plant model coupled with PCC system is setup by Thermoflow STEAM PRO. Based on the model, various steam extraction options and their impact on the steam turbine performance are studied, the impact of large-scale PCC operation on power plant performance under various boiler loads (100%, 75%, 60%) is investigated, and the impact of PCC operation on heating supply during winter is studied. An environmental assessment is also conducted by investigating the impact of PCC operation on the emission of CO_2 and pollutants such as SO_2, NOx and dust. In addition, process optimization is conducted by APSEN Plus simulation to reduce the steam consumption of reboiler. The impacts of mechanical vapor recompression (MVR) system on the regeneration duty of stripper is studied. The application of MVR can reduce the regeneration duty from 3.85 to 3.1 GJ/ t CO_2 if the flash pressure is 100 kPa. The impact of flash pressure of MVR system on the regeneration duty and electricity consumption is also studied. It found that the regeneration duty decreases with increasing flash pressure, however the electricity consumption increase with flash pressure dramatically. The optimal flash pressure is between 50~100 kPa.

Geological characterization and numerical modelling of CO_2 storage in an aquifer structure offshore Guangdong Province, China

Authors

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Abstract

The Lufeng (LF) 2-1 structure, which is the largest anticlinal structure developed in the Zhu I depression of the Pearl River Mouth Basin, offers high-quality source-sink matching with onshore CO_2 emissions. In this paper, a 3D model using the TOUGH2/ECO_2N tool was developed based on typical formation parameters obtained from a review of well and seismic structural data. Numerical results indicated that doubling the injection quantity does not result in a doubling of the CO_2 distribution, which suggests the presence of nonlinear variations between the two variables. The CO_2 plumes remain within the LF2-1 structural trap based on injection rates of either 1 Mt/y or 2 Mt/y. The maximum increase in formation pressure is less than 2 bars, which is 0.9% of the primary formation pressure. Therefore, the reservoir and seal properties of LF2-1 are optimal, which suggests that the prospect of injecting and storing a total of 40 Mt of CO_2 is good. Overall, the LF2-1 may be used as a suitable offshore site for large-scale storage of industrial CO_2 in deep saline aquifers. Additionally, the findings can guide site selection decisions in Guangdong Province for offshore CO_2 geological storage demonstrations.

CO_2 geological storage potential and suitability evaluation of Tarim Basin and Junggar Basin

Authors

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Abstract

In recent years, global warming and greenhouse effect get more and more attention. Carbon dioxide as a major greenhouse gas, to reduce its emission is especially important. CO_2 geological storage is one of the most direct and effective way to reduce its emission. Xinjiang region is the key area of west development, according to the requirements of the national 12th five-year plan, Xinjiang will be established oil and gas production base, refining base, petrochemical base, coal base, and develop SNG, coal to liquid feuls and coal-based polygeneration demonstration, therefore, CO_2 emission reduction will be very important. In order to ensure the long-term interests, to achieve sustainable of economic and social development, the CO_2 geological storage project in Xinjiang will be imperative. Tarim basin and Junggar basin are two of the largest basins in Xinjiang. And they play an important role in energy industry for their huge reserves of oil, natural gas and coal. This paper evaluated CO_2 geological storage potential and suitability of this two basins. CO_2 geological storage potential evaluation results show that the total CO_2 geological storage potential of tarim basin and junggar basin were 89450.45×106t and 6361.23×106t, very large. Jurassic reservoir is the most important reservoir of tarim basin, because its large CO_2 geological storage potential, good reservoir property and suitable buried depth; and the Jurassic, Triassic and Permian reservoir is major reservoir in junggar basin. The results of CO_2 geological storage suitability assessment show that tarim basin and junggar basin were suitable for CO_2 geological storage, and the suitability of tarim basin was slightly better than in junggar basin. Comprehensive consideration, the northern depression of tarim basin and the west uplift of junggar basin are the most suitable tectonic units for CO_2 geological storage. Finally, this paper after considered social and economic condition, carbon source distribution, road transport and economic benefit factors, selected Yakela-Shaya buried hill zone, Luntai-Erbatai buried hill zone of tarim basin and Dushanzi anticline, Changji anticline, Shanan anticline of junggar basin as suggested target areas for CO_2 geological storage.

How much CO_2 is stored and verified through CCS/CCUS in China?

Authors

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Abstract

Over last decade, Chinese government has funded several CCS/CCUS projects in CO_2 capture, CO_2 utilisation, CO_2 mineralization, CO_2-EOR and sequestration separately or in a full chain project. According to the statistics of The Administrative Centre of China's Agenda 21 (ACCA21) of the Ministry of Science and Technology of China, CCS/CCUS project funding accounts for 20% of the total CO_2 emission reduction project funding. How to evaluate the effectiveness of CCS/CCUS projects in reducing emissions has become the main concerns and a controversy among the Chinese government, industry and the scientific community. The emission reductions and costs achieved through CCS/CCUS have also been a matter of global concern.

If the CO_2 emission reduction achieved through CCS/CCUS technology was lower than that of renewable energy reduction technologies compared with the cost and amount of CO_2 emission reductions, it would lead to stagnating investment in CCS/CCUS technology and projects in the concerns of the government and industry.

Regarding the effectiveness of CCS/CCUS technology in reducing CO_2 emissions, many scholars compared it with renewable energy technologies in previous studies. In particular, comparing the effect of reducing CO_2 emissions from coal-fired or gas-fired power plants with CO_2 capture to investment in renewable energy, the premise here is that the captured CO_2 is completely stored underground, whether it is aquifer storage or oil reservoir storage through CO_2-EOR. Examples of CO_2 capture in electricity sector with CO_2-EOR and geological storage have been successfully demonstrated at Saskpower Boundary Dam and Petra Nova.

The most successful commercial CCUS projects are currently from low-cost capture such as coal chemical industry, combined with CO_2-EOR and storage. Such as the Weyburn project, its CO_2 emission reduction effectiveness is recognized by the public and can be commercialized in the long term.

CO_2 emission reduction achieved through CCS/CCUS project is also an important issue in the GHG emission reduction measurement methodology. CCS/CCUS incentive policy such as 45Q incentives works when the net reduction of CO_2 emissions is provided. This paper focuses on the evaluation the quantity of CO_2 stored underground when monitoring data is not sufficient. To sequester CO_2 permanently is the ultimate objective of CCS/CCUS project as well.

It is not easy to assess the exact amount of CO_2 geological storage of a CCS/CCUS project. It can be the most accurate when the fundamental measurement, monitoring, and verification (MMV) data of the project is perfect. However, in the absence of MMV data, it is not easy to estimate the volume of CO_2 that stored through CCS/CCUS projects. There is a great uncertainty in the assessment of CO_2 geological storage. However, such types of assessment are necessary and helpful to evaluate the CO_2 emission reduction effectiveness of CCS/CCUS implementation for the government and industry. It is also beneficial to the stakeholders to choose CCS/CCUS projects with good prospects to

corporate or invest.

This study combined with the CO_2 geological storage project implemented in China, proposed evaluation and judgment criteria for assessing CO_2 geological storage. Examples are given and combined the analysis of Gao 89 CO_2-EOR area of Sinopec Shengli Oilfield and CO_2-EOR area in Jingbian Oilfield of Shaanxi Yanchang Petroleum Group in China.

