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Measurement of coal permeability using large samples

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ABSTRACT: A project being undertaken by a multidisciplined group at The University of Queensland is described. The project is examining fundamental aspects of coal seam methane and the scope of the various project sections is outlined. Coal bed methane flow into mine openings or drainage networks is strongly influenced by the seam property of permeability. Representative measurement of permeability must take into account aspect such ground stress, gas pressure, existence of water and structures within the coal. Laboratory measurements of this property have often in the past been undertaken on small diameter (<25mm diameter) core. An approach to large sample permeability testing is described based on the use of HQ (61 mm diameter) core tested in a permeability cell. This apparatus allows both axial and transverse core loading. Permeability is tested under varying gas pressures in either axial or transverse directions. Transverse testing allows permeability in flow paths parallel to coal plies to be established in core from holes drilled across the seam.

1 INTRODUCTION

Potential methane gas extraction from coal seams is dependent on many factors. Important considerations relate to the origin of the gas, the form in which it is stored within the seam, flow mechanisms and production technology. A multidisciplined group within The University of Queensland is attempting to gain a fundamental understanding of gas and coal seam properties through an interlinked study involving disciplines of engineering, surface chemistry and geology.

An overview is given of this project and the approaches being undertaken to gain a better fundamental understanding of Queensland's and Australia's coal seam methane resources. Emphasis is placed on the project component devoted to gaining a better understanding of coal permeability. Methane flow into mine openings or drainage networks is strongly influenced by the seam property of permeability. Representative measurement of permeability must take into account aspects such as ground stress, gas pressure, existence of water and structures within coal. Laboratory measurements in the past have most frequently been undertaken on small diameter cored samples. An approach to large sample permeability testing is described based on the use of HQ sized (61 mm diameter) core tested in a permeability cell. The apparatus allows both axial and transverse core stress loading. Permeability is tested under varying gas pressure in either core axial or transverse directions.

2 PROJECT STRUCTURE

This broad project examining fundamental aspects of coal seam methane is being undertaken by The University of Queensland through the Departments of Chemistry, Earth Sciences and Mining and Metallurgical Engineering under the administration of Uniquest. Principal support has come from a major grant from the Queensland Electricity Commission. The Energy Research and Development Corporation have made a substantial grant to the project. A number of Queensland resource companies are involved in the project through provision of financial support and newly drilled coal seam core. Overall direction is given to the project through the proposing of the questions:

1. What geological and geochemical conditions predispose coal to gas generation?
2. What is the source of the gas?
3. How and where is gas stored and retained?
4. When and how is gas released from site?
5. How can this knowledge be used to increase coal mine safety and predict (commercial) gas production?

The approach taken is that all participants undertake research on coal samples from the same source to allow cross interpretation between the various disciplines.

coal seam gas formation and the role of macerals in gas generation and retention. Also, the chemical compositions (C, H, N, O) of coals, individual macerals and their pyrolysis products and coal seam gases are being measured to place additional constraints on models for gas generation from coals.

The objectives of the gas storage and transport understanding project phases are:

1. To identify the site specific storage and release characteristics of gas in coal at the molecular level.
2. To identify the transport mechanisms of gas in coal at the molecular level.
3. To measure and gain an understanding of the transport of gas in coal at the macroscopic level.

Achievement of these objectives involves measurement of sorption isotherms using gravimetric techniques. A second phase involves the measurement of gas movement and storage using a series of high technology techniques including static and dynamic secondary ion mass spectrometry, electron spin resonance, diffuse reflectance Fourier transform infrared spectroscopy, atomic force microscopy and cross polarisation 13 C nuclear magnetic resonance. The samples in this study are to be progressively transferred between the sorption apparatus and the various instruments while maintaining the environment.

The macroscopic phase involves block and large diameter core sample multiphase permeability measurement. Large sized coal samples are being used to represent the behaviour of coal in the mass where formation structures and stress induced planes and fine discontinuities play a part in determining flow within the permeability measurement apparatus. Samples are returned to stress conditions found in the field. Gas pressure across samples is so applied to simulate a drainage cycle as though gas production was underway. Porosity and other related fluid mechanics property tests will be undertaken. It is to the details of coal permeability testing that a major section of this paper is directed.

