International Journal of Mining Science and Technology 27 (2017) 307–314

Contents lists available at ScienceDirect

International Journal of Mining Science and Technology

journal homepage: www.elsevier.com/locate/ijmst

Sorption behavior of coal for implication in coal bed methane an overview

Manasi Manjari Mohanty [a,*], Bhatu Kumar Pal [b]

[a] N.I.T., Rourkela 769008, Odisha, India
[b] Mining Engineering Department N.I.T., Rourkela 769008, Odisha, India

A R T I C L E I N F O

Article history:
Received 24 May 2015
Received in revised form 27 August 2015
Accepted 12 October 2015
Available online 22 February 2017

Keywords:
ECBM
Greenhouse gases
Sequestration
Adsorption and desorption
Porosity and permeability

A B S T R A C T

CBM has been recognized as a significant natural gas resource for a long time. Recently, CO_2 sequestration in coalbeds for ECBM has been attracting growing attention because of greater concerns about the effects of greenhouse gases and the emerging commercial significance of CBM. Reservoir-simulation technology, as a useful tool of reservoir development, has the capability to provide us with an economic means to solve complex reservoir-engineering problems with efficiency. The pore structure of coal is highly heterogeneous, and the heterogeneity of the pores depends on the coal type and rank.

1. Introduction

The effect of increasing atmospheric carbon dioxide (CO_2) concentration on global warming is now recognized as one of the most important environmental issues facing society. The connection between anthropogenic emissions of CO_2 with increasing atmospheric CO_2 levels and temperatures has been well-established and well-accepted. To stabilize atmospheric levels of greenhouse gases (GHGs) while minimizing the world economic impact, four options are being explored, which project the use of (1) less carbon intensive fuels, (2) more-energy-efficient methods, (3) carbon sequestration, and (4) increased conservation. A successful stabilization program for atmospheric GHGs will, most likely, involve all four options. To counteract the effect of increasing GHGs in the atmosphere during the 21st century, the U.S. Department of Energy (DOE) has established energy research and development programs in carbon sequestration science. This direction complements two long-standing program options directed toward generating energy in the future using (1) less carbon-intensive fuels and (2) more-energy-efficient methods to develop a "pathway to stabilization" of carbon emissions. A U.S. DOE office of fossil energy report 1 (and the wealth of international references within) provides an overview of the potential methods that have been suggested as routes to carbon sequestration.

Our proposal is applying CO_2 sequestration combined with enhanced production methods to enhance coal bed methane production. In order to find out the best techniques for CH_4 production and CO_2 sequestration, simulation works turn out to be a good candidate for analyzing and estimation. Thus, the literature review focuses on the theories and strategies of CO_2 sequestration, production enhancement and simulation works for coal bed methane reservoirs.

2. CO_2 sequestration

CO_2 sequestration is responsible for declining global warming. CO_2 as a major component of greenhouse gas is the biggest contributor to global warming. Thus, in order to control the climate change due to excessive CO_2 venting, several countries have signed an agreement to reduce CO_2 emission. One of the potential techniques to control excessive CO_2 emission is the CO_2 sequestration. CO_2 sequestration is a technique which permanently stores CO_2 in deep geological formations without emitting out to atmosphere. In practical, CO_2 sequestration can be categorized into three groups [1]. First, a sequestration depends on environmental conditions called biosphere sequestration. For example, soil, forest and ocean ecosystem are members of it. Second, a sequestration consists of natural reservoirs named geosphere sequestration. Coalbeds, depleted oil and gas reservoirs, deep aquifers and reservoirs fit for enhanced oil recovery (EOR) belong to this group. Third, a

* Corresponding author.
E-mail address: manasi9705@yahoo.co.in (M.M. Mohanty).

http://dx.doi.org/10.1016/j.ijmst.2017.01.014
2095-2686/

sequestration is defined as material sequestration which is storing CO_2 into artificial pools.

Among these techniques, CO_2 sequestration into coalbed is regard as a promising possibility to safely store CO_2 at relatively low costs. Injecting CO_2 into coalbed brings about two benefits. One benefit is that coalbed is a good medium for CO_2 sequestration. Due to gas storage mechanism of coal dominated by adsorption, coalbed has a stronger affinity to CO_2 than CH_4 [2]. Thus, CO_2 will be adsorbed in coal matrix without emitting out. The other benefit is injecting CO_2 into coalbed can be considered as a kind of gas flooding. Therefore, it would enhance coalbed methane production by displacing the desorbed CH_4 to production well. Then, the extra production of CH_4 offsets the costs of CO_2 sequestration.