CO_2 storage capacity estimation through static reservoir modelling: a case study of the Lower Cretaceous Gage Sandstone reservoir in offshore Vlaming Sub-basin, Perth Basin, Australia

Authors

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Abstract

The Lower Cretaceous Gage Sandstone is a deep saline aquifer which is overlain by the regionally extensive Lower Cretaceous South Perth Shale seal in the offshore Vlaming Sub-basin, Perth Basin, Australia. This paper is focused on the CO_2 storage capacity estimation in the Gage reservoir by integrating both the well and seismic data. After a 3D grid system was constructed, well log interpretations, depth converted interval velocity and seismic relative acoustic impedance data were imported into the 3D grids. The volume fraction of shale was first constructed combining the neural networks modelling and residual stochastic simulation from the well and seismic attributes data. Porosity was modelled using sequential Gaussian co-simulation with the volume fraction of shale model. The CO_2 storage capacity was estimated using the total pore volume and storage coefficients in US-DOE methodology. The best estimate (P50) of carbon storage capacity in the Gage Sandstone reservoir is 493 million tonnes based on the static reservoir modelling.

An upgraded storage site model of the Shenhua CCS demonstration project

Authors

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Abstact

As the only project for CO_2 storage in deep saline aquifers in China, the Shenhua CCS demonstration project is of great importance in the geological storage of CO_2 in continental sedimentary strata. Despite achieving the designed injection goal of 302,000 tons, the demonstration project currently does not have a widely accepted storage site geological model because of the large overall thickness of the injection layers, low porosity and permeability, and high heterogeneity. Based on geological study of the storage site system, combined with vertical seismic profiling (VSP) seismic monitoring data, we used the well log-constrained seismic inversion method to predict the lithology, porosity and permeability of the storage site. We constructed a new 5 km × 5 km × 1.2 km site geological model centered on the injection well. Our new geological modeling method and the related reservoir parameters are innovative compared with previous studies and enhance geological understanding of the site, providing a reference for CO_2 migration reservoir simulation and deep geophysical monitoring in the future stages of the project.

The effect of WACO_2 ratio on CO_2 geo-sequestration efficiency in homogeneous reservoirs

Authors

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Abstract

Various factors such as reservoir temperature, wettability, caprock properties, vertical to horizontal permeability ratio, salinity, reservoir heterogeneity, injection well configuration affect the CO_2 geo-sequestration efficiency. Furthermore, it was previously investigated that CO_2 storage efficiency can be improved by using water alternating CO_2 (WA CO_2) technology. However, the effect of the WA_{CO2} ratio (the ratio of the total amount of injected CO_2 to the total amount of injected water) on CO_2 storage efficiency has not been addressed adequately. Thus, in this paper, a 3D homogeneous reservoir simulation model has been developed to study the impact of the WACO_2 ratio on CO_2 mobility and CO_2 trapping capacity using five different WACO_2 ratios (i.e. 3, 2, 1, 1/2, and 1/3). For all WACO_2 ratios tested, 9000 kton (kt) of CO_2 were injected during 3 CO_2 injection cycles (2 years each) and at an injection rate of 1500 kt per year. Each CO_2 injection cycle was followed by a 2 years water injection cycle with injection rates of 500 kt/year, 750 kt/year, 1500 kt/year, 3000 kt/year, and 4500 kt/year for the 3, 2, 1, 1/2, and 1/3 WACO_2 ratios, respectively. Then, this 12 years WA_{CO2} injection period was followed by a 100 years post-injection period. Our results clearly indicate, after 100 years post-injection period, that the WACO_2 ratio has an important effect on the CO_2 migration distance, CO_2 mobility and CO_2 trapping capacity. The results demonstrate that lower WACO_2 ratio leads to reduce the vertical CO_2 plume migration and CO_2 mobility. Furthermore, low WACO_2 ratio enhances the capacities of capillary and solubility trapping mechanisms. Thus, we conclude that WACO_2 has a significant impact on the geo-sequestration efficiency and less WACO_2 ratios are preferable.

Practice of CO_2 injection and storage in low porosity and low permeability saline aquifer

Authors

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Abstract

CCS technology is considered to be the single technology with the greatest potential for CO_2 emission reduction. The saline aquifer storage is considered to be the most potential technical route in CCS technology. If CCS technology is the main way to deal with climate change, CO_2 applications such as EOR, EGR, ECBM and other CO_2 applications will not meet the needs of carbon emission reduction in China, so the saline aquifer storage must be implemented. The geological features dominated by continental sedimentary basins have determined the direction of saline aquifer storage in China, and must face the problems of low porosity, low permeability, complex pore structure and many thin reservoirs and cover intervals. Therefore, it is of great significance to carry out the CO_2 storage technology in low porosity and low permeability saline aquifers in China. Shenhua CCS demonstration project is a full process demonstration project of 100,000 tons annual .High concentration carbon dioxide tail gas capture from coal chemical industry and inject in low porosity and low permeability saline aquifer. The project has solved the suitability of site, The possibility of injection of low porosity and low permeability saline aquife, safety of coal mine pressure overlay, and effectiveness of monitoring system through engineering practice.The successful completion of 302 thousand and 600 tons of injection mission, continuous monitoring system showed that the injected CO_2 did not have a negative impact on the geological structure of the demonstration site, underground drinking water, surface soil, and surface vegetation. The successful practice of the project has accumulated rich experience in engineering technology and project management in the storage of low porosity and low permeability saline aquifer. At the same time, it also found that the current laws and regulations are not perfect and the evaluation system is not perfect.

Fessibility for CCS-EOR in Ordors area in China

Authors

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Abstract

The vast basin of Ordos has stable geological conditions and possesses multiple reservoir-seal assemblages. Meanwhile, as Chinese energy and heavy chemical industry base, the basin possesses lots of CO_2 emission sources, such as, coal chemical plants, cement Plants, thermal power plant and so on. So it is necessary and meaningful to do the evaluation of potential and suitability of CO_2 geological storage in Ordos basin.

This paper use CSLF method to calculate the CO_2 storage potential in deep saline aquifers and coal fields; The CO_2 storage potential in oil and gas fields will be calculated through Ecofys method. Based on different geological units, the potential of CO_2 storage is computed at different media, strata, buried depth. The results are as follows: the potential of CO_2 geological storage in Ordos Basin is 22918.79 Mt; the potential of CO_2 storage over 3500 m is 22918.79 Mt; the potential of CO_2 storage in Deep saline aquifer, Gas fields, Oil fields, Coal fields, Jurassic, Triassic, Permo-Carboniferous and Ordovician, is 13318.09 Mt, 7120.9 Mt, 2787.4 Mt, 2316.6 Mt, 1726.34 Mt, 12580.07 Mt, 8907.43 Mt, 2329.16 Mt respectively.

This paper has determined the suitability evaluation index system of CO_2 storage in Ordos basin from geologic feature, reservoir-seal feature, geothermic feature, socio-economic feature and storage potential. According to this index system, CO_2 storage suitability assessment in Ordos Basin has been made. The evaluation shows that Yimeng uplift is comparatively appropriate, Weibei uplift is generally appropriate, Jinxi fault-fold belt is generally appropriate, Shanbei slope is appropriate, Tianhuan depressions is comparatively appropriate, fault-fold belt of west margin is generally appropriate.
On the basis of the evaluation of potential and suitability of CO_2 geological storage in Ordos Basin, this paper has analyzed the source/sink of CO_2, according to the CO_2 source distribution in Ordos basin.