5 PERMEABILITY MEASUREMENT

The principal approach taken to large sample permeability is to test large diameter core in a laboratory cell. Samples utilised are core sections obtained from field drilling programmes which have been desorbed. Samples are HQ size (61 mm diameter). Samples are prepared by cutting a length of about twice the diameter (about 120 mm) and finishing ends. Coal sample often shatter easily. This approach is generally more successful in delivering an intact core sample than the alternative of attempting to drill out a core from a block sample in the laboratory.

The laboratory permeability and associated control system core testing was designed by Sigra Pty Ltd. Fig. 2 shows a section view through the permeability cell in the axial direction. In use, the cell is placed in a load frame which allows loading representative of ground stress in the axial (or vertical) direction to be applied.

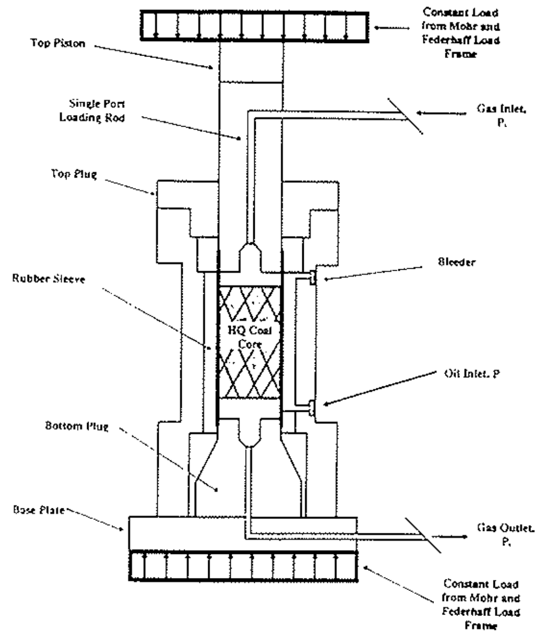

Fig. 2. Axial permeability test cell.

The core sits within a rubber sleeve. Hydraulic load is applied to the outside of the sleeve to create lateral force on the core representative of ground stress in the horizontal direction. The test gas passes through an orifice in the top loading rod piston and through a diffusion plate on top of the specimen. It leaves the cell through a similar arrangement at the bottom after having passed through the test core.

An extra feature of the cell design is its ability to undertake permeability tests in the transverse direction on the same specimen that has had axial direction tests. The transverse direction tests cell as shown in Fig. 3 uses a double port loading rod. Inlet gas passes through one of these ports and is led to copper braid which lies in two strips running vertically on opposite faces of the core (set 180° apart). The copper braid (material used for earthing strap on a car battery) is a web matrix of fine copper wire enclosing air filled interconnected spaces. The test gas passes down the braid along the length of the core under pressure and then permeates across the core to an identical braid arrangement on the opposite face. The test gas then flows up the braid and up through the gas outlet port in the loading rod. Tests are undertaken under triaxial load conditions to represent ground stress.

3 BACKGROUND

Underground coal mining practice has been forced to develop strategies for combating methane and other seam gases which permeate into the workings. Methane is explosive across the range of about 5 to 15 per cent in air at standard temperatures and pressures. As a first defence, mine ventilation air is used to dilute any gas to a safe working level (1.25 per cent at the working face under Australian practice). There are limits to the capacity of ventilation systems to handle the problem where high flows exist and so forms of methane drainage technology have been developed. These involve use of extraction boreholes placed approximately horizontally in seam in advance of workings, inclined holes drilled from underground to capture gas in overlying or underlying strata and vertical holes drilled from the surface.

Increased energy costs in the 1970s and these mine safety considerations initiated consideration being given to use of coal seam methane as an energy source. Initial developments occurred in the US relying on well established petroleum industry technology. Considerably success has been achieved commercially in extracting seam gas in the Black Warrior and San Juan Basins in North America to the point where a significant industry is in place.

Australia has a major domestic and export coal industry with over 90 per cent of extraction from the Sydney and Bowen Basins. Parts of both of these Basins carry coal with high methane contents which have led to difficulties with mine safety in underground extraction. Forecasts of coal seam methane resources in these Basins have calculated vast reserve figures which may potentially exceed national conventional gas resources (Anon., 1994). Furthermore, these energy resources lie close to major population and industrial centres in New South Wales and close to expanding industrial centres on the Queensland seaboard.

