The Application of Production Testing to the Assessment of Potential Water Flows in Coal Seams

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ABSTRACT

A prototype production tool capable of operation in the hole sizes (<100 mm dia) commonly used in Australia for coal lease evaluation is described. Examples are given of its application, with typical data and a discussion of the appropriate methods of data reduction. The results of analysis of production tests are compared with results obtained from other techniques.

INTRODUCTION

Current Australian practice for groundwater investigations conducted from the surface during the evaluation of coal leases revolves predominantly around the use of various types of pumping (drawdown) tests, and, to a lesser extent, packer (injection) tests.

Pumping tests may be very appropriate for the assessment of the bulk quantity of water potentially required to be handled from open pit mines, and in some cases, from underground mines. Such tests are not necessarily selective enough, however, to allow discrimination of specific aquifers in a sedimentary sequence, necessary for the proper evaluation of the impact of mining on the groundwater regime. Another drawback is that existing technology generally requires the use of hole diameters larger than those commonly employed for evaluation of coal leases destined for underground mining.

In light of these limitations, packer tests have been introduced into the evaluation of underground mining prospects. Packer tests lend themselves to application in small diameter holes and are an attractive means of gaining information on the permeabilities of specific units. A fundamental drawback to such tests is, however, that they involve injecting water into the horizon under test at a pressure in excess of the natural piezometric pressure, in contrast to the direction of flow accompanying the development of mine workings.

Production tests (Drill Stem Tests (DST)) have been a common part of the evaluation of oil and gas wells for many years. Their ability to simulate flows in the direction of interest (toward a low pressure "sink" such as represented by mine workings) from specific target horizons makes them a potentially valuable means of obtaining information necessary for evaluation of underground mining prospects. The main reasons for the lack of widespread use of production tests to date in the assessment of mining properties would appear to be the relatively large holes required for the equipment commonly employed in the oil and gas industry. This paper deals with the development and initial application of a tool allowing the conduct of production tests in holes less than 100 mm diameter.

PRODUCTION TEST TOOL AND ANCILLARIES

The normal test configuration employed with the tool is shown in Figure 1 and the principle of operation in Figure 2. The system is essentially capable of the same function as a conventional DST tool, but with adaptations aimed specifically at compatibility with normal coal exploration drilling practice. All instrumentation necessary to produce the required data is contained within the tool, providing "real-time" information at the surface during a test. This feature is not generally available with conventional DST testing, but has been found essential, in the author's experience, for adequate test control.