At present, the most stable to implement CO_2 storage is the oil-bearing formation of Triassic in Shanbei slope; the comparatively appropriate is the deep saline aquifer of Permo-Carboniferous in Yimeng uplift and the oil-bearing formation of Triassic in Tianhuan depressions. Regarding qiaojiawa block of Jinbian oilfield, wuqiyougou block of Wuqi oilfield, tangshan block of Dingbian oilfield as a typical case, analyzing the suitability of CO_2 storage from carbon source, transport and storage.

Geospatial analysis of near-term potential for CCUS in China

Authors

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Abstract

With increasing international attention towards the expected consequences of global climate change, particularly among academic researchers and policy makers, an emerging technology, carbon capture, utilisation and storage (CCUS), is considered to have great potential in reducing carbon emissions and mitigating anthropogenic climate. Domestically, China's heavy reliance on coal, as well as its surging energy consumption and rapid economic development, have led the nation to currently rank first as the greatest gross carbon emitter globally. Given these circumstances, CCS may become the technological solution to meet China's energy needs and to mitigate its environmental concerns, while also enabling the country to move closer to a low-carbon future. In addition, with in excess of 2500 coal seam wells and extensive deep saline aquifers nationally, the domestic sequestration potential would enable the country to meet its full storage demand. Furthermore, opportunities for carbon utilisation, such as EOR (enhanced oil recovery) and ECBM (enhanced coal bed Methane), have the potential to significantly improve opportunities for oil and gas exploitation. For these reasons, CCS technologies have great strategic significance for China's carbon abatement and low-carbon economic development, with the Chinese government emphasizing its importance as a potential mitigation instrument nationally.

However, the future technical potential of CCUS remains uncertain. Two significant deployment barriers that have largely been overlooked by previous studies are the suitability of spatial colocation of suitable storage basins availability, in the absence of long-distance CO_2 transport. These conditions could constrain the near-term technical deployment potential of CCUS due to social and economic barriers that exist for CO_2 transport. To date, much of the academic discussion surrounding the feasibility of large-scale deployment of CCUS has focused on economic cost and the potential mitigation of CO_2 emission but has often neglected to consider the availability and characteristics of suitable storage sites for sequestration. Studies that have considered storage and injection rate capacity in the context of CCUS have considered only aggregated global or national storage and injection rate capacities. While global aggregated storage capacity is generally not considered a limiting factor for CCUS deployment, capacity of specific storage sites varies widely and may lead to regional storage constraints. Injection rate capacity, a function of the porosity, permeability, and thickness of the porous storage basin, is the annual CO_2 injection rate achievable in a single well in a storage site. Injection rates that exceed the injectivity of a particular storage reservoir increase subsurface pressures to unacceptably high levels and may create fractures in the cap rock, induce seismicity, or activate faults, making the project more prone to leakage and costlier to monitor. Although additional injection wells could, in principle, achieve similar injection rate capacities while minimizing such risks, drilling and subsequently monitoring more wells will drive up costs. As a result, storage sites with large injection rate capacity are most attractive for CCUS because they can sustain high CO_2 sequestration rates. Consideration of the storage and injection rate capacity of storage formations at a fine spatial scale is crucial in determining potential storage sites suitable for near-term CCUS deployment. In addition to the availability of suitable storage sites, the ability to transport CO_2 between the two resources can be an important factor that constrains the potential of CCUS. Studies assessing the complexities and cost of CO_2 transport have concluded that building new CO_2 pipelines

is a time consuming process that faces potential public opposition, and that economies of scale strongly favor building large pipelines compared with many smaller ones. Complex permitting required for building CO_2 transport pipelines is a time-consuming process. Strategically siting CCUS plants using high-resolution spatial data can help inform near-term opportunities that minimize social and economic barriers to CCUS deployment that arise from transportation constraints.

This study leverages site-specific injection and storage capacity estimates at high spatial resolution to assess the near-term deployment opportunities for CCUS in China. High-resolution spatial assessment as conducted in this study can inform near-term opportunities that minimize social and economic barriers to CCUS deployment.

CO_2 utilisation

Study on field -scale of CO_2 geological storage combined with saline water recovery: A case study of East Junggar basin of Xinjiang

Authors

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Abstract

Xinjiang is the major energy exporter in China, and it is also one of the regions with the most serious water resources scarcity issues in China. In particular, the coal-fired power and coal chemical industry base in East Junggar basin has faced severe carbon emission reductions and water shortages. There is an urgent need to seek a sustainable development mode. This paper takes the East Junggar basin as the research object. After collecting the seismic, well testing, well logging and their interpretations data, the 3D static geological model was built for the Cretaceous Donggou Formation reservoir in East Junggar basin of Xinjiang. Based on the 3D heterogeneous geologic model, the research of field-scale CO_2 enhanced water recovery (CO_2-EWR) was carried out in order to provide technical reference for the future field-scale CO^2-EWR engineering practice in Xinjiang to the solve carbon emission reduction and water shortage issues.

Nine combinations of CO_2-EWR mode were designed in the study, including three types of CO_2 injection and three types of saline water recovery. CO_2 injection mode: 1) constant rate injection for 50 years, 2) constant rate injection, when the reservoir pressure reaches the design value, injection stops, 3) constant pressure injection, and saline water recovery mode: 1) no pumping, 2) constant pressure Pumping, 3) constant rate pumping. When the output quantity of CO_2 in the production well reaches the design value, production stops.

The results show that the combination of CO^2 injection with saline water recovery can effectively increase the distribution of CO^2 in the reservoir, which greatly contribute to increase the potential and safety of CO^2 sequestration in deep saline aquifers, and at the same time can generate considerable groundwater resources. The 50-year CO^2 injection at constant speed combined with water exploitation mode can significantly reduce the pressure changes in the deep saline reservoirs, with a cumulative CO^2 injection of 50.01 Mt and a deep groundwater acquisition of 45.92 Mt. Constant-velocity CO^2 injection (stopping injection when the reservoir pressure reaches the design value) combined with water exploitation mode, the maximum CO^2 sequestration can be up to 70.86 Mt, the storage potential increases by 2.1 times, and if the exploitation is continued for 40 years, the deep groundwater resources can be acquired by 45.92 Mt. The constant pressure injection combined with the saline water exploitation mode can also effectively increase the storage potential of deep saline aquifers, with a maximum CO^2 storage capacity of 53.55 Mt. However, the constant pressure injection mode has a large amount of CO^2 injection in the early stage and the closure conditions of production wells were met in a relatively short period of time (14 years, or as short as 6 years), and the amount of groundwater resources was relatively small.

Comparing of the above schemes, it is recommended that the CO^2-EWR engineering practice be carried out with a constant rate of injection, which can not only obtain the maximum CO^2 injection volume and the maximum amount of water resources, but also be highly sustainable and in line with industrial production.

The CO^2-EWR project also has significant economic benefits. The treatment cost of the produced water is about RMB 5-7/ton while the industrial water price in East Junggar basin is about RMB 10/ton, and a large amount of salt resources can also be obtained (each ton of produced water can obtain salt resources 30-35kg) is used for industrial production.

CO^2 geological storage combined with saline water recovery can effectively open up reservoir space, reduce reservoir pressure accumulation, increase CO^2 storage potential and safety, and obtain abundant groundwater resources at the same time, with broad prospects for development. It is of great industrial and practical significance to carry out CO^2-EWR engineering and technology practice in the Xinjiang region.