According to Sing et al. [3], there are three types of pores in the coal mass: micro pores (<2 nm), mesopores (2–50 nm) and macro pores (>50 nm). The combination of micro pores (small intra-aggregate pores, which are controlled by deposition and lithification) and macro pores (inter-aggregate pores, which are controlled by fracture, fissures, and jointing) is called the dual porosity system of coal mass. Normally, micro pores occupy 95% of the coal mass porosity and control the gas sorption capacity in the coal mass. On the other hand, macro pores control the permeability of coal mass. Although carbon dioxide sequestration process in coal is greatly affected by coal gas permeability, the effect of CO_2 on coal mass permeability has not yet been confirmed. Especially for low rank coals, only few studies can be found [4–7]. In case of Victorian brown coal, although many studies have been conducted for water permeability [8], very few studies can be found related to the effects of CO_2 on permeability variation. One recent study related to the effect of CO_2 on coal permeability for Victorian brown coal has been carried out by Viete and Ranjith [5], who explained the simple expected behavior of coal gas permeability with axial load. According to them, coal gas permeability for CO_2 movement first decreases with applied load due to pores coming closer to each other and then with fracturing this permeability starts to increase rapidly with applied load and then coal gas permeability starts to decrease with the applied load due to cracks coming closer to each other. Although many studies can be found related to permeability with CO_2 injection for coal [9,10], there has been no good experimental study related to the effect of supercritical CO_2 injection on it. A number of factors affect coal gas permeability such as gas type, matrix shrinkage, pore volume compressibility, effective stress, and coal mass properties.

3. Structure of coal

The origin, formation, and structure of coal have been studied and an enormous amount of literature is available [11]. Coal is an extremely heterogeneous material consisting of organic matter, mineral matter, moisture, and a complex pore network. It is generally accepted that the organic portion of coal was formed from concentrated deposits of swampy organic matter originally derived from terrestrial plants. (60) Plant structures (leaf, stem) were converted into coal through complex biological, chemical, and geochemical processes driven initially by selective microbial action and later by the temperature and pressure generated by overlaying sediments over several hundred millions of years. The organic sedimentary rock is composed of these fossilized plant remains called macerals and mineral inclusions. The macerals are the microscopically distinct areas in coal and are mainly classified as vitrinite, liptinite, and inertinite [12]. Vitrinite is derived from woody plant material and is the most common maceral. Liptinite is formed from lipids and waxy plant substances whereas the inertinite probably originates from char formed by prehistoric pyrolysis processes, such as forest fires. The process of conversion of the plant matter into lignite, bituminous coal, and anthracite is called "coalification". During the coalification process, large volumes of volatiles principally CH_4, CO_2, and water were liberated [13]. Although CO_2 is more strongly adsorbed to the coal matrix than the other volatiles, it is more easily dissipated because of its solubility in the water present throughout the coalification [14]. Therefore, CH_4 is the dominant gas in coal beds (about 95%) [15].

Higher rank coals typically contain more CH_4 [16] and the various coal ranks in increasing order are: lignite, subbituminous, high volatile bituminous, medium volatile bituminous, low volatile bituminous, semi-anthracite and anthracite [17]. Because large quantities of water are released during the maturation process, coals are typically water saturated. In addition, fractures, known as cleats, form perpendicular to bedding during the coalification process and these are the primary permeability mechanism within coal [16]. The more continuous, primary cleats are called face cleats and the secondary cleats, orientated orthogonal to the face cleats, are called butt cleats.

Through-going cleats formed first and are referred to as face cleats; cleats that end at intersections with through-going cleats formed later and are called butt cleats [18,19]. Although fractures in coal are relatively unimportant in strip mining, their significance in efficient design and safety of underground coal mines has continued to command the attention of the mining industry [20–22].

Cleats are sub vertical in flat-lying beds and are typically oriented at right angles to stratification even where beds are folded. In many cases cleats are confined to individual coal beds, or to layers composed of a particular maceral type. Commonly they are uniform in strike within an outcrop or core and arranged in sub parallel sets that have uniform regional trends [23]. Yet they locally show abrupt lateral and vertical shifts in strike [24]. Coals containing closely spaced faults rather than opening-mode fractures are apparently rare. This reflects either proximity to large faults, reactivation by slip on pre-existing cleats. Coalbeds are characterized by their dual porosity: they contain both primary (micro pore and mesopore) and secondary (macro pore and natural fracture) porosity systems. The primary porosity system contains the vast majority of the gas-in-place, while the secondary porosity system provides the conduit for mass transfer to the wellbore. Primary porosity gas storage is dominated by adsorption. The primary porosity is relatively impermeable due to small pore size. Mass transfer for each gas molecular species is dominated by diffusion that is driven by the concentration gradient. Flow through the secondary porosity system is dominated by Darcy's flow that relates flow rate to permeability and pressure gradient.

4. Coal characteristics under CBM and ECBM conditions

4.1. Adsorption isotherms

CO_2 sequestration rate in coal depends to a great extent on its adsorption and desorption processes. The methods, which can be used to determine amount of gas adsorbed into coal mass, can be divided into two categories: direct and indirect methods. (1) In the direct method, the volume of gas released from the coal seam into a sealed desorption canister is measured. (2) In the indirect method, adsorption isotherms are used and gravimetric, manometric and chromatograph methods are used to find the adsorption isotherms, which are the plots between the adsorbed amount and pressure at a particular temperature. Up to date, most of the studies related to gas sorption in coal have been done basically for high rank coals and very few studies can be found for low rank coal. Among these studies, some studies have been done for Victorian brown coal. Berkowitz and Schein [25] obtained methanol adsorption isotherms using coal samples taken from the Bacchus