Various commercial producers, consultants and research groups have undertaken studies and production trials over recent years in both the Sydney and Bowen Basins. Results have been mixed, apparently due to the differences in geological and geotechnical conditions from areas being successfully exploited in the US. The current University of Queensland project is attempting to interlink understanding of the various complex factors that influence the presence and flow of methane through a multi-disciplined approach.

4 PROJECT DESCRIPTION

The project is divided into three principal sections:

1. Acquisition of test core and initial desorption studies.
2. Studies on gas generation and retention.
3. Studies on gas storage and transport.

A number of Queensland companies holding coal exploration or mining leases have agreed to give freshly drilled core for use within the project. Pressure tested stainless steel canisters to hold HQ size (61 mm diameter) have been constructed. Newly drilled fresh core of approximately 300 mm length is placed under water in these canisters on field sites for transport to Brisbane. Normally a number of core lengths through the seam are taken as drilling intersects coal and a number of intersected seams are sampled from the same hole. On arrival in Brisbane, cores remain within the canisters and desorption rate is plotted. Gas released is collected in "wine cask" bladders held under water with volume measured through water displacement. This process avoids problems of gas loss in solution. Gas is then analysed through gas chromatography. Desorption usually takes about one month. A typical desorption plot is shown in Fig. 1. Core material is then available to be used intact or in a crushed form for the remainder of project tests.

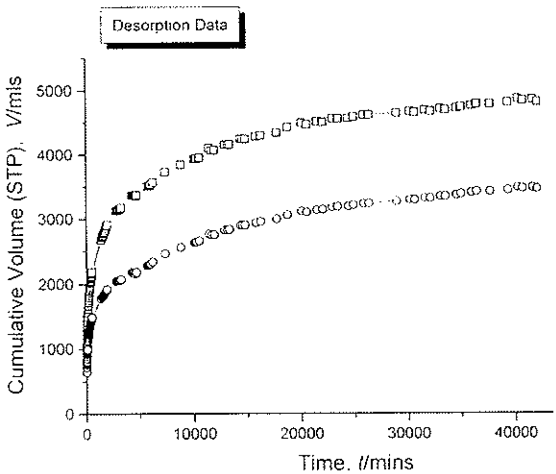

Fig. 1. Desorption data from HQ coal core.

The objectives of the gas generation and retention understanding project phase are:

1. To identify the constituent of coal that are responsible for gas generation.
2. To identify the mechanism of gas generation.
3. To gain an understanding of the physio-chemical changes which occur in coal during gas generation.
4. To identify likely movements of gas within the seam and stratigraphic sequences.

Achievement of these objectives involves the use of optical and transmission electron microscopy to determine the precise rank of coal and the role of individual maceral groups in gas generation and retention. Laboratory simulation of the processes of in-seam hydrocarbon generation in sedimentary basins by maturation experiments are to be undertaken. Measurement of the stable carbon and hydrogen isotope compositions of individual hydrocarbons of coal seam gases and pyrolysis products of coals and individual macerals is being undertaken to establish the processes responsible for

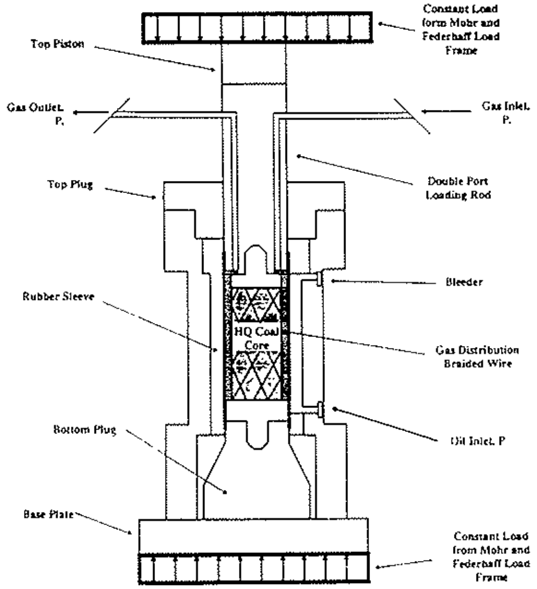

Fig. 3. Transverse permeability test cell.