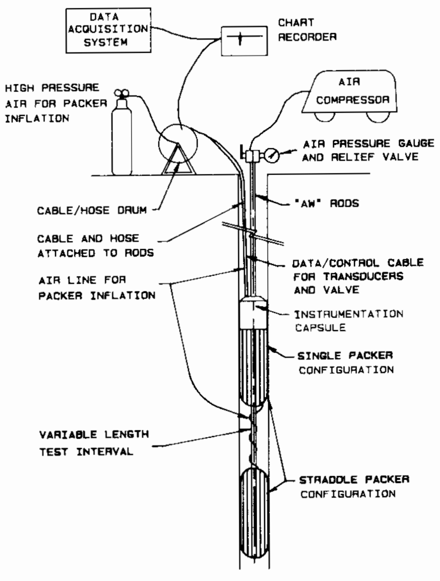

Fig.1. General arrangement for testing

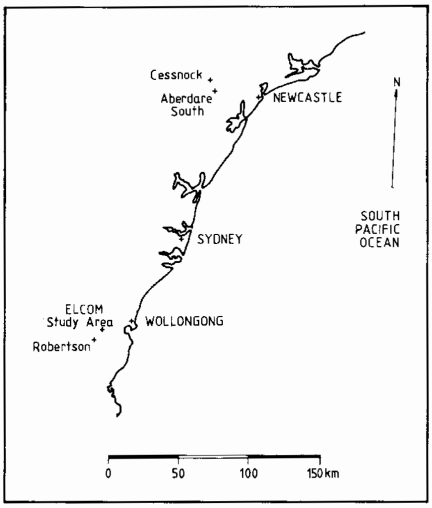

Fig.3. Location map showing test sites

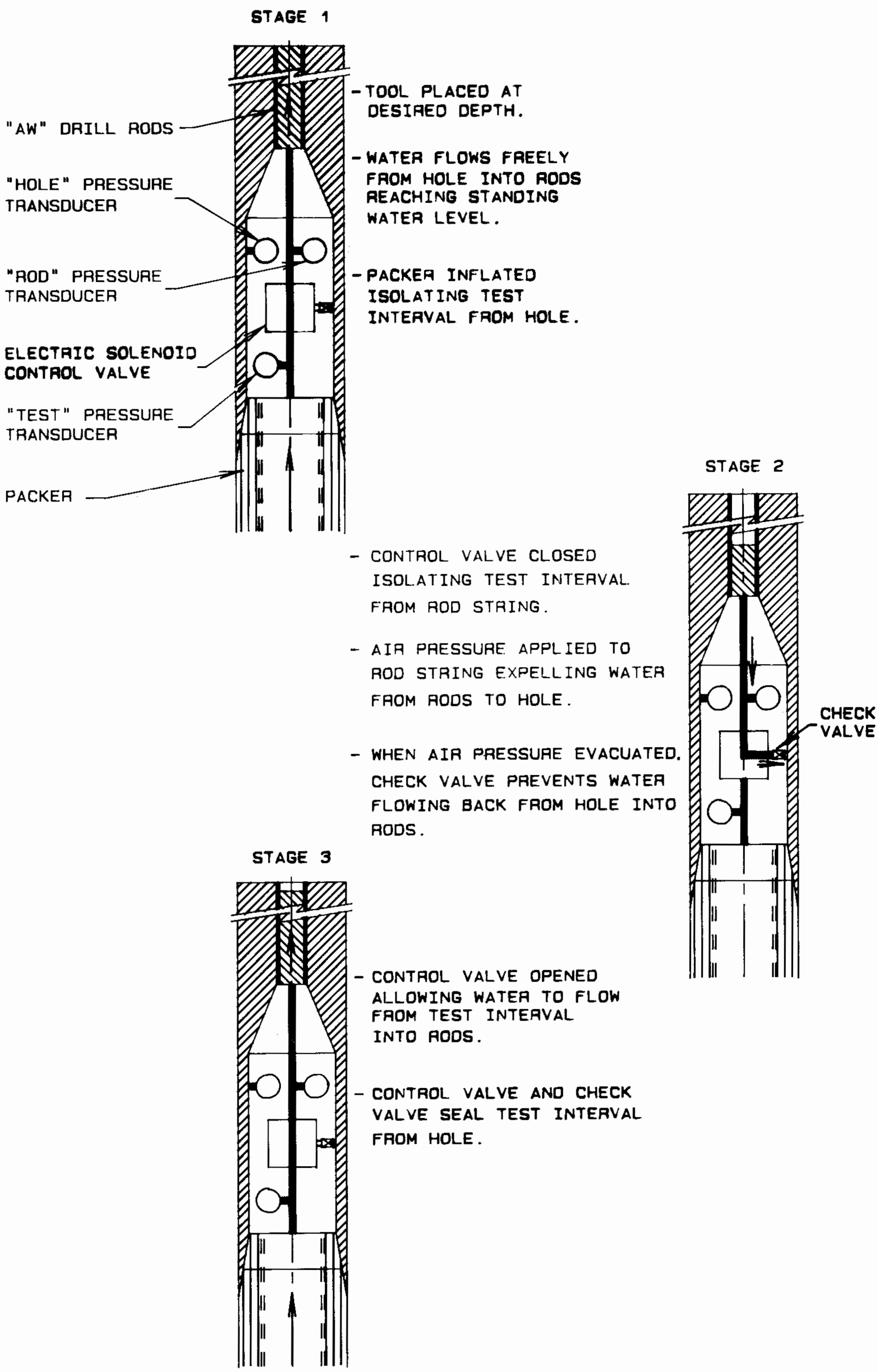

Fig.2. Principle of operation for production test

High pressure air-inflated packers have been used in place of the mechanical or hydraulically inflated packers normally used for conventional DST testing. This has been found to be satisfactory for use to depths (max. 550 m) consistent with coal lease evaluation to date in Australia. The packers can be configured for either "straddle" or "blind end" operation. The tool is designed for operation in holes as small as "N" size (76 mm dia) but has found use so far in "H" size holes (96 mm dia). The tool is "run" on a string of modified "AW" diamond drill rods handled by drill rigs commonly used for mine exploration work. "O rings" included in the couplings ensure no leakage into or out from the rod string during testing. The choice of "AW" rods (O.D. 44 mm, I.D. 31 mm) is a compromise between providing a sufficient production volume within the rod string and the necessary clearance between the rods and the hole wall for the packer inflation hose and instrumentation data cable. The hose and cable are attached to the outside of the rods at periodic intervals during tool placement. This system has proved satisfactory in both vertical and inclined (dip 70°) holes to depths in excess of 400 metres. The production volume available within the "AW" rod string has proved satisfactory for all tests conducted so far. A provision can ben made for additional volume, if required, by incorporating a chamber made up of "NQ" (I.D. 60 m) drill rods immediately above the tool.

The use of a remotely operated electrical valve to control the test (permitting multiple tests without removal from the hole) and air pressure to remove water from the drill string (providing a production volume as required) offers significant advantages over conventional drill stem tests. The system employed for the tool described here provides for the possibility of controlling the maximum differential head applied to a test horizon, by controlling the volume of water expelled from the rod string. This latter feature is important when testing coal seams, to ensure that they are not damaged by an excessive pressure differential.

In addition to the production testing function, the tool has been found very convenient for injection testing. The "down-hole" instrumentation overcomes problems associated with the common practice of measuring pressure at the surface.

EXAMPLES OF APPLICATION

