Direct Injection of Flue Gas into Coal Seams for Carbon Storage and Methane

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ABSTRACT

This paper describes the potential for enhanced coal bed methane production and CO_2 storage through the direct injection of flue as into virgin coal seams.

- The current deployment of horizontal well bore drilling technology is about to unlock a significant new source of natural gas from coal in the UK
- Recovery of natural gas from coal may be greatly enhanced by the direct injection of raw flue gas into coal
- The process of raw flue gas injection will result in CO_2 entrapment within the coal
- Carbon dioxide's affinity for coal is such that once injected it will remain trapped
- Coal has the capability to be a clean energy source and a net extractor of carbon from the environment
- Coal has the potential capacity to provide a significant contribution to the UK's future CO_2 storage needs to meet the UK Government's Energy White Paper targets
- A privately funded research programme to assess the suitability of the central Scotland coalfield for a pilot flue gas injection scheme is underway

1 INTRODUCTION

Carbon capture technologies and geological capture and storage have largely been focused upon use in enhanced oil recovery, storage in depleted hydrocarbon reservoirs or natural aquifers (Ref 1,(2). All of these techniques involve purification and processing of the CO_2, transport and subsequent injection. Unfortunately disposal in this way is costly and consumes energy, with the only benefit being small incremental hydrocarbon recovery where the injection is deployed in former oil reservoirs. The longevity of the CO_2 trapping mechanism is also questionable when the geological pressure seal has been breached by wells which, in their abandoned state, may not be able to maintain a seal indefinitely (Ref. 3).

Coal offers a new and significant source of natural gas in the form of coalbed methane (CBM). CBM exists naturally in coal where it adsorbs onto coal surfaces and within the coal micropore system. The presence of this gas can be hazardous during mining operations and has been well documented over many years. CBM has grown to become a significant source of gas in North America over the last 10 years, currently supplying in excess of 8% of total US domestic gas production. Significant coal reserves and associated gas reserves exist in the UK and, whilst some well drilling has been completed, these reserves have largely been underestimated and have not been successfully exploited to date.

Coal's ability to adsorb gases is not limited to methane. Coal has a much greater affinity for carbon dioxide, CO_2. Coals vary in their relative affinity for CO_2 but will typically adsorb between 2 – 3 times (Ref. 4), and up to 6 times, more CO_2 than they will adsorb methane. Furthermore, CO_2's affinity for coal is such that it will displace trapped methane within the coal micropore space, effectively enhancing extraction of methane from coal. Once adsorbed to the coal it becomes very difficult to displace it i.e. the CO_2 becomes trapped. This property of coal means it has the potential to extract more CO_2 than is generated from the methane it gives up; in other words coal can both provide energy in the form of natural gas and be a net extractor of CO_2 from the environment.

In essence coal offers a medium which:

- Can provide a source of natural gas
- Can adsorb and trap CO_2
- Has the potential to provide an energy source and be a net extractor of CO_2 from the environment

2 COAL BED METHANE (CBM)

The presence of natural gas in coal has been well known to the coal industry since mining began but has only recently been developed as an energy resource its own right. Over the last 10 years coal bed methane developments have flourished in North America where today gas extracted from coal makes up over 8% of US domestic gas consumption.

In its natural state methane is held within the coal micropore structure and is released by relieving pressure on the coal. This allows the methane to diffuse through the micropore structure until it reaches natural fractures or cleats in the coal. Connecting to these cleats is the key to good productivity in conventional CBM wells. The ease by which methane is able to diffuse from the micropore structure depends on molecular forces and is a function of the coal's affinity for methane.

Gas may be present in varying quantities in coal and the quality and thickness of the coals varies enormously. In the US, coals of all types have been developed successfully to produce gas commercially. Generally the technology employed is to access the gas with conventional vertical well bores which are either cavitated or fracture stimulated to enhance the flow properties of the coal. Gas does not flow readily from coal and the normal production method is to drain the coals of their naturally occurring formation waters using beam pump or electric pump technology. Removing the formation water reduces the pressure in the coal and this leads to the release of gas which is gathered at each well bore and collected by simple low pressure gathering networks on surface.

In the UK there is a significant untapped coal bed methane resource. Several attempts to explore for and develop coal bed methane have followed the US approach and although a number of the wells drilled in the UK have achieved gas rates equivalent to those in North America (typically 3000 m3/d), this has been insufficient to justify widespread development – the reasons for this were primarily the higher cost base for drilling in the UK, the presence of more stringent planning requirements and because of different energy market conditions.

The development of new technology particularly in the area of horizontal drilling is about to radically change the commerciality of coal bed methane in the UK. Horizontal wells have now been drilled all over the world in the oil and gas sector and some of the most challenging of these have been achieved offshore in the UK. The technology behind these wells was once prohibitively expensive for marginal onshore developments but this has changed markedly over the last 5 years. Horizontal drilling is now being employed in Australia and the US in coal to develop more marginal CBM plays where the coals may be thin or of low permeability. Essentially a horizontal well can achieve a much greater exposure of coal than a vertical well by increasing the area of coal available for flow. This leads to higher production rates and an accelerated depletion of the gas within the coal. Both factors significantly improve the commerciality of coal bed methane developments.