Evaluation of the role of water-shale-gas reactions on CO_2 enhanced shale gas recovery

Authors

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Abstract

CO_2 enhanced shale gas recovery technology is promising in addressing global energy crisis and climate change by realizing the natural gas production and CO_2 geological storage at the same time. To explore the impact of CO_2-water-shale reactions on shale gas recovery and CO_2 storage potential, a simplified 2D reactive transport model was established. Results show that the geochemical reaction plays an important role in determining the feasibility of CO_2 enhanced shale gas recovery by influencing the shale gas recovery ratio and the formation conductivity. It is suggested to include the geochemical effect in the future study of CO_2 injection in shale reservoirs.

Synthesis and interfacial property of sulfonate surfactant for CO_2-foam

Authors

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Abstract

CO_2 Foam Flooding is a kind of proven and promising flooding technology in the present CO_2-EOR. One of the most important and effective composition is the surfactant. In this paper, a series of Daqing vacuum residual sulfonate have been prepared using the basic material of vacuum residue. The reaction conditions have been confirmed and the interfacial properties of vacuum residual sulfonate have also been investigated. Firstly, the vacuum residue from Daqing crude oils was separated into 17 fractions by the Supercritical fluid extraction and fractional (SFEF) technology, according to the average relative molecular. The chemical compositions, structure of the vacuum residue fractions were determined by means of UV, IR, element analysis and VOP. The oil-water interfacial tension was also studied. The results show that the interfacial tension of the Daqing vacuum residue fraction was 5 mN m-1 under the condition of 1% NaOH. And the light Daqing vacuum residue fractions correspond to the lower interfacial tension.

A series of Daqing vacuum residual sulfonate were prepared using the basic material of vacuum residue and 50% oleum. The effects of oleum/material weight ration, sulfonation temperature and sulfonation time on the product yield and structure were studied, and the process on the unreacted H2SO4 and neutralization was also discussed The results show that the product yield can be 31.2% when the oleum/raw material is 2.2, sulfonation temperature is 60℃ and sulfonation time is 2 h.The interfacial tension of primary and fine product was measured by JJ2000B spinning drop interfacial tensiometer. The mass fraction, salinity and alkali concentration of 0914# and DQ5 had also been investigated.

Competitive adsorption of carbon dioxide and methane in shale: experimental investigations by low-field nuclear magnetic resonance

Authors

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Abstract

In recent ten years, shale gas has become more and more popular in the world because of its reach storage and cleanliness compared with traditional fossil fuels like coal. On the other hand, the pressure of greenhouse effect urges us to find new ways to deal with carbon dioxide emission. As an important part in the Carbon Capture and Storage System, CO_2 is injected into the shale gas reservoir in order to enhance the gas production through competitive absorption between methane and carbon dioxide. In shale reservoir, carbon dioxide is much stronger in adsorption than methane, so the adsorption methane will be desorbed into the free phase by carbon dioxide. More shale gas is then produced by reducing its partial pressure during the production period. It is estimated that continuous carbon dioxide injection at overpressures of 8 MPa enhance gas recovery of 28.5% respectively over 30 years [1]. Moreover, in reservoir of high water sensitivity, CO_2 has its advantage for the limitations of hydraulic fracturing [2]. Thus, the technique of carbon dioxide displacement of the methane stored in the shale nanopores is of great significance for future exploitation of shale gas as well as the efficient application of carbon dioxide.

However, there is currently limited understanding of the mechanism of competitive absorption between methane and carbon dioxide, especially in nanopores under 10 nm, where how effectively carbon dioxide replace methane is of great importance for the production of shale gas. Although the similar mechanism in CO_2 enhanced coal bed methane (CO_2-ECBM) has been studied for many years [3], the research in shale gas has its unique challenge due to the ultra-low permeability and ultra-complex pore structures in the shale rock [4]. The traditional experiment investigation of adsorption process like volume method or weight method struggles in distinguishing the two phases of adsorption gas and free gas in nanopores. In addition, it can hardly tell the influence of different pore structures in shale to gas contents and adsorption capacity.

Here, we try to find an effective quantitative measuring method for gas adsorption. Low-field nuclear magnetic resonance (NMR) technique can meet our requirements of obtaining the scanning signal of free methane gas in nanopores. In the NMR system, the 1H atoms absorb energy from the electromagnetic radiation and jump to the high energy level. When the excitation is stopped, the atomic magnetic moment perpendicular to the external magnetic field will reduce to zero, which is called transverse relaxation. By the inversion of the relaxation time T2, the distribution of free methane in nanopores can be analysed as shown in Fig. 1.

Figure 1. T2 distribution of the CH_4 NMR signal after the adsorption process. The T2 relaxation time represents different pore size in general. The largest relaxation P3 peak represents the free phase methane in sample chamber. P2 peak represents methane gas in particle accumulation bed. P1 peak is caused by methane in cores in shale rock and its area represents the amount of free methane in sample. When the pressure goes higher, the peak moves right and the area increases.

Figure 2 shows the schematic diagram of experimental system in our lab. In our experiment, when opening the valve between two cavities, gas mixture of carbon dioxide and methane in different cavities will reach a stable equilibrium in several hours. By analysing the pressure change, we can

figure out the total quantity of mixture gas in shale samples including adsorption and free gas. Meanwhile, the amount of free methane content in the pore is determined by the area of peak measured by NMR. Also, by taking gas from sample cavity, the components of methane and carbon dioxide in the mixture gas are analysed by gas chromatography. Combining the above methods, the adsorption content of the two gases can be calculated.

Figure 2. Schematic diagram of experimental system. The two cavities are filled with mixture gas of CO_2 and CH_4. At some point, gas in two cavities reach a pressure equilibrium. The amount of free methane content in the pore is calculated by NMR. The components of mixture gas are analysed by gas chromatography.

The results show that the CO_2 injection can significantly enhance the shale gas recovery. When injecting CO_2, methane in large cores are first desorbed into the free state. As the adsorption experiment continues, methane in small cores are desorbed and the adsorption rate gradually reduces to zero. If carbon dioxide is adequate, CO_2 quickly reach saturated adsorption and the pore surface can hardly form methane adsorption, the adsorption volume of CO_2 is higher than methane in competitive adsorption. When temperature is higher, the equilibrium adsorption pressure increases, and the recovery of shale gas improves.

To sum up, more investigations and actions should be taken for carbon dioxide displacing methane. We introduce a new experiment way of isothermal shale adsorption by means of NMR, which can distinguish the adsorption state and the free state of methane. This work helps us to explore the mechanism of the competitive adsorption of carbon dioxide and methane in shale under different pressures or temperatures, which will be helpful to the CCS projects in the future.

Monitoring and sensor technologies

Evaluation of sensitivity of downhole temperature estimates from distributed temperature sensing measurements

Authors

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Abstract

A range of Australian CCS research activities (CO2CRC Otway Stage 3, CO2CRC Otway shallow controlled release and CSIRO Insitu-lab) involving subsurface characterization and/or CO_2 injection are at planning stage. Fiber optic sensing is considered as part of the downhole reservoir characterization and surveillance monitoring system for all these projects. Ahead of phase 2 of the CO2CRC Otway shallow CO_2 controlled release experiment, a DTS system was installed at the CRC 3 well for equipment testing and baseline characterization. In this work, we investigate the sensitivity of DTS for the detection of thermal anomalies in view of the design of future geological storage activities in Australia. Temperature measurements were acquired from well-head to total depth at a sampling of 25 cm for 13 days at a rate of one-minute measurement every 4 minutes. The temperature profile does not change significantly over time, the integration and processing of more than 3400 temperature traces enabled to estimate a temperature profile with a resolution of 0.01 °C. The use of DTS during the CO2CRC M5 survey highlights the detectability of a VSP tool producing 11 and 4 W at two distinct depth. The setup was capable of detecting a 0.7 °C anomaly very quickly. A smaller anomaly (0.1 °C) was detected with the benefit of data processing of the long term dataset. The high spatial resolution of the DTS enable to locate thermal anomalies (tool) within 2m.