Two applications in which the tool has been employed are used here to illustrate its effectiveness. The first was as part of a study of the suitability of an abandoned coal mine for underground storage of natural gas. This study, undertaken by The Australian Gas Light Company (AGL) Pty Ltd,involved an integrated programme of geotechnical and hydrogeological investigations to evaluate the potential for containment of gas under pressure in the workings of the Aberdare South Colliery. This mine is located in the South Maitland district of the Sydney Coal Basin (Fig. 3). The Greta Seam was worked at a depth of approximately 400 metres until the 1920's, from which time the mine has been abandoned and the workings flooded. Part of the investigation centred on the integrity of a narrow (200 m) barrier pillar of coal between Aberdare South and adjacent workings. Large scale pumping tests between Aberdare south and the adjacent mine, involving flow through the barrier pillar, were conducted. To complement these, a hole (70° dip) was drilled into the barrier pillar from the surface. Injection and production tests were conducted in this hole to obtain values of permeability of the pillar coal. The results of these tests are discussed below.

The second application (the "Robertson Area Study") was as part of a regional hydrogeological study of a prospective new underground coal mining area being investigated by the Electricity Commission of New South Wales (ELCOM) near the southern boundary of the Sydney Coal Basin (Fig. 3). The investigation was prompted by substantial inflows of water into an adjacent mine extracting the same coal seams as those of interest in the area under investigation, and a concern for the potential impact of mining on the groundwater regime. The study has involved the measurement of piezometric heads in a number of exploration holes and detailed investigation of the permeabilities and potential water production rates of the various coal seams in one hole. In the latter hole injection and production tests were conducted on the five coal seams comprising the Illawara Coal Measures, at depths from 290 - 370 metres. The results of these tests are discussed below.

TYPICAL DATA

Figures 4(a & b), 5(a & b) and 6(a & b) are plots of the digital data recovered directly from three separate production tests (Figures 4, 5 and 6 respectively). Figure 4 (Hole GS2) is typical of data obtained during the investigation at Aberdare South. Figures 5 and 6 (Hole EH12) represent the different styles of data obtained from different coal seams during the "Robertson Area" study. In all cases the data obtained from the test section and rod string pressure transducers are shown. Apart from the digital data format, a continuous strip chart record is kept of each data channel during the course of a test. This format is used for "on-line" test control.