DTI estimates of CBM potential in the UK have been put at 30 billion m3 (Ref. 6). These are extremely conservative and do not correspond with the British Coal estimates of remaining UK coal in place of some 190 billion tonnes (Ref. 5). Gas in place associated with this estimate of coal tonnage could be in excess of 1 trillion m3.

3 ENHANCED COAL BED METHANE (ECBM)

Conventional CBM development involves the recovery of primary gas from coal by reducing the naturally occurring formation pressure within the coal formations. Not all the gas is recovered because significant quantities remain entrained in the micropore structure of the coal. However, it is possible to enhance the recovery of methane by displacement using an alternative gas having a much greater affinity for the coal. Laboratory experiments and field pilot studies have shown that carbon dioxide (CO_2) is capable of displacing methane from the matrix, thereby enhancing the short term production and long term ultimate recovery of methane gas from coal.

There have been three major pilot studies in recent years which have taken place and for which a large amount of public data is available. These are:

Alberta Research Council:
Fenn-Big Valley Pilot Study, Alberta Canada (7)

Burlington Resources:
Allison Unit, St Juan Basin, New Mexico, USA (4)

BP-Amoco:
Tiffany Unit, St Juan Basin, Colorado, USA (4)

In addition a further privately funded project, RECOPOL (8), is currently ongoing in Poland.

Although there are a number of outstanding technical issues identified and uncertainties regarding certain scientific explanation of what was recorded, these studies concluded that methane recovery could be enhanced by the injection of CO_2 and, furthermore, that a CO_2 / N_2 mixture offered improved overall results technically (in terms of injectivity) and commercially (acceleration of reserves and improved ultimate recovery).

All the above referenced studies only considered conventional vertical or deviated wells where the coals are well understood. However the increased potential of employing a similar approach with horizontal well technology has not yet been attempted and this would appear to be a logical next step, particularly where CBM

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development is more challenging due to either modest coal thickness and/or permeability.

The enhancement of methane recovery from coal using carbon dioxide also clearly offers a further potential benefit: CO_2 storage (9).

4 CO2 CAPTURE AND STORAGE

Initially in the laboratory and subsequently in field studies it has been demonstrated that CO_2 has a much higher affinity for coal than the naturally occurring methane. When introduced under pressure CO_2 will adsorb onto the coal surface and diffuse readily into the micropore structure displacing methane as it does so. The capacity of the coal to adsorb CO_2 is a function of the coal type but various laboratory measurements have indicated that coal can adsorb between 2 and 6 times more CO_2 than the methane it gives up. This is an attractive property for two reasons. Firstly, CO_2 should act as a very effective displacement gas for enhanced recovery of methane from coal and, secondly, the coal clearly has a considerable capacity for adsorbing CO_2 which can be measured.

A key question in considering any potential geological trapping medium is how well the CO_2 is trapped and whether future release of the CO_2 is possible. In conventional reservoirs it is proposed to store CO_2 at many thousands of pounds pressure in its pure form. The storage capacity is limited by the pore space ultimately available as well as geological connectivity of that pore space within the reservoir. The trapping mechanism is good so long as the abandoned well bores which were used to inject the CO_2 never leak. Failure of the cement used to plug the wells or tectonic activity affecting the integrity of the cement seals could potentially result in leakage. Research is ongoing to evaluate the longevity and long term effectiveness of such cement plugs (Ref. 3).

In coal the storage and trapping mechanism is very different. Because CO_2 is stored at a molecular level coal has a much greater capacity to store CO_2 per unit volume of 'rock'– it is not limited by the physical pore spaces within the reservoir rock matrix. More importantly however, is the fact that once adsorbed to the coal it becomes bound by molecular forces and, as a result, is very difficult to remove; effectively it becomes trapped. This is a very attractive property from a sequestration point of view and has been demonstrated in the field. Wells where CO_2 has been injected have been back flowed and whilst they initially flowed some CO_2, the flow was dominated by methane which had been displaced by the adsorbing CO_2 – the bulk of the CO_2 had become trapped within the coal (Ref. 4).

The only uncertainty is over the impact large volumes of trapped CO_2 would have on the properties of the coal and its potential use later, either for mining or gasification purposes. If CO_2 injection was limited to deep unmineable coal this is unlikely to be an issue. Gasification involves the partial combustion of the coal and the production of CO_2 anyway – clearly the trapped CO_2 would add to the volume produced – but this would likely be a future environmental issue and not a technical one.

5 FLUE GAS INJECTION

Two of the main pilot studies previously referred to have focused on CO_2 as a displacement gas for enhanced coal bed methane production, primarily because of its known high affinity for coal. Pure CO_2 is not always readily available, however, and conventional sources (e.g. combustion products) require processing, conditioning and often transport if it is to be used in its pure form.

Nitrogen, or N_2, is a gas with a lower affinity for coal than that of methane which makes it behave differently when in contact with coal. The ready availability of flue gas, and its high N_2 content has led to an interest in how the combination of nitrogen and carbon dioxide would behave when injected directly into coals. Power station flue gas is typically 15% CO_2, 85% N_2.