Integrated monitoring of China's Yanchang CO_2-EOR demonstration project in Ordos Basin

Authors

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Abstract

As facing severe water shortage, carbon dioxide (CO_2) enhanced oil recovery (CO_2-EOR) is a helpless option in the coming large-scale development process of Yanchang Oilfield, the Ordos Basin, China. As a shining model of the carbon capture, utilisation and storage (CCUS), the CO_2-EOR is attracting much more attention than before. However, the leakage risk of sequestered CO_2 drives the interests in monitoring of the CCUS process in practice. The aim of our research is to develop an integrated monitoring scheme and to identify related key monitoring indicators for CO_2-EOR Demonstration Project at Yanchang Oilfield. In this paper, the detailed monitoring plan was tailored for the Jingbian CO_2-EOR Block in the Yanchang Oilfield according to the existing situation of monitoring technologies and project planning in China. The principles was also proposed for the selection of key monitoring indicators for CO_2-EOR activity.

On-line monitoring technology for internal corrosion of oil field

Author

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Abstract

In view of the fact that the internal corrosion of well bore is becoming more and more serious in the development of oil and gas fields in China, this paper develops an in-situ monitoring technology suitable for downhole deep corrosion rates, which including inductive corrosion probe, downhole data real-time transmission system, pressure and temperature sensor, etc. This paper introduced the development process of corrosion probe, the composition and function of each module. The device is based on the underground environment design. Through high temperature and high pressure test, the device can work steadily and reliably in the environment of 60 MPa and 125 ^{o}C. Using this device to measure the corrosion rate of 20# in urban tap water and compare with the data measured by the hanging sheet method, it is proved that the device can reflect the actual corrosion rate. The monitoring instrument has been tested in Sheng li oilfield, the temperature and pressure sensors can work normally, and the corrosion rate obtained is in line with the actual situation of the environment and achieves good results.

Anthropogenic emissions of atmospheric CH_4 and CO_2 using satellite observation over Tibet

Authors

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Abstract

The greenhouse gases emissions due to human activities are considered to be the major source of climate change. CH_4 is the second most important trace gas in the atmosphere and contributes about 18% of the total global warming whereas CO_2 has a contribution of 50%. The global warming potential of CH_4 is 25 times over CO_2 at the 100 years horizon. CH_4 is also the active participant in the process of atmospheric chemistry. The average lifetime of CH_4 in the atmosphere is 12 years, which is long enough to allow CH_4 transporting globally. The primary anthropogenic CH_4 sources are: fossil fuel combustion, rice, livestock, and landfills. The ruminants are responsible for 37% of anthropogenic methane emissions. Tibet has a huge livestock population, including cattle, buffalo, and yak. The livestock methane emission was estimated to account for 50% of the total agricultural methane sources.

A lot of previous studies had made direct measurements of the emission factors and estimated the CH_4 emissions from livestock with measured emission factors. Up to now, the spatial distribution and temporal variation of CH_4 emissions from livestock was made by considering only the variation of the livestock population. Space-borne observations of atmospheric CH_4 and CO_2 have been made using the Atmospheric Infrared Sounder (AIRS) on the EOS/Aqua satellite since August 2002. With the large spatial and temporal coverage, these satellite sensors provide complementary measurements with respect to surface and airborne observations of atmospheric CH_4 and CO_2. In this study, the AIRS data used is from AIRS level-2 version 6 supporting products AIRX2SUP.v006, downloaded at NASA Goddard Earth Sciences Data and Information Services Center (NASA/GES/DISC). Spatial and temporal analysis was statistically studied over Tibet.

The impact of water on CO_2 leak rate measurements for CCS projects

Authors

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Abstract

For regulatory compliance, environmental accounting and public assurance, it is important to demonstrate that any leaks that might arise in the case of breached CO_2 stores can be detected and quantified (Feitz et al., 2014, Dixon et al., 2015). This must be possible in a range of environments, both onshore and offshore. However, most approaches to detecting and quantifying CO_2 leakage have so far focused on dry terrestrial environments. For onshore stores, CO_2 could leak into water saturated environments e.g. it could dissolve into groundwaters (and perhaps emerge as a dissolved constituent of natural springs) or seep into water bodies such as lakes or rivers. Indeed, studies of onshore natural analogues and field sites find that CO_2 seeps are more likely to emerge in topographic low points (Roberts et al., 2014) where the water table is more likely to be close to ground surface. CO_2 leaking from offshore stores could emerge to seabed as bubble plumes that interact with the water column.

Quantifying CO_2 leakage is challenging; the majority of onshore CO_2 release experiments conducted around the world to date have found it problematic to estimate the proportion of injected CO_2 that leaked to surface (Roberts and Stalker, 2017). Similarly, the observations and challenges at the world's only offshore CO_2 release experiment, QICS, illustrated the need to develop and test techniques to measure and quantify the fate of injected CO_2 in the marine environment. This project highlighted the difficulties attributing and understanding the fate of injected CO_2 without chemical fingerprinting approaches (Blackford et al, 2015). It is therefore important to establish which methods would be most appropriate for calculating leakage into aqueous environments whether terrestrial or marine. Chemical tracers could be inherent, including isotopes of the CO_2, impurities in the CO_2 stream, or added chemicals. However, it isn't clear how such tracers will behave in the overburden or water column, nor how they may be sampled (Roberts et al., 2017).

To this end, we use a benchtop experimental setup to simulate gas leakage across the sediment-water interface of terrestrial water bodies, and into the atmosphere. The gas dissolution, leak distribution and partitioning of co-released gases is measured in these environments to explore how gas leak rates and gas fate can be usefully constrained, and the best approaches of doing so. For this study a known mixture of CO_2 and methane was slowly eluted into the water column using a calibrated mass flow controller. As methane is significantly less soluble in water than CO_2 in water, the effects of water on the measurements at the surface can be quantified and explained. We also explored the effect of sand (selected to mimic sands below seabed at QICS) on gas fate and ebullition. Through these studies, we have shown how experimental conditions affects the concentration and rate of change in concentration measured in the headspace. Our results show a significant depletion in the rate of increase in CO_2 relative to CH_4 compared to the composition of the gas mixture (i.e. as the experiment evolves the concentration of methane in the gas bubbles increases relative to the CO_2). Furthermore, we find that the presence of and thickness of sand and the overall flow rate have an effect on the style of seepage (continuous vs. periodic), the fate of the release gases and the concentration measurements in the headspace. We discuss the implications for how tracers may be used to quantify CO_2 leak rates in aqueous environments.

This work contributes to ongoing efforts to improve environmental monitoring techniques and provides a basis for understanding how bodies of water and/or sediment influence CO_2 leak style and monitoring outcomes. Methane is a natural component of many reservoir rocks, is a likely constituent of CO_2 from pre-combustion capture (Porter et al., 2015) and is present at trace levels in atmosphere. Methane could therefore act as a low-cost tracer that could aid identification, attribution and quantitation of leaked CO_2. However, preferred tracers include inherent CO_2 isotopes and noble gases (Flude et al., 2015; Roberts et al., 2017), which we will explore in future work.