The bottom plug of the test cell has been designed to allow strain gauge wires to be led into gauges attached to the core specimen. Up to 9 strain gauges can be used, configured in both axial and transverse directions

The cell can be used in a number of loading modes. It is the intention of this project to reproduce as accurately as possible the in situ conditions. To do this the coal sample can be resorped with gas, saturated and brought up to in situ virgin stress. Then to simulate drainage the fluid pressure can be lowered producing both water and gas. Whilst doing this the vertical load can be held constant so as to represent overburden load. Through the use of strain gauges, lateral strain can be maintained by changing the confining load. This represents the actual situation that exists in a laterally extensive coal seam. The importance of the effect can be seen in the increasing rates of permeability that occur during drainage. This phenomena is theoretically explained on the microscopic scale by Gray (1987) and will hopefully be explained on the molecular and macroscopic scale by this project.

To allow accurate permeability test results to be obtained, tests on low value specimens will be undertaken over extended periods, necessitating automation of the process. Fig. 4 sets down a schematic diagram of the permeability cell with flow measurement and control arrangements.

A data acquisition card senses transducer readings for computer storage. Key features are as follows:

1. The Mohr and Federhaff hydraulic load frame applies a constant load in the axial direction.

2. The pressure of test gas from the high pressure cylinder is read from a dial gauge and recorded by transducer before delivery to the cell. Gas pressure difference across the test specimen can be adjusted and is recorded by a differential pressure transducer (that is, outlet gas pressure does not have to be set at zero gauge pressure). Test gas is collected in a bladder in water so that volume flow is calculated from water displacement readings. Gas flow is also recorded by a flow sensor transducer.

3. Moisture in outlet gas is measured by means of a micro-balance. A constant volume pump can be set to add moisture to the gas input line to simulate groundwater conditions.

4. Strain gauge wires are connected to amplifiers and thence to the computer. Changes in these reading activate software which alters the transverse hydraulic load on the specimen to maintain constant load in this direction.

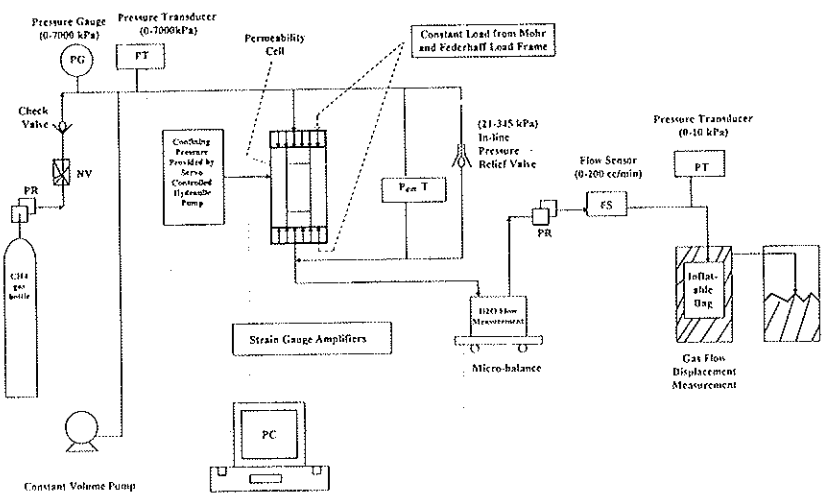

Fig. 4. Schematic diagram of relative permeability testing apparatus.

The permeability cell when loaded weighs in excess of 50 kg. A special loading table and lifting device has been constructed to assist in setting the cell into the load frame. The complete laboratory assembly is housed in an air-conditioned room to maintain standard test conditions.

The permeability cell has successfully proved that it can measure a parameter essential to the calculation of methane flow through the ground. It has the ability to test large sized specimens, vary simulated ground stress conditions in all directions, incorporate water saturation features, test flow in the directions parallel to and across or normal to coal plies and undertake tests over extended periods under automated operating conditions.

5 CONCLUSIONS

An overview of a research project being undertaken at the University of Queensland into fundamental aspects of coal seam methane has been given. The project is multi-disciplined and the scope of each section has been briefly discussed. The design of a new test cell for permeability measurement has been discussed. This new approach allows measurements to be undertaken on the same specimen in both axial and transverse directions. Variations in important ground condition aspects can be simulated and complete data acquisition and control features are incorporated for automated operation.

ACKNOWLEDGMENTS

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