The notation included on Figure 4 explains the various features of the test record common to all tests. The differences between the respective records for the three tests can be attributed to the different production flow rates concerned. The relatively high flow rate generated during the test from GS2 (Fig. 4(a)) resulted in a significant friction loss through the tool. A substantial difference between the initial pressure drops was recorded by the test section and rod string pressure transducers when production was allowed to occur. In this case the valve in the tool appeared to act as a "choke", forcing an almost constant flow rate over most of the test. By contrast, a very low flow rate was encountered during testing of the American Creek seam in EH12 (Fig. 6(a)). In this case there was an apparent absence of friction loss through the tool as suggested by comparing the records obtained from the test section and rod string transducers. In this instance the flow rate was approximately constant (albiet low) over a substantial period of time owing to the small change in differential pressure over the duration of the test. The result obtained from testing of the Wongawilli seam in EH12 (Fig 5) lies somewhere between the other two tests. In this case there is evidence of some friction loss through the tool during production (Fig. 5(a)) c.f. (Fig. 5(b)), but not of

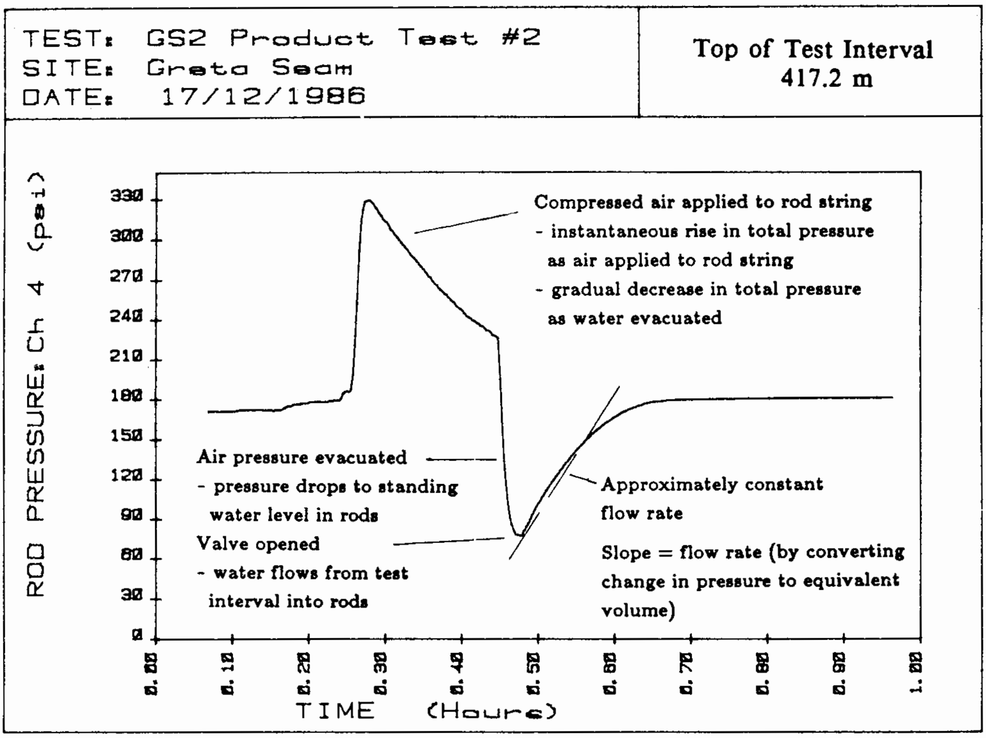

Fig. 4(a). Data from rod-string pressure transducer- Hole GS2, Greta Seam

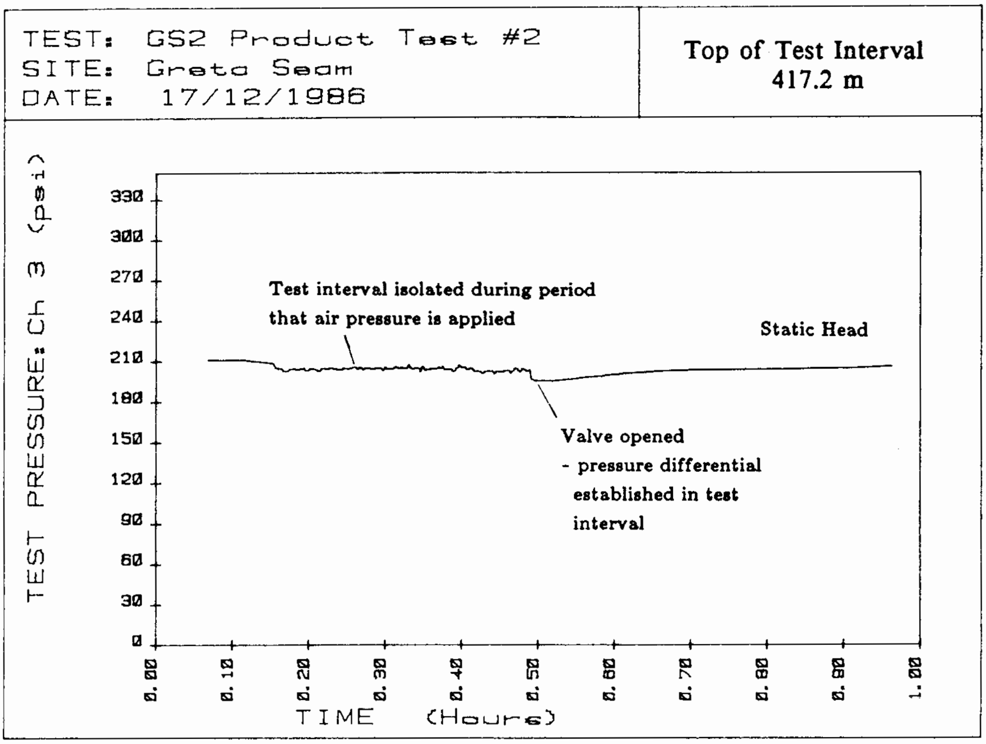

Fig. 4(b). Data from test interval pressure transducer- Hole GS2, Greta Seam

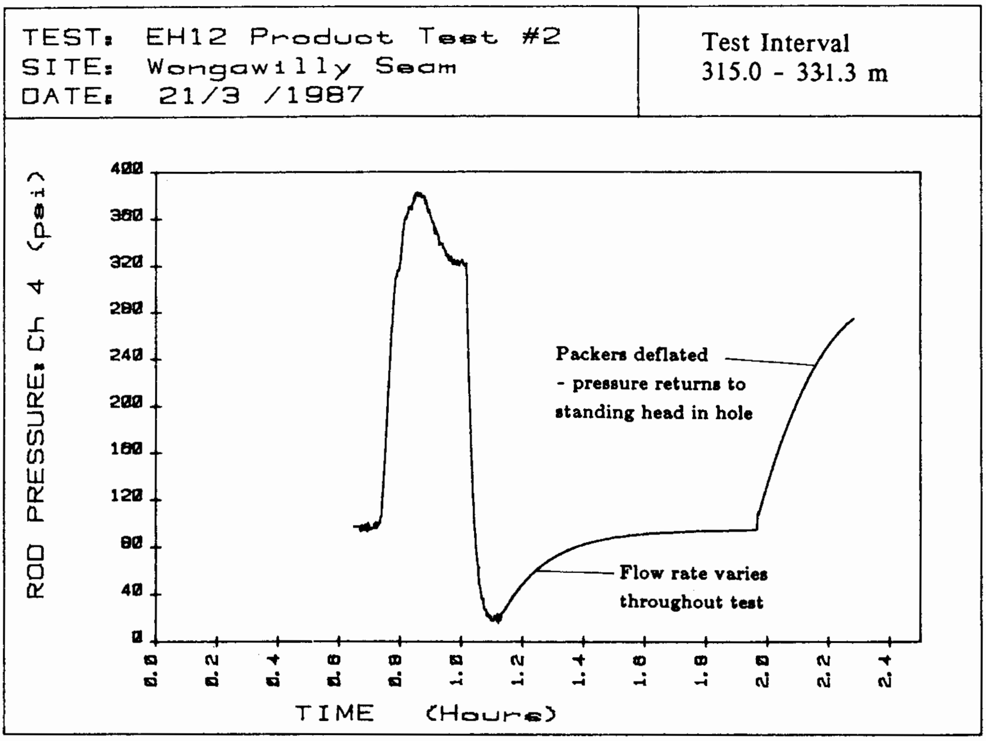

Fig. 5(a). Data from rod-string pressure transducer- Hole EH12, Wongawilli Seam

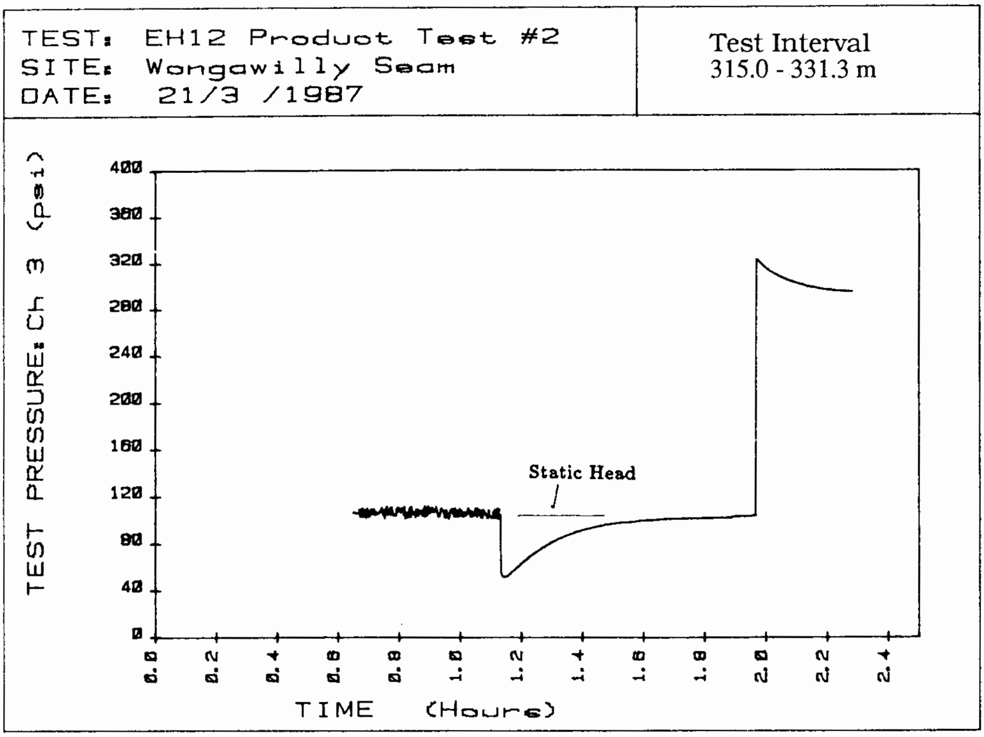

Fig. 5(b). Data from test interval pressure transducer- Hole EH12, Wongawilli Seam