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Multi-level CO_2 injection testing and monitoring at the South West Hub in-situ laboratory

Authors

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Abstract

The In-Situ Laboratory Project entails completing, instrumenting and pump testing five intervals in an existing well and injecting a small volume of CO_2 for testing purposes into the Lesueur Formation at the South West Hub project in Western Australia. The project commenced in the middle of October 2016 and is scheduled to run until the end of April 2019, with hydraulic testing and CO_2 injection planned towards the end of 2018. The purpose is to aid demonstration of the commercial viability of geologically storing carbon and contribute to broadening the portfolio of globally evaluated geological settings for storage via testing of a more than 1000 m thick injection reservoir in which CO_2 migration is largely governed by residual saturation and dissolution trapping. The project will develop the first part of an enduring research facility at the South West Hub to enable further research of a geological environment that has more uncertainty than many other current projects; i.e. in the case of the South West Hub there is uncertainty around the extent of a regional seal.

The effects of high soil CO_2 concentration on soil N_2O and CH_4 emissions — a field study

Authors

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Abstract

High soil CO_2 concentration induced by potential CO_2 leakage from CCS project would have altered surrounding ecosystem including plants, animals and microbes. While a number of studies reported negative effects of high soil CO_2 concentration on plant species, the effects on microbial community were not consistently reported. However, it was reported that microbial community was switched from aerobic to anaerobic species and N_2O and CH_4 emission were stimulated. As far we know, there is few studies which have focused on the processes and functional microbial groups. The objective of this study is to investigate the effects of high soil CO_2 on soil microbes and their interaction with plant and soil environment. An artificial gassing field study was conducted in Eumsung, Korea (36°57′44.2″N, 127°28′03.1″E). The soil is a sandy loam which consisted of 60% sand, 21% silt and 19% clay, with pH 5.3, total carbon 4.7 g kg-1 and total nitrogen 0.8 g kg-1. Total five plots of 2.5m×2.5m (length × width) were conducted. Three of five plots were used for CO_2 gassing treatment, rest of two control plots without injection were located 3.5 m away from CO_2 plots to prevent gas migration. Sweet potato (Ipomoea batatas L.) was selected and transplanted in each plot on May 17, 2017. Seedlings planted in ten rows × ten lines, to give 100 plants per plot. Urea fertilizer was applied on June 1 at a rate of 160kg ha-1 in each plot. After plants were established, pure CO_2 was delivered from a tank and injected into plot center via an injection pipeline at a constant rate of 3 L min-1. The end of the pipeline was inserted into the soil at the 0.5 m depth at a 45˚ angle to the vertical, to ensure the releasing holes located at the plot center. CO_2 injection started from June 20 to July 20, 2017, to have 30 days' injection period. We expected different effects in the low CO_2 zone (beyond 1.7m from injection point) and high CO_2 zone (within 0.5m from injection point). Four sampling points were set up at the low CO_2 zone, high CO_2 zone and control in each plot. Soil CO_2 and O_2 concentration, moisture, N_2O and CH_4 flux were measured at 0, 1, 3, 7, 17, 29, 37 days after injection. Soil inorganic nitrogen (ammonium and nitrate), pH, amoA genes of ammonia-oxidizing bacteria (AOB) and ammonia-oxidizing archaea (AOA) which were involved in nitrification process, methyl coenzyme M reductase (mcrA) gene for methanogens and particulate methane monooxygenase (pmoA) gene for methanotrophs were selectively analyzed. Above-ground biomass within a 0.2 m^2 quadrat area was collected at each sampling point at the end. Mean soil CO_2 concentration in the low CO_2 zone was 5.3% and that in the high CO_2 zone was 52.2%. While mean CO_2 concentration in controls was 0.3%. Mean soil O_2 concentrations in the low CO_2 zone was 18.8% and that in the high CO_2 zone was 10.5%. Soil pH was not altered by CO_2 injection. Soil water-fill pore space (WFPS) ranged from 3% (0 day) to 40% (29 days) due to monsoon rains. Plant leaves turned red after 7 days of injection in the high CO_2 zone and those plants died at 29 days. Soil ammonium contents decreased in control plot and the low CO_2 zone, while that was remained in a high level at the high CO_2 zone due to absent of plants (r2= -0.55, P<0.001). The overall trend of AOB and AOA populations were increased during the experimental period. However, gene abundance of AOB was significantly lower in the high CO_2 zone than those in the low CO_2 zone and control at 29 days. This indicated that prolonged CO_2 injection could have negative effects on ammonia-oxidizing microbes. The gene abundance of methanotrophs showed a decreased trend in all treatments during the experimental period. While the gene abundance of methanogens in CO_2 plots increased at 7 days and maintained until the end of experiment, compared to the control. The N_2O and CH_4 emissions in CO_2 plots were significantly increased after 1 day of

injection, especially in the high CO_2 zone, compared to the control. These stimulation effects were supported by high correlation between soil CO_2 and the emission of N_2O and CH_4 gases. However, those effects on two gasses emission occurred at a different time period after CO_2 injection. The maximum values of N_2O emission were observed 47 times higher in the high CO_2 zone than control at the early stage of 7 days, it did not continue at 17 and 29 days of injection. Stimulation effect on N_2O emission could be originated from the enhanced nitrification process which utilizes CO_2 as C source, and it was not explained by soil pH, high soil ammonium and water level at 29 days. Prolonged CO_2 exposure negatively affected the abundances of ammonium oxidizing microbes might be the reason of this subdued stimulation effect. At 37 days, although the injection was stopped for 7 days, soil N_2O emission was still higher in the CO_2 plots than control due to the higher substrate of ammonium. On the CH_4 emission pattern, the maximum values were observed 240 times higher in the high CO_2 zone than control at 17 days, high soil CO_2 concentration and high WFPS induced anaerobic microsite which was in favor of methanogens might have explained this stimulation effects at that day. The microbial processes related to N_2O and CH_4 emission were stimulated by high soil CO_2 concentration and these effects were observed earlier than those on plants and microbial population (DNA level). However, the stimulated effects on N_2O emission did not continue with the prolonged CO_2 injection. The gene copy numbers of ammonium oxidizing microbes could be lowered by high soil CO_2 concentration and that of methanogens could be increased. The inhibition on plant absorption would be increase the ammonium substrate for N_2O emission. CO_2 leakage from CCS project could lead to secondary effects of increasing greenhouse gas emission of N_2O and CH_4.

Characterization of environmental drivers controlling the baseline of soil surface CO_2 flux using Wavelet-based multiresolution state-space model and Wavelet denoising

Authors

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Abstract

Multivariate environmental time series including soil surface CO_2 flux (FCO_2) have non-stationarity and mutual interdependence, and thus the i.i.d assumption-based conventional regression techniques inevitably lead to spurious regression or lose the dynamic characteristics in the process of variable transformation. In this paper, we adopted a wavelet threshold technique for our newly developed wavelet-based multiresolution state-space model (MRSSM) to overcome these limitations and to quantitatively evaluate the environmental drivers (EDs) controlling the baseline of FCO_2. First, the structural characteristics and the potential EDs (PEDs) of FCO_2 were explored by wavelet denoised (threshold) SSM for complex environmental observation data. Then, the major EDs (MEDs) were identified using the scale localized correlation and the wavelet coherence analysis between PEDs and observation data. Next, the contribution of MEDs to FCO_2 was quantitatively evaluated by calculating the effective dynamic efficiency using the wavelet energy ratio of the maximum-correlation time-frequency bands. Finally, the effectiveness of the wavelet threshold method for MRSSM was discussed. The proposed wavelet denoising method is expected to improve the performance of MRSSM which is effective to identify, evaluate and predict the main environmental factors inherent in the observation data from complex environmental systems where physicochemical and biological processes of various spatio-temporal scales occur simultaneously.