The field trial in Alberta (Ref. 7) looked at employing pure CO_2 and different combinations of N_2 and CO2 (artificially generated flue gases) to evaluate enhancement of methane production from the coals and also the potential for CO_2 sequestration.

What these field trials indicated was that the presence of nitrogen improved the effectiveness of the secondary recovery – this was believed to be because the N_2, being less inclined to adsorb to the coal, flowed more rapidly into the cleat structure, 'stripping' methane from the cleat surfaces by reducing the partial pressure to methane within the natural fracture system. It also appeared to sustain cleat permeability by counteracting the effect of coal swelling induced by the adsorption of the CO_2 witnessed in the earlier, pure CO_2 trials. Experiments with different combinations suggested a 50/50 mix of both gases was optimum. A N_2 dominated gas injection stream (typical raw flue gas) would be more readily injected but would likely result in early, possibly premature, N_2 breakthrough at the production wells. This was technically undesirable but not necessarily a commercial obstacle.

Of course the ideal mix of gases in terms of their suitability for enhanced methane production and CO_2 storage will be a function of the coal type. Furthermore all the pilot studies completed to date have only been deployed in conventional vertical well completions. A horizontal multi-lateral well configuration would radically change the volume of coal exposed and the manner in which the well bore interacts with the cleat structure of the coal. Such a configuration could dramatically change the optimum gas composition in terms of maximising either enhanced methane production / recovery or CO_2 sequestration.

Finally, the Alberta project used artificially generated flue gases in its pilot field trial. The NOx and SOx gases present in normal flue gas were not present and yet their consideration in any practical application is very important. How these acid gases interact with the coals and their impact on the coal if they are readily adsorbed would need to be considered and tested in any future laboratory evaluation or field pilot test.

6 FUTURE WORK PROGRAMME

There is little doubt that coal in the UK offers a new and exciting potential source of natural gas for the future. It also offers a very serious option for storage of CO_2 in sufficient quantities to play a significant role in meeting the UK Government's carbon abatement targets beyond 2020.

Initial pilot studies in North America have demonstrated the potential in this area and have highlighted the possible advantages of deploying raw flue gas to achieve this. However, none of this field work to date has considered the use of horizontal well technology, which could provide a very considerable advantage in terms of exposing much larger surface areas of coal, greatly facilitating the CO_2 adsorption process. This has the potential to be a breakthrough technology.

A privately funded research project has been established to investigate the technical feasibility of injecting flue gas into coal for enhancing methane recovery and the potential for CO_2 storage. This project proposes to conduct research into the optimal horizontal well drilling and ECBM production strategy, to establish the fundamental knowledge necessary for the assessment and design of the enhanced methane recovery process and to determine the potential for CO_2 storage.

A combination of laboratory scale micro and macro structure investigations are being undertaken along with field scale numerical modelling of the response of the CBM reservoir to CO_2 and flue gas injection for enhanced coalbed methane recovery and CO_2 storage using horizontal wells. Although the research will target coals in the central Scottish coalfield, this work will form the basis of a set of standard test and reservoir modelling procedures that can be performed on any coal resource to determine its methane, enhanced methane and CO_2 storage potential.

Five key areas will be studied:

(1) Comprehensive review of the deposition history of the coals in central Scotland, in situ reservoir properties and the stress regime in the selected CBM/ECBM licence areas

(2) Coalbed methane reservoir flow properties for ECBM and CO_2 storage including permeability response to CO_2 and flue gas injection

- Matrix shrinkage/swelling due to pure and mixed gas sorption
- The effect of matrix swelling/shrinkage on permeability of coals under simulated reservoir conditions (confining stress and pore pressure):

(3) Coal micro structure, gas/mixed gas adsorption and CO_2 coal interaction research for the coal seams relevant to the selected CBM/ECBM licence areas

- Porosity, pores size distribution and pore surface area
- Characterisation of the sorption behaviour of CH_4, CO_2, N_2 and their binary and ternary mixtures in coals
- to measure the kinetics of displacement of CH_4 by CO_2 (relevance to enhanced methane recovery)
- To determine the kinetics of CH_4 release in a simulated flue gas environment (relevance to enhanced methane recovery)
- To determine the total CO_2 adsorption potential of the coals tested

(4) Mechanical and elastic properties of coals

- Young's modulus, Poisson ratio and cleat volume compressibility

(5) Horizontal well performance assessment for ECBM and CO_2 storage: Field design and optimisation of drilling and production strategy

- A parametric study of the effect of CBM reservoir characteristics, injected gas type and well parameters on horizontal well performance
- A study of the nature of flow and production in a number of horizontal well configurations:

This research work is currently underway and is expected to be completed towards the end of 2008. The results are expected to support a commitment to a field pilot stage

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which will entail the drilling of several horizontal wells along with pilot flue gas injection facilities. The UK's second largest coal fired power station situated in the central belt of Scotland could potentially provide a convenient source of flue gas for a future pilot scheme.

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