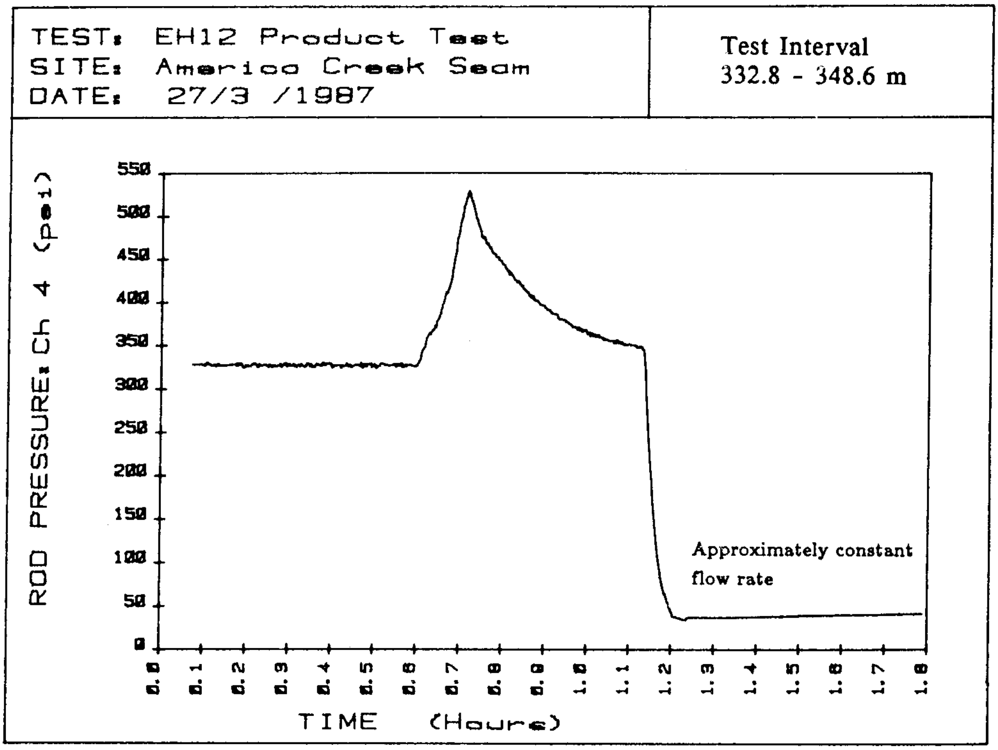

Fig. 6(a). Data from rod-string pressure transducer- Hole EH12, American Creek Seam

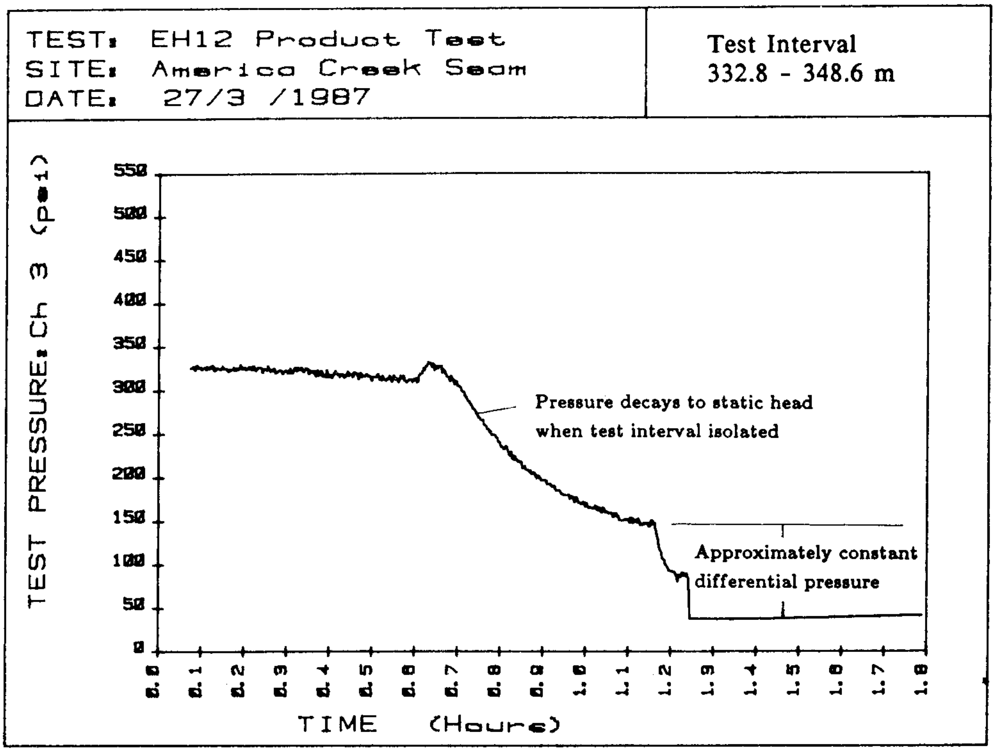

Fig. 6(b) Data from test interval pressure transducer- Hole EH12, American Creek Seam overriding importance as in the case of the test in GS2. In this instance the production rate appears to vary approximately in accord with the increasing head of water in the drill string.

DATA ANALYSIS

The most appropriate method of analysis depends on the style of the data obtained. In cases where there is an approximately constant flow rate and differential pressure over a substantial part of the test (Figs. 5 and 6), it is appropriate to analyse the differential pressure (from the test pressure record) - flow rate (from the rod pressure record) data by steady state drawdown analysis based on the assumption of a confined aquifer [1]. When there is a significant change in pressure and flow rate during a test (Fig. 5) transient flow analysis based on analogy with the well known Slug Test [2] and as used commonly for DST analysis in the oil and gas industry [3] is more appropriate. The results derived from the sample test data summarised in Figures 4, 5 and 6 by the appropriate methods of analysis are given in Table 1. Also included in Table 1 are the results of other types of tests conducted in conjunction with the production tests.

TABLE 1 SUMMARY OF RESULTS OF ANALYSIS

Hole	Seam	Production Test		Permeability from Other Test Results m/sec x 10^{-8} (md)		
		Method of Analysis	Permeability m/sec x 10^{-8} (md)	Steady State Injection	Post Injection Decay	Bulk Pump Test
GS2	Greta	Constant flow drawdown	270 - 390*	20 - 37**	390	300-400
EH12	Wongawilli	"Rising Head" Analysis	34 - 22***	0.5-0.8****		
EH12	American Creek	Constant flow drawdown	0.13	$\div$ 0		

*range for radie of influence considered

**range for injection pressures employed (200-800 KPa)

***range for differential pressures employed (190-500 KPa)

****injection under influence of water column in hole only

DISCUSSION OF TEST RESULTS

The most obvious feature of the results summarised in Table 1 is the consistently greater permeability determined from production tests compared to the corresponding values determined from steady state injection test analysis [1]. This may reflect a systematic impact of the respective methods of analysis employed, or the influence of some underlying physical mechnaism.

Consideration has been given to the influence of cleat in coal seams on variations in permeability with flow direction, in the context of water/gas migration [4]. The opening and closing of cleats may account for the variations in permeability with increasing pressure, during injection tests and production tests respectively, noticeable from the results summarised in Table 1. The same mechanism does not, however, logically explain the gross difference between the results obtained from production and injection tests in the same test interval. Two possible explanations for this are the impact of "fines" being forced into the cleat structure during injection testing, and/or the locking together of blocks of coal, loosened during drilling, in the wall of the test hole under the influence of the radial compression generated during injection testing. Both of these mechanism would result in non-representative (low) permeabilities being measured during injection testing, but may not necessarily influence the conduct of production tests. Further evidence for a mechanism of this type is given by the results of the post injection decay analysis conducted on the injection test data from hole GS2. This analysis suggested a low permeability "skin effect", superimposed on decay curves yielding a permeability consistent with the permeability obtained from the production test.

The general agreement between the permeability obtained from the production test conducted in GS2 and the permeability of the barrier pillar derived from the bulk pump test lends credence to the result obtained from production testing.

CONCLUSION

Experience obtained to date using the production testing technique for evaluation of the permeabilities of coal seams has proved encouraging. Seemingly reliable results have been obtained, suggesting possible shortcomings with the use of conventional packer tests in coal seams.

The prototype tool has proved generally reliable and relatively simple to use within the framework of conventional coal lease exploration practice. At the date of writing an updated version of the tool is being developed, incorporating features designed to overcome minor shortcomings encountered with the existing tool. The new tool is designed for "wireline" operation avoiding the need for special drill rods and minimising the hold-up time for drill rigs.

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