Geochemistry, leakage risks and faults

CO_2 saturated brine injected into fractured shale: An X-ray micro-tomography In-situ analysis at reservoir conditions

Authors

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Abstract

Fracture morphology and permeability are key factors in enhanced gas recovery (EOR) and Carbon Geo-storage (CCS) in shale gas reservoirs as they determine production and injection rates. However, the exact effect of CO_2-saturated (live) brine on shale fracture morphology, and how the permeability changes during live brine injection and exposure is only poorly understood. We thus imaged fractured shale samples before and after live brine injection in-situ at high resolution in 3D via X-ray micro-computed tomography. Clearly, the fractures' aperture and connectivity increased after live brine injection.

Experimental study of supercritical CO_2 injected into water saturated medium rank coal by X-ray MicroCT

Authors

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Abstract

Carbon dioxide geosequestration into deep unmineable coal seams is a technique which can mitigate anthropogenic greenhouse gas emissions. However, coal composition is always complex, and some minerals such as calcite chemically react when exposed to the acidic environment (which is created by scCO_2 mixing with formation water). These reactive transport processes are still poorly understood. We thus imaged a water-bearing heterogeneous coal (calcite rich) core before and after scCO_2 injection in-situ at high resolutions (3.43 µm) in 3D via X-ray in-situ microCT flooding system. Indeed, the calcite-coal mixed layer was partially dissolved, and absolute porosity and connectivity significantly increased. We thus suggested that such process could be used as an acidizing method in CO_2 ECBM. However, such dissolved damage also can significantly affect the rock mechanical properties and potentially induce geohazards.

Theoretical analysis and pore-scale experimental study of drying effects of CO_2 injection into deep saline aquifer

Authors

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Abstract

Injectivity is an important determinant of CO_2 geological storage and influences the storage capacity significantly. When the dry carbon dioxide is injected into the formation, the water in the formation will continue to evaporate, eventually causing the solution to super-saturation and consequently precipitation. The formation of precipitation in the pores could reduce the porosity and permeability of the reservoir and ultimately damage the injection of carbon dioxide. Many investigations on drying effects of CO_2 were performed in the recent years. However, the results were quite different and the influence of drying-out on the porosity- permeability relationship has not reached a consensus yet. Furthermore, the mechanism of precipitation and the evaporation kinetics of water were lack of further research. Such as, it needs to be better understood the effects of evaporation rates on salt precipitation behavior. Therefore, it is a crucial issue to study the evaporation kinetics of water under different reservoir and carbon dioxide injection conditions.

In this paper, a theoretical model of water evaporation and salt precipitation during CO_2 injection was established. The model gives the distribution of water vapor in different formation conditions, carbon dioxide injection parameters and the distance from injection well. According to this model, we can give the relationship between the evaporation rate and the spatial location under different conditions. Thus predicting the spatial location of salt precipitation. In addition, pore-scale micromodel visualization experiment has been carried out to verify the reliability of the model. The micro-model, coupled with the appropriate fluid-driven and control system and optical visualization system, can clearly observe the precipitation position of salt and the entire nucleation and growth process during water evaporation. Microfluidic chip is the experimental section of the pore scale visualization experimental system, Fig.1 is the microfluidic chip used in this study. The effect of temperature, solution salinity and injection parameters on the evaporation rate of water was studied through the experiments.

According to the theoretical model, it can be found that the evaporation rate of water increases with the increase of the flow rate of carbon dioxide (318K), and the greater the rate, the farther the water evaporates (fig.2). This is because the greater the speed of carbon dioxide, the water vapor that evaporates from the water is rapidly taken away by the carbon dioxide, reducing the accumulation of moisture, thereby increasing the evaporation rate.Therefore, it can be inferred that the larger the area where salt precipitation occurs. As can be seen from Fig.3(a), the saturated concentration of water vapor in carbon dioxide increases with increasing temperature because the saturated vapor pressure of water is a single-valued function of temperature (0.01m/s). Fig.3(b) shows that the higher the formation temperature, the greater the evaporation rate of water, but the formation temperature will not affect the salt precipitation area. The results of micro-model visualization experiment are consistent with the theoretical model results. The larger the evaporation rate, the more salt precipitation and the salt tends to precipitate at the gas-liquid interface and grow to the CO_2 phase, which may damage the injection significantly. On the contrary, the salt is more prone to be uniformly precipitated in the residual solution when the evaporation rate is much smaller.

We established the theoretical model to elaborate the evaporation kinetics of water under different reservoir and carbon dioxide injection conditions, which has a very significant theoretical guidance on the site selection and operation control of the actual engineering of carbon capture and storage.

Assessment of pore characteristics in Janggi conglomerate using micro-focus CT image analysis

Authors

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Abstract

This study was conducted to access pore characteristics of Janggi Conglomerate for evaluating carbon dioxide (CO_2) storage efficiency and its stability using micro-focus X-ray CT (computed tomography) image analysis. The Janggi conglomerate collected at a depth of 960 m at the Janggi basin, which is targeted to demonstrate an onshore CO_2 injection project. By utilizing micro-focus X-ray CT scanning, 2,183 CT images for core sample of which the pixel size was 62.1 μm× 62.1 μm and the dimension was 1,024×1,024 were obtained. In order to improve accuracy and precision of the analyses, the sequence of cropping and filtering processes was conducted to improve the raw CT images. Next, the segmentation process between pores and grain-matrix was conducted by varying the threshold CT value until acquiring reasonable match between experimentally determined porosity (16.1%) and the porosity calculated from CT images.

Absolute (16.70%) and effective porosity (16.10%) were quantified from the volume ratio of all pores and only connected pores relative to the total core volume, respectively. In addition, the profiles for both absolute and effective porosity were predicted along the longitudinal axis. Especially, differences between two porosities were distinct only within the grain-matrix dominant section within the highly heterogeneous conglomerate core. The 3-D rendering technique for effective pores and isolated pores was conducted. In addition, the number of effective pores was counted in the Janggi core where 105,268 pore chambers were existed. An individual analysis of pore chambers revealed that an average pore volume was 0.167 mm^3 and the volume of 91.4% of pore chambers were less than 0.5 mm^3.Furthermore, the size of pore throats was assessed to evaluate CO_2 storage stability.

Finally, the tetrahedral meshes delineating pore structures were developed from X-ray CT images, and the intrinsic permeability was quantified by directly solving Navier-Stokes equation. The calculated intrinsic permeability was 4.045×10-11 m^2, and also revealed small degree of anisotropy.

This study confirmed that both pore characteristics and associated microscopic fluid behavior can be evaluated efficiently by using micro-focus X-ray CT image analyses. The future studies will include modeling of multi-phase fluid flow to evaluate the maximum CO_2 storage capacity.

Effect of fracture on gas migration, leakage and CO_2 enhanced shale gas recovery in Ordos Basin

Authors

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Abstract

Although the CO_2 enhanced shale gas recovery (CO_2-ESGR) have been studied to respond to energy shortage and climate changes, previous studies have not examined the effect of fracture on the process of gas migration and leakage. Therefore, this study presents a 3-D numerical model base on geological data of Ordos basin. Results show that the leakage of CH_4 happens at the beginning of shale gas production in SGR scenario, and the injection of CO_2 in CO_2-ESGR scenario may increase the leakage of CO_2 and inhibit the leakage of CH_4. To further study the factors affect the gas migration and leakage process, three different CO_2 injections rate and fracture permeability are choose to evaluate the process. Results show higher injection rate will make the leakage of CO_2 easier. And the higher permeability of fracture can result in the smaller maximum CH_4 gas saturation of the upmost grid in shale layer closest to fracture (grid A) and larger of that in lowest grid in aquifer closest to fracture (grid B).

The CO2CRC Otway shallow CO_2 controlled release experiment: preparation for Phase 2

Authors

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Abstract

CO2CRC is undertaking a feasibility study for a planned CO_2 controlled release and monitoring experiment on a shallow fault at the CO2CRC Otway Research Facility. In this project we plan to image the migration of CO_2 up a fault from a controlled release point at approximately 30 m depth using a diverse range of geophysical and geochemical CO_2 monitoring techniques. This paper describes the results of site characterisation and modelling work undertaken to date. It also includes a description of the activities planned that will enable for a more detailed characterization of the fault and proposed injection interval. Together these results will enable an assessment as to whether the planned injection experiment is feasible and how it can be optimally designed.

Risk assessment for CO_2 leakage and associated secondary contaminations in portable aquifer

Authors

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Abstract

CO_2 leakage from designated deep reservoirs could induce to secondary contamination at upper shallow aquifers. Leaked CO_2 dissolves into ambient groundwater and develops CO_2 plume characterizing low-pH. Within the low-pH plume, the toxic heavy-metals preserved in aquifer minerals could be released, which induced secondary geochemical reactions. The goal of this study is to understand behavior of mobilized arsenic species under the subsurface environments when leaked CO_2 was released to the shallow aquifer.

Arsenic is considered to be one of carcinogenic species when human-being is chronically exposed during a long period. For this reason, it is necessary to evaluate the relationship between the amount of leaked CO_2 into the shallow portable aquifer and a degree of released arsenic. For this purpose, 2D multi-species reactive transport models were developed and simulated CO_2 leakage processes in the shallow groundwater aquifers. In addition, sensitivity analyses were conducted by varying ambient groundwater velocity, CO_2 leakage rate, sorption rate of arsenic, and geologic heterogeneity. Finally, health risks for human-being through variable exposure pathways were quantified in conjunction with sensitivity analysis from reactive transport modeling, which aids to evaluate a list of geologic parameters enhancing human health risk.

Methodologies for improved fault risk assessment: examples from the CO2CRC Otway project

Authors

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Abstract

During the development of a carbon capture and storage (CCS) project, scientists and managers must carefully evaluate and attempt to quantify the various uncertainties and risks associated with gas injection in the subsurface. One of the potential risks associated with such projects is the behaviour of subsurface faults, when subjected to buoyant CO_2 gas at pressures that are greater than those prevailing pre-injection. Elevated fluid pressure within a fault zone reduces the effective normal stress on the fault plane and therefore reduces the shear strength required to activate fault slip. If a fault is already supporting a significant shear stress magnitude, then only a small or moderate fluid pressure increase will be required to shift the fault from the stable field to the unstable. An unstable fault, otherwise referred to as fault reactivation, has important implications, from the potential generation of seismicity to the creation of new fluid pathways which can mobilise CO_2 to unwanted areas in the subsurface. Furthermore, even in cases where fault reactivation does not occur it is important to gain some understanding of how the fault will behave when exposed to CO_2 gas, mainly in terms of its vertical and lateral flow properties.

In this study, we review the various techniques that have been used to assess fault properties at the CO2CRC Otway Project, aimed at constraining static models and also minimizing operational risk. This work has been done as part of the CO2CRC projects into storage research. The CO2CRC Otway Research Facility is located in south-western Victoria, Australia approximately 300 km southwest of Melbourne. To date there have been three different operational stages, each of which have involved faults to one degree or another. The specific workflows applied to faults at the Otway Project can be categorised into the following focus points:

- Characterisation of the local contemporary in situ stress tensor and associated fault stability modelling
- Determination of fault mechanical properties such as friction and cohesion using rock mechanical testing techniques
- Characterisation of fault transmissibility and permeability using the shale gouge ratio algorithm and juxtaposition relationships

The likelihood of fault reactivation is controlled by the shear/normal stress ratio on the fault plane (a function of the fault's orientation with respect to the in situ stress field), and the frictional and cohesive properties of the fault plane. To conduct any meaningful geomechanical assessment, it is critical to have an adequate understanding of the in situ stress field, which encompasses the magnitudes and orientations of the three principal stresses. The stress regime at the Otway Project site was determined to be normal faulting, with a maximum horizontal stress direction of 142°, which is consistent with regional measurements. In early work, there was a poor constraint on fault friction and cohesive properties, which led to weak and strong fault hypotheses being tested. These modelling scenarios showed portions of the faults that would have a greater propensity for reactivation based on their orientation and also indicated the allowable pressure build up under best and worst case

scenarios. Using such models, various CO_2 injection tests were able to proceed with some fair understanding of the underlying fault mechanical stability.

In Stages 2 and 3 of the Otway Project, the target formation for the injection tests was the shallower Paaratte Formation, which is a saline aquifer, in which there was a lack of understanding of how faults would affect the migration of CO_2, both laterally and vertically. The potential for CO_2 flow across the main reservoir-cutting faults was therefore quantified using the shale gouge ratio algorithm. Results indicated that the faults should be sealing to some degree and should therefore restrict the lateral movement of CO_2. A dynamic simulation characterizing the potential for CO_2 flow vertically through the Naylor South splay fault indicated that a very limited volume of CO_2 gas would migrate up the fault. According to dynamic simulations of a deliberately leaky fault, CO_2 is only able to migrate 10s of metres vertically after 100 years, which is still more than 350 metres below the top of the Paaratte Formation. These findings were broadly confirmed by time lapse seismic results that were able to track the CO_2-roch plume immediately following injection.

Most recently, the fault mechanical properties that introduced some uncertainty to the early fault stability models have been revisited via a rock mechanical testing campaign. A continuous high-resolution record of unconfined compressive strength (UCS) was determined through the scratch testing technique along approximately 80 m of CRC-2 core. Multiple correlations between UCS and several different wireline log suites resulted in the development of a strength proxy that could accurately predict strength and lithologic transitions. The strength proxy was then applied to a section of the CRC-1 well which traverses the Naylor South splay fault. The proxy predicts a UCS of approximately 20 MPa for the splay fault, which is a central learning as it constrains a key parameter that is used in fault stability modelling. A number of triaxial rock mechanical tests were also conducted to complement the scratch testing and also characterise the poroelastic properties of the various units. UCS and stiffness of the rocks appear to be positively correlated, albeit with significant data scatter and data gaps at moderate strength values. Finally, the triaxial tests were extended deep into the post failure domain so that the frictional evolution of fractured specimens could be examined. It was found that all the Otway lithologies exhibit velocity strengthening frictional behaviour. This suggests that fault movement in a reactivation scenario should exhibit aseismic behaviour, which is favourable from an operational perspective. The workflow developed in this latest study provides a more accurate and higher resolution mechanical framework at potential CCS sites and provides a predictive methodology for mechanical properties when actual mechanical tests may